Austroads

Research Report
AP-R543-17

Assessment of Key Road Operator Actions to Support Automated Vehicles

Assessment of Key Road Operator Actions to Support Automated Vehicles

Prepared by

Rosie Huggins, Rebecca Topp, Lachlan Gray, Lachlan Piper, Ben Jensen, Lauren Isaac, Shivaani Polley, Scott Benjamin, Andrew Somers.

Project Manager

Stuart Ballingall and Chris Jones

Abstract

Australian and New Zealand road agencies and operators are preparing for the introduction of Automated Vehicles (AVs). 'This report investigates the potential changes needed to the way road networks are managed to consistently support and optimise the outcomes from the introduction of AVs.

The project reviewed international and local documents and initiatives and consulted a range of stakeholders to determine the emerging requirements for AVs to operate on public and private road networks (including urban and rural areas).

The report captures key issues in three broad categories:

- physical infrastructure
- digital infrastructure
- road operations.

The report concludes with high level guidance for road agencies and operators. There are obvious challenges in providing practical guidance to agencies in a still evolving and changing environment, and some of the guidance, although still relevant, may be beyond the purview of individual road operators.

Keywords

automated vehicles, road design, pavement design, bridge design, barrier design, road signs, road markings, roadworks, road classification, network operations planning, land use planning, data management, data access, positioning technology, communication technology, mobility

ISBN 978-1-925451-69-6

Austroads Project No. BN2045

Austroads Publication No. AP-R543-17

Publication date May 2017

Pages 73

Publisher

Austroads Ltd.
Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia
Phone: +61 2 8265 3300
austroads@austroads.com.au
www.austroads.com.au

About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

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.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- 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.

© Austroads 2017

This work is copyright. Apart from any use as permitted under the *Copyright Act 1968,* no part may be reproduced by any process without the prior written permission of Austroads.

This report has been prepared for Austroads as part of its work to promote improved Australian and New Zealand transport outcomes by providing expert technical input on road and road transport issues.

Individual road agencies will determine their response to this report following consideration of their legislative or administrative arrangements, available funding, as well as local circumstances and priorities.

Austroads believes this publication to be correct at the time of printing and does not accept responsibility for any consequences arising from the use of information herein. Readers should rely on their own skill and judgement to apply information to particular issues.

Glossary and Abbreviations

Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ACMA	Australian Communications and Media Authority
AdaptIVe	Automated driving applications and technologies for Intelligent Vehicles
ADAS	Advanced Driver Assistance Systems
ADRs	Australian Design Rules
AEB	Autonomous Emergency Braking
AI	Artificial Intelligence
ANRAM	Australian National Risk Assessment Model
AusRAP	Australian Road Assessment Program
AV	Automated Vehicle
BIM	Building Information Modelling
BITRE	Bureau of Infrastructure, Transport and Regional Economics
CAM	Cooperative Awareness Message
CAV	Connective Automated Vehicle
C-ITS	Cooperative Intelligent Transport Systems
Connected Vehicle	Vehicles that use wireless communication to receive and send data to enable various services
CORS	Continuously Operating Reference Stations
CSD	Context Sensitive Design
DARPA	Defense Advanced Research Projects Agency (US)
DDA	Disability Discrimination Act
DDT	Dynamic Driving Task
DENM	Decentralized Environmental Notification Message
DIRD	Department of Infrastructure and Regional Development
D-GPS	Differential Global Positioning System
DSRC	Dedicated Short Range Communications
ERTICO	European Intelligent Transportation System (ITS) organisation
ESC	Electronic Stability Control
EuroRAP	European Road Assessment Programme
EV	Electric Vehicle
Freeway	A divided highway with no access for traffic between interchanges and with grade separation at all intersections.
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GSMA	Global System for Mobile communications Association
HOV	High-Occupancy Vehicle
IAP	Intelligent Access Program
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers

Abbreviation	Definition
IoT	Internet of Things
iRAP	International Road Assessment Programme
ITS	Intelligent Transport Systems
LDW	Land Departure Warning
LiDAR or LIDAR	Light Detection and Ranging
LKA	Lane Keep Assist
LTE	Long Term Evolution
MaaS	Mobility-as-a-Service
Motorway	A divided highway for through traffic with no access for traffic between interchanges and with grade separation at some interchanges. Certain activities or uses may be restricted or prohibited by legislative provision.
MUARC	Monash University Accident Research Centre
NHVR	National Heavy Vehicle Regulator
NOP	Network Operation Planning
NTC	National Transport Commission
NZTA	NZ Transport Agency
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
OEM	Original Equipment Manufacturer
PPP	Precise Point Positioning
RLAN	Radio Local Area Network
RTK	Real Time Kinematic
SAE	Society of Automotive Engineers
SAE AV taxonomy	(SAE J3016) http://www.sae.org/misc/pdfs/automated_driving.pdf
SBAS	Satellite-Based Augmentation System
SLAM	Simultaneous Location And Mapping
SPaT	Signal Phase and Timing
SVID	Simultaneous Vehicle and Infrastructure Design
UMTRI	University of Michigan Transportation Research Institute
V2V	Vehicle-to-Vehicle communication
V2I	Vehicle-to-Infrastructure
V2X	V2V, V2I, and vehicle-to-other (including but not limited to pedestrians, cyclists)
VKT	Vehicle Kilometres Travelled

Summary

The purpose of this report is to provide guidance for Australian and New Zealand road agencies and operators on what changes may be required to the way road networks are managed, to support a consistent approach towards supporting and optimising the outcomes from the introduction and use of Automated Vehicles (AVs).

This project was commissioned by Austroads to review international and local documents and initiatives and carry out consultation with a range of stakeholders to determine the emerging requirements for AVs to operate on public and private road networks (including urban and rural areas). The project has sought to capture key issues that were identified, assess these issues for validity and relevance to our local road networks, and summarise the conclusions and/or recommended approaches for each key issue identified. Key issues were captured in three broad categories:

- Physical infrastructure
- Digital infrastructure
- Road operations.

Physical infrastructure requirements of our roads will differ for different AVs, and for different use cases. Feedback suggests that many AVs will be designed to operate on our road networks as they currently are. However, to best support a wide range of AVs and their use cases, the following physical infrastructure design and maintenance elements were identified as requiring consideration by road operators:

- **Physical attributes:** road and intersection design may need to be considered differently depending on the AV use case that may need to be supported.
- **Road pavement and structures:** consider changes to loads on bridges, pavements, and barriers, if automated heavy vehicle platoons are to be supported. Road and asset maintenance programs may also need to consider increased loads from platooning. Feedback also suggested that road condition could affect the operation of some AVs.
- **Signs and lines:** need for consistency in design, implementation and maintenance of road signs and line marking. Existing infrastructure is noted to be problematic for a number of AV manufacturers. There appear to be issues with readability of electronic signs, and therefore greater consideration of machine readability is required when designing signs.
- **Roadworks:** there is a need for consistency of traffic management treatments which vary significantly between projects and across different jurisdictions. The need for real time information about current road conditions was also highlighted (and further detailed under Digital Infrastructure).
- **AV certification:** Some agencies have mentioned their consideration of the possible need to “certify” roads as AV compliant. Another approach could be to provide some guidance or framework, outlining where certain AV use cases should or should not operate.

Digital infrastructure requirements, in a similar manner to physical infrastructure, will vary depending on the AV and the use case being supported. Data management, positioning services, and communication technologies are important areas to be considered. The following issues with digital infrastructure may need to be considered to support AVs operating across the road network:

- Australia and New Zealand are both challenged by relatively low geographical coverage of cellular communication services in comparison to many other developed countries.
- Many vehicle systems emerging overseas utilise free access to a Satellite Based Augmentation System (SBAS) for absolute positioning. Australia and New Zealand do not currently have access to such a system.

- There will be greater focus on digital mapping and data exchange as part of core operating capabilities into the future. Road operators will need to consider how best to support these elements, which data it should make available, and what it should be the authoritative source for. The fact that the private sector is currently collecting and supporting AVs with data, may mean that the balance of the roles of public and private sectors may shift over time. Ensuring that data is available to ensure the best operational outcomes on the network will be a key challenge for road operators. The need to consider and protect the privacy of road users will continue to be a significant issue.

Road operations may need to evolve to support new use cases that come with the introduction of AVs, and to optimise the potential transport outcomes across a road network. The following issues may require further consideration:

- Network management approaches such as Movement and Place, and supporting tools like Network Operating Plans, may need to be reviewed and amended to ensure they appropriately consider future AV use cases.
- A range of standards, guidelines, and regulations will need to be reviewed and updated to ensure the best possible outcomes in implementing AVs. These processes will support consistency of operations, which is paramount for AVs.
- Roadworks are a key aspect noted to be of particular concern to AV manufacturers and system suppliers. It is necessary to ensure that roadworks become well planned events and real time information is provided to AVs. This information should include physical changes to the road layout, which may be more complex for an AV to negotiate.

The report concludes with high level guidance for road agencies and operators. There are obvious challenges in providing practical guidance to agencies in a still evolving and changing environment, and some of the guidance, although still relevant, may be beyond the purview of individual road operators.

Contents

Tables

Figures

1. Introduction

1.1 Purpose

This research report has been written to provide guidance for road agencies and operators on what changes may be required to the way road networks are managed, so that there is a consistent approach towards supporting and optimising the outcomes from the introduction and use of Automated Vehicles (AVs).

The project was commissioned by Austroads to review international and local documents and initiatives regarding the emerging requirements for AVs to operate on public and private road networks including urban and rural areas. The project aimed to capture key issues that were identified, assess these issues for validity and relevance to our local road networks, and summarise the conclusions and/or recommended approaches for each key issue identified. Consideration was also given to how any learnings and conclusions from international initiatives would translate to Australian and New Zealand road networks. A key objective of the project investigation was to provide guidance that will facilitate an effective and consistent approach to designing, maintaining and operating road networks to support the deployment and use of AVs on Australian and New Zealand roads.

1.2 Background

Automated Vehicles (AVs) is a term used for vehicles that involve some automation of the primary driving controls (i.e. steering, acceleration, braking). There is a significant trend towards higher levels of automation in new vehicles. ‘Partially’ automated vehicles that can drive themselves in limited scenarios are already on our roads, but the driver is still responsible for monitoring the driving environment and must be ready to take back control (e.g. highway driving assist, traffic jam assist).

Highly automated vehicles, in which an automated driving system can perform the entire dynamic driving task when the system is engaged, are anticipated to start entering the market before 2020. Some of these may be ‘self driving’ vehicles that still require a human to be ready to take back the driving task, while others may be ‘driverless’ vehicles that do not require a human to be present but are limited in what road environment they operate in.

In addition to AV technology, a number emerging technologies such as connected and electric vehicles will also be prevalent on future roads. During the opening ceremony of the 2015 ITS world congress Cees De Wijs, the Chairman of ERTICO noted the following key trends for transport:

- electrification
- automation
- the shared economy (including on demand shared mobility services).

While it is likely that vehicles of the future will make use of all of these three trends, this report focuses on AVs, and where applicable connected AVs (CAVs). The term AV for the purposes of this report can be applied to encapsulate CAVs as a functional iteration of AVs. Electric vehicles and shared vehicles will not be specifically addressed by this report.

AVs have the potential to change all aspects of mobility and many aspects of our communities. Examples of this include driver safety, insurance liability, and car ownership. Broader implications could also be expected on a more community level, changing the way we move, connect, work, and play in our cities. AVs can be considered a ‘disruptive’ innovation introducing a range of vehicle applications not previously possible. In addition to innovation disruption, market disruption will be also experienced across a broad spectrum of industries.

Potential synergies between AVs and the Internet of Things (IoT) may offer significant benefit to road operators in the future. IoT refers to a network of physical objects linked with technology allowing objects to exchange data. In broad terms it means devices talking to each other or talking directly to back end systems through digital communications. AVs will make use of this technology to connect vehicles and to connect fixed infrastructure on the road. This new level of “connection” will provide opportunities for safety and optimisation not previously available.

Federal, State/Territory, and Local Governments will play a key role in dealing with these new disruptive technologies. It is vital that the policies, laws, and regulations are established finding a balance between guarding public safety, regulating insurance liability and encouraging investment in research and development of more automated vehicles. It is anticipated that vehicles with automated driving systems will begin to become more prevalent in the near future with some forecasts suggesting that highly automated vehicles could be on the market before the end of this decade.

1.3 Scope

The purpose of this study is to identify and assess key actions required by road agencies to support the use of AVs on our road networks. This includes examining key issues relating to road operations and addressing these with a consistent approach to support the following fundamental outcomes:

- safe and effective operation of AVs on the road network
- achieve an optimised level of safety and mobility benefits from AVs.

The long term implications for sustainability and wider societal impacts have also been considered as part of the project.

The scope is limited to AVs operating on roads, and does not extend to vehicles that operate on footpaths or aerial drones. There is however some discussion within this report of ‘last mile’, fixed route automated solutions which could be envisaged to operate on the public road network as well as off road.

1.4 Methodology/Approach of Study

The approach to delivering the project has been considered in three main stages:

1. **Inception and Scoping:** This includes inception meeting and scoping workshop with Austroads to confirm the scope, agree the project plan, and discuss the stakeholder consultation group.
2. **Stakeholder Consultation and Gap Analysis:** Following a desktop review on national and international literature, a stakeholder engagement process was carried out with industry experts gathering information in relation to key project issues.
3. **Review and Reporting:** Upon collation of results and drafting of submission documentation. Following return of comments, this report was revised and a final document completed.

1.5 Structure of this Report

This report has seven sections including this introduction:

1. Introduction
2. Societal
3. Framework
4. Physical infrastructure
5. Digital infrastructure
6. Road operations
7. Guidance for road operators.

2. A Framework to Consider Automated Vehicles

This section of the report provides an introduction to the concept of Automated Vehicles and brief commentary on functionality and instrumentation. It also discusses a framework to assist with consideration of the potential impacts and opportunities of AVs. It is divided into sections, as follows:

1. What is an Automated Vehicle? An introduction to AVs
2. Basics of AV operation
3. Frameworks for AV operation
4. AV operational use cases
5. Timeline for deployment
6. Summary.

2.1 What is an Automated Vehicle? An Introduction to AVs

“Automated Vehicle” (AV), is a term used for those motor vehicles that involve some automation of the primary driving controls (i.e. steering, acceleration, braking). Over the last one hundred years manufacturers have been increasing the level of assistance that is provided to drivers to ensure safe control of motor vehicles. Systems such as power assisted steering and brakes which started being introduced approximately 50 years ago, have gradually entered the realm of standard inclusions.

The concept of greater levels of automation of vehicle control has been mooted for a very long time. Some of the more interesting examples include the 1964 World Fair General Motors Exhibition “Futurama” and later General Motors concept cars such as the Firebird. Today, the level of driving automation may vary from systems such as cruise control to driverless vehicles without need for human control.

Whilst relatively mature forms of Advanced Driver Assistance Systems (ADAS) such as antilock-braking system (ABS) or cruise control have had significant impact, they have not fundamentally changed the responsibility of the driver.

Automation in a vehicle is commonly expressed in terms of the sophistication of the automated driving offered. Levels of driving automation may be discussed in the context of the Society of Automotive Engineers (SAE) taxonomy. This nomenclature is presented in Figure 2.1 and is an extract from the SAE International Standard J3016.

An important consideration for road operators is the changeover that can occur in some AVs from human control and supervision to automated control of the vehicle. According to SAE J3016, the automated driving system undertakes the entire dynamic driving task, when it is engaged and operating at level 3 (conditional), 4 (highly automated), and 5 (fully automated). At these levels of automated driving there is no need for a human to monitor the driving environment, although at level 3 (conditional automation) a human must be present and take back the driving task if requested.

The fundamental changes in vehicle automation and control outlined above have resulted in the need for a wide range of organisations to consider the impacts, and implications of these technologies. Well established processes and procedures such as vehicle regulation and driver licensing require review.

Figure 2.1 SAE automated driving taxonomy

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**

Source: SAE International Standard J3016

2.2 Basics of AV Operation

Many AVs will operate by combining digital maps with data gathered from sensors and positioning systems to build a digital model of the physical world. The vehicle then uses this digital model to perform driving tasks safely, reliably, and predictably.

2.2.1 Operational Modes

AVs are required to adapt to complete a range of tasks from simple through to very complex. Broadly speaking, AV functionality can be deconstructed into the following areas:

1. Repetitive tasks in controlled environments.
2. Varying tasks in dynamic environments.

Repetitive Tasks in Controlled Environments

To perform repetitive tasks in controlled environments (e.g. adaptive cruise control on a freeway), vehicles rely on internal sensors and systems. System performance should be monitored by the vehicle, and in the event of a failure, the automated driving system should either alert the human driver to take over, or bring the vehicle to a minimum risk condition (which may be to stop).

Varying Tasks in Dynamic Environments

To undertake varying tasks in an uncontrolled environment (e.g. urban street with pedestrians), the vehicle must be able to correctly interpret the surrounding environment and take appropriate, timely control of the vehicle. These actions are based on sensor inputs (LIDAR, radar, and cameras); or other external inputs such as data packets from other connected vehicles or cloud services. These inputs allow the machine to develop a model of its environment and continually interpret the model to control the vehicle appropriately. This aspect is extremely complex and challenging for AV manufacturers. The difficulty can be summarised as the difference between operating in a constant speed freeway/motorway environment versus driving in a local street at low speed and sharing space with pedestrians.

2.2.2 Sources of Error

When seeking to automate vehicles to assess the surrounding environment AV manufacturers are challenged by two broad types of problems[1]:

- **False negatives (Type I error):** Not perceiving an object or road user is where they actually are. This could result in a disastrous outcome e.g. collision.
- **False positives (Type II error):** Perceiving that an object or road user is somewhere when they actually are not. This could result in a sudden and unnecessary evasive manoeuvre or more likely braking.

Artificial Intelligence (AI) and Machine Learning are approaches to addressing the errors defined above.

2.2.3 Artificial Intelligence and Machine Learning

Selected AV manufacturers are seeking to employ some component of AI or machine learning into their AV systems to assist AVs with interpretation of the surrounding environment and improve driving safety performance. These technologies are expected to address the sources of error encountered in the two primary modes of operation.

There appears to be three key defining elements of AI that many AV developers are building into their automated driving systems. Understanding these can help to understand the performance and behaviour of AVs on our roads. Each of these aspects can be summarised as follows:

- **Biomimicry:** is an approach that seeks to emulate what happens in nature. With AV development, this approach assumes that if a human can read and respond to something in the road environment, then an automated driving system can too. However, our consultations highlighted that this approach does not necessarily aim to mimic human drivers, as humans do not always perform the dynamic driving task well.

1 Retrieved Jun 15, 2016 from Explorable.com: https://explorable.com/type-i-error

- **Swarm intelligence:** is defined as natural and artificial systems composed of many individuals that coordinate using decentralised control and self-organisation. In particular, the discipline focuses on the collective behaviours that result from the local interactions of the individuals with each other and with their environment[2]. In the AV context, swarming refers to the ability of an AV to communicate with other vehicles and users of a transport network, allowing the continual refinement of its system based on data received from others. Many AV manufacturers appear to be focusing on connectivity with a centralised service that supports data exchange with vehicles of the same make. An alternate approach is to support data exchange across multiple brands and transport modes, which may better support what is generically being considered as "Connected Automation".
- **Machine learning:** is an approach where computers have the ability to learn without being explicitly programmed. In the context of AVs, a vehicle may sense a bump from a pothole in a road, and the next time it drives along that road it will steer away from the location of the pothole. Deep learning, a subset of machine learning, is being employed by many AV developers, and involves a deeper abstraction and learning from multiple layers of data.

2.2.4 Sensing and Navigating

This section of the report discusses how AVs consider and navigate a model of the world in greater detail. It is necessary to establish a base understanding of the implications of this for design and maintenance of a range of infrastructure as well as operation of the road network. It is necessary for a vehicle to be equipped with a suite of sensors in order to construct a model of its environment. Sensors enable three distinct processes for AV operations (AASHTO 2001):

- **Navigation:** trip planning and route following.
- **Guidance:** following the road and maintaining a safe path in response to traffic conditions (including lane choice).
- **Control:** steering and speed control (including braking).

Guidance and control processes are reliant on the suite of sensors available. Navigation in most cases requires absolute positioning via Global Navigation Satellite Systems (GNSS).

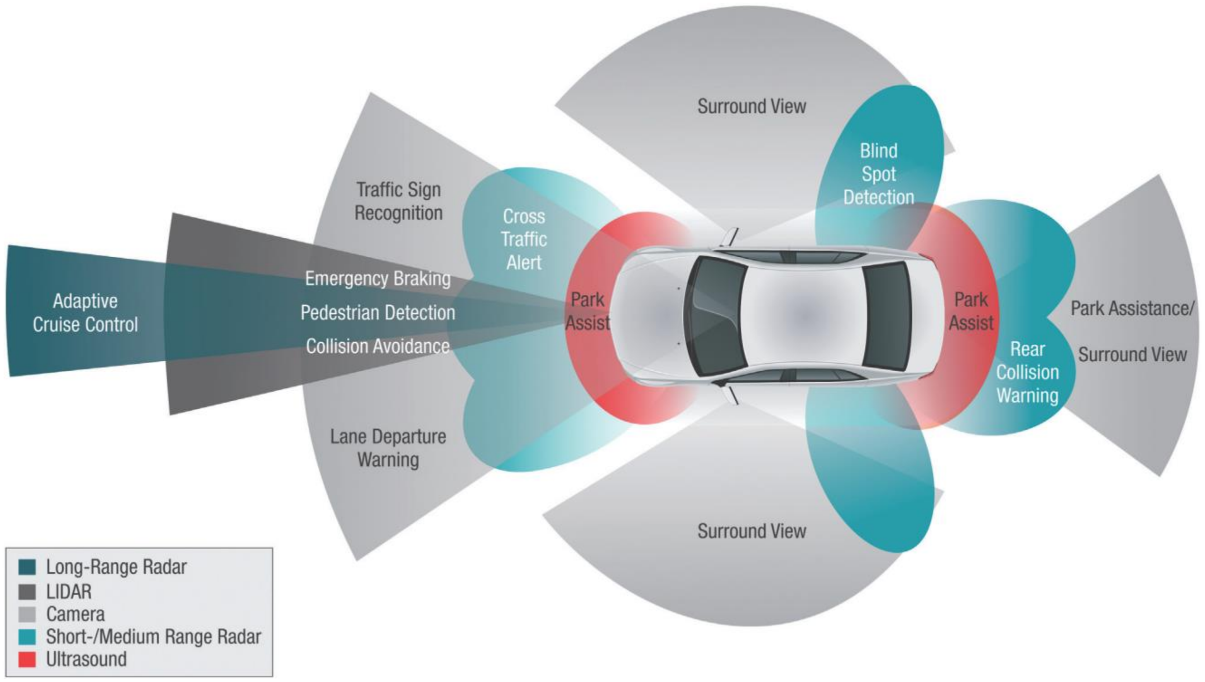
Sensors used by AVs to detect other vehicles or obstacles can include:

- RADAR
- LIDAR
- cameras
- ultrasonic sensors
- GNSS fused with map data can be used to identify known hazards or obstacles.

An illustration of these sensors is presented in Figure 2.2 and described in greater detail in Table 2.1. The range and function of sensors illustrated in the figure and described in the table is not exhaustive with products evolving and developing rapidly. Operating distances vary between manufacturers.

2 http://www.scholarpedia.org/article/Swarm_intelligence

Figure 2.2 Vehicle sensor overview



Source: Texas Instruments 2015

Table 2.1 Summary of sensor types utilised in AVs

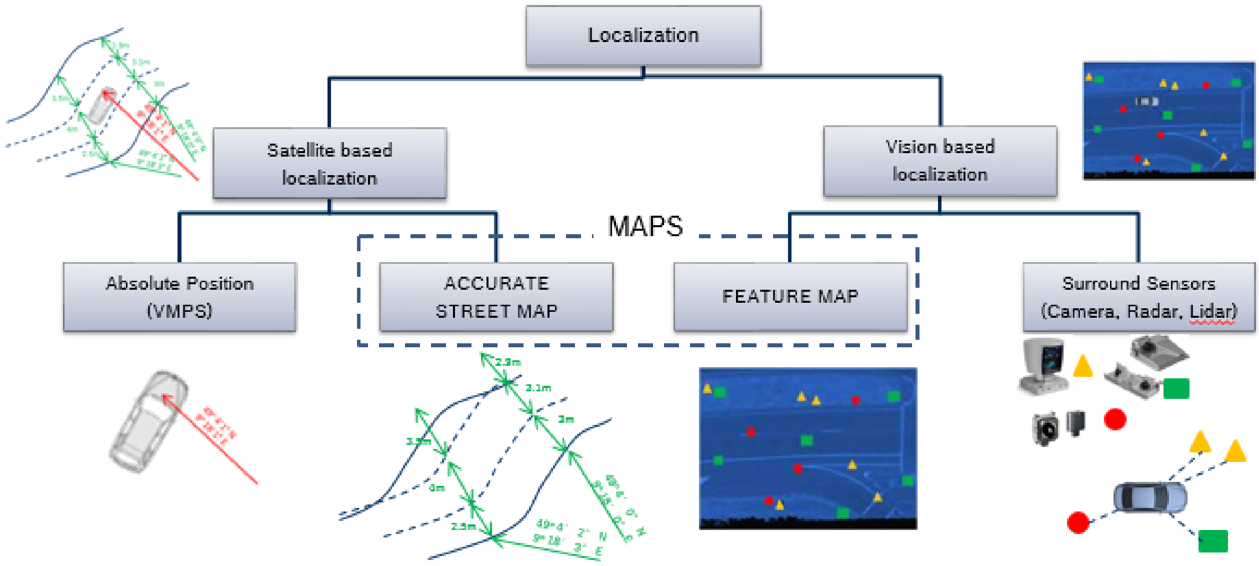
Sensor type	Description and abilities	Operating distance	Environmental conditions	Limitations
Radar (long, medium and short-range)	Radio Detection and Ranging Used to monitor the range and velocity of nearby vehicles by emitting radio frequency (RF) signals and waiting for reflected signals from other vehicles or obstacles to be received. Long range sensors use the Doppler effect to directly provide velocity information. They are already employed in adaptive cruise control (ACC) systems. Medium and short range radar is used within cross traffic alert, blind spot detection and rear collision warning systems.	Long Range (R>150m). Range is reduced if environmental conditions such as rain, snow or hail are present. Narrow field of view and reduced angular resolution.	Extreme weather conditions such as rain, snow or hail adversely affect the effectiveness on this type of sensor.	Can be susceptible to radio frequency interference. Can deliver better performance in low light & poor weather conditions due to weak absorption of RF waves, which allows for greater detection distances than light based systems. Resolution of data captured may not be as detailed as cameras or LIDAR.
LIDAR	Light Detection and Ranging Sensors emit pulses of near Infra-Red (NIR) light and detect the reflected pulse off vehicles or obstacles. These are analysed to identify lane markings and the edges of the road. LIDAR is much higher resolution than RADAR (and also more expensive). Since it is based on NIR light only a greyscale image of the surroundings can be rendered. Fast, accurate and detailed imaging. Ability to detect smaller objects at longer distances.	Medium range (1<R<50m). Greater range in excess of 50m can be obtained with specialist LIDAR modules.	Light based sensor system more susceptible to absorption from poor atmospheric conditions such as precipitation. Hot weather conditions may also impact sensor performance as it is based on infrared wavelengths.	Cannot detect colours (greyscale image only), so camera sensors are typically used to “read” traffic lights and signs. Currently not a primary source of information to read line marking. Performance can be affected by inclement weather.

Sensor type	Description and abilities	Operating distance	Environmental conditions	Limitations
Ultrasonic	The sensors emit acoustic pulses (chirps), with a control unit measuring the return interval of each reflected signal and calculating object distances. The system in turn warns the driver with acoustic tones, the frequency indicating object distance, with faster tones indicating closer proximity and a continuous tone indicating a minimal pre-defined distance. These sensors are also known as parking or proximity sensors which alert the driver to obstacles while parking. Some manufacturers also use ultrasonic based sensors for blind spot assist systems.	Short range (0<R<5m). Due to high frequency and resulting narrow directivity of beam.	Sensitive to dusty and poor atmospheric environments which reduce their performance. Immune to environmental noise (unless there is a significant ultrasonic component)	Must have an unobstructed view of a surface to receive ample sound echo signal. Sensor response time is relatively long compared to RADAR and LIDAR being about 0.1s. Suitable for short range detection only.
Cameras	A range of different types of cameras are applicable: colour, monochrome, stereoscopic; infrared (IR). Cameras are used by systems such as detection of traffic lights, reading road signs and line marking to assist in keeping lane position and position relative of other vehicle, pedestrian and other objects. Cameras as also used by systems to detect inattentive drivers. They also provide additional visual support for drivers with rear vision and more recently side vision/surround vision. A stereoscopic camera has two lenses with separate image sensors for each lens. This allows the camera to simulate human binocular vision. They are used for range imaging and hence are capable of performing distance measurements.	Short to medium range (1<R<50m). Range dependent on optical zoom of lenses and also sensitive to environmental conditions such as rain, snow, fog or hail which adversely affect sensor performance.	With the exception of IR, performs optimally in well-lit environments or requires external lighting from vehicle headlights to obtain further range. Performance reduced in rain, snow, fog or hail environments.	This sensor type is based on visible light to render an image of the scene (with the exception of IR). Hence, poor light, fog, snow and extreme weather conditions can reduce the sensors ability to render a useable image for processing.
Global Navigation Satellite Systems (GNSS)	GNSS refers to global and regional satellite constellations used for positioning, navigation and timing. A popular and most well-known example is GPS. GNSS may be supplemented by other systems and broadcast to enable various augmentation services such as SBAS, GBAS, RTK and D-GPS. Real Time Kinematic (RTK) is a navigation approach used to enhance the precision of position data derived from satellite-based positioning systems. It relies on a reference base station to provide real-time corrections, providing up to centimetre accuracy. Can be used to detect fixed dangers such as approaching the stop signs through a location database	Global. Functional as long as the sensor is within line of sight on a satellite and accuracy is enhanced if within range of base station (see Section 5)	Robust against rain, fog, snow and hail with system operational in these conditions.	GNSS can become unavailable due to poor atmospheric conditions or driving through a tunnel with no coverage. Can also be affected by urban canyons, multi-pathing and 'spoofing'. Free access to an SBAS is not currently available in Aus/NZ. RTK and D-GPS services are available but at an additional cost.

AVs will have a sensor system, comprising multiple sensor types, capable of safely navigating through a road environment full of vehicles, obstacles, pedestrians and underlying road rules. One method vehicles may use to achieve this navigation is “localisation”. Localisation involves fusion of data from several sources including on-board sensors for relative positioning, plus external absolute positioning, e.g. GNSS.

Figure 2.3 is one model of localisation which uses sensor fusion to obtain data (this one is provided by Bosch). Sensor fusion utilises the strengths of each sensor type listed in Table 2.1 and enables higher levels of automation.

Figure 2.3 Sensor fusion and localisation



Source: Bosch 2015

The difficulty in achieving full automation relies on the effectiveness of the sensor technology at gathering and processing the data in sufficient time to enable the AV to drive at a safe speed in a particular environment. Redundancy must be built-in by vehicle manufacturers to enable other sensors to take over if one fails during operation. The vehicle must have compensatory systems in place to maintain a view of localisation and control of the vehicle. Ensuring these systems are highly robust is one of the greatest challenges facing AV manufacturers. Other new sensor types are likely to be introduced in the future to help improve AV operation.

Alternatively, infrastructure may be required to provide positioning broadcasts to alert AVs of their presence as a safety precaution. Further clarity is required as current generations of AVs mature and more data on operation becomes available.

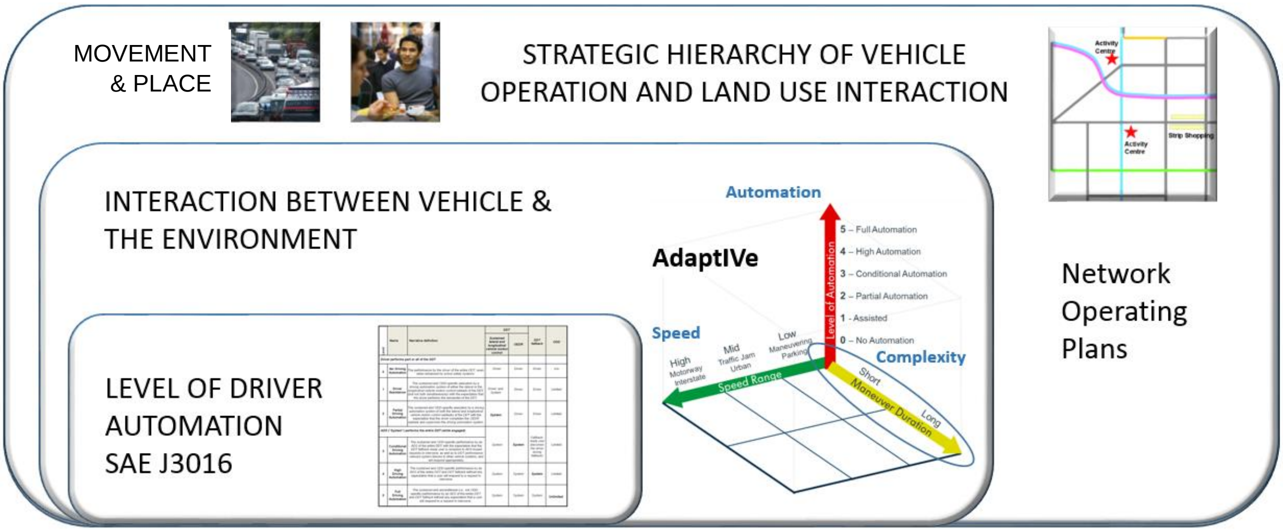
2.3 Frameworks for AV Operation

A common framework, describing the form and function of automated driving, will allow road operators to consider potential impacts, opportunities and implications of increasing vehicular automation. This framework should be applicable to all project types, covering the planning, design, operation, maintenance and use of AVs on the road network. Additionally, the framework will need to consider the potential opportunities afforded by completely driverless vehicles operating on our transport networks.

Government and industry have collaborated on a wide range of frameworks to allow more meaningful consideration of what AVs are, and the short and long term impacts of their implementation. The three primary driving tasks identified in Section 2.2.4 are: navigation; guidance (path following); and control. All three of these inputs are needed for a human driver or automated driving system to complete a journey. In alignment with this concept, a three-part framework is proposed for consideration, which is also outlined in Figure 2.4 below:

1. **The Vehicle (level of driving automation):** SAE AV Taxonomy (SAE J3016) classifies/defines levels of 'driving automation' as discussed in Figure 2.1. This is generically described as the SAE AV Taxonomy throughout this report. Perhaps the most important consideration for road operators regarding the SAE Taxonomy is the need to consider the division between human control and automated control of the vehicle. For levels 3, 4 and 5, the automated driving system performs the entire dynamic driving task when engaged. At level 3 (conditional) automation, a human must be present and able to take back the driving task if requested. Vehicle operation at levels 4 (highly) or 5 (full) automation will not require a human to be 'in-the-loop' of the driving task at all.
2. **Interaction with the Road Environment:** The European research project *AdaptIVe* (Automated Driving Applications & Technologies for Intelligent Vehicles) has developed a model as a base to consider AV interaction with the road environment. It considers use cases for interaction between the road system and the AV system. Some use cases considered include low speed parking, highway driving and light or heavy vehicle platooning. The objective of the project was to develop "automated driving functions for daily traffic by dynamically adapting the level of automation to situation and driver status."
3. **Strategic Management of Road Use:** Use the existing framework of considering the strategic road use hierarchy (Network Operating Plans (NOP)) combined with the concept of Movement and Place which considers the importance of streets in communities as destinations not just a conduit for transport. By strategically considering the role of AV with NOP as a base we are able to utilise a well-used base to discuss impacts on a wide range of road users and scenarios. The need to consider place is vital – this will allow more meaningful discussions with issues impacting on land use which are generally of primary interest to local road operators and communities.

Figure 2.4 Strategic view of land use and hierarchy, vehicle interaction and vehicle automation



These three models are being promoted for consideration in this report. It is important to note that there is a diversity of models and use cases that have been upheld by different government, academic and private sector research groups for a wide range of reasons. Many deal with a myriad of use cases that relate to regulation. These use cases do not sufficiently discuss the underlying factors that determine key road operations principals.

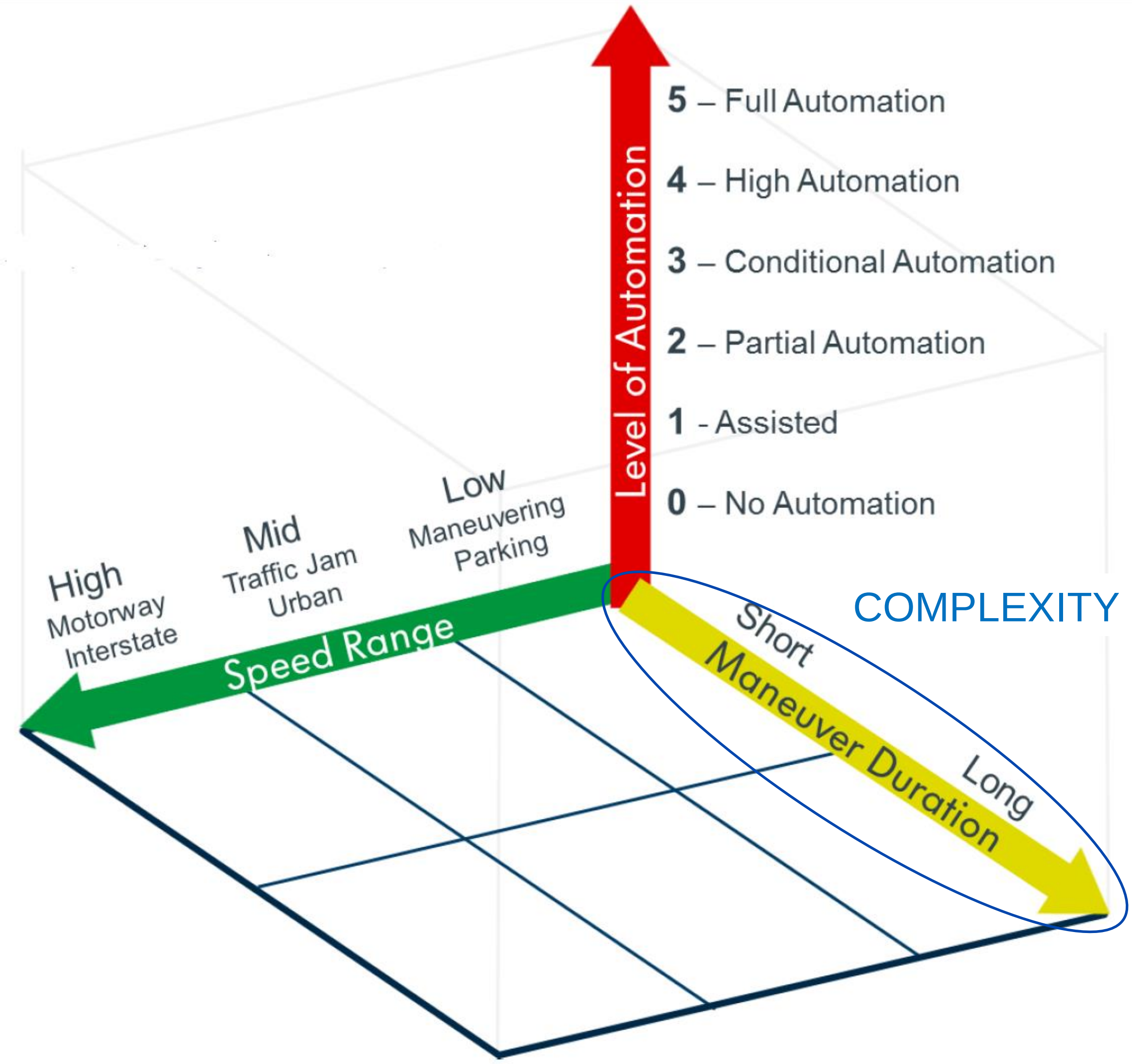
The first model for consideration is the SAE AV Taxonomy. Australia's regulatory framework for the market introduction and use of motor vehicles, does not currently specifically address differing levels of driver automation. The Informal Group on ITS and Automated Driving (IG-ITS/AD) under UN Working Party 29 is currently working towards an agreed definition for automated driving. They currently refer to the SAE AV Taxonomy but it is important to note that the taxonomy hasn't been referred to in any regulated standards.

The second part of the suggested framework (based on *AdaptIVe*) builds on the SAE taxonomy to present the interaction between the vehicle and the environment. Most standards and frameworks relating to AV are written solely from the perspective of vehicle systems. The *AdaptIVe* model being proposed is developed with more consideration of the road operator and the need to test the functions of the vehicle in a structured gateway process prior to implementation.

The project involved the development of a framework for assessing the implementation of a specific type of AV under certain environmental conditions. Figure 2.5 outlines three key dimensions that were assessed when evaluating the operational safety of AVs.

1. the level of automation
2. the speed of the vehicle
3. road complexity (the particular vehicle manoeuvres to be performed).

Figure 2.5 Consideration of functional safety



Source: AdaptIVe 2015

Limiting the operational environment in terms of speed and complexity (for a given level of automation) allows the safety of implementation to be assessed in a more efficient, systematic manner.

The *AdaptIVe* group and other organisations interested in defining levels of automation (including the SAE) define automation as “continuously automating [vehicle] functions”[3].

Movement and Place and NOP provide the most strategic view of the framework with a focus on land use planning and operational hierarchy and are discussed in greater detail in Section 3 as a key influence on transport and land use outcomes.

As mentioned above there are many other ways to consider AV frameworks depending on the need of the information and interactions taking place. Another way of considering a framework from a vehicle centric perspective is to consider information flow. Key information flows have been described as navigation, path, and control optimisation (which aligns with our discussion of AV frameworks above). In addition, other information flows are: provision of environmental information (road conditions potentially shared with a traffic management centre and other road users), updating vehicle capability, monitoring the vehicle performance, monitoring occupant health, and occupant emergency (Wachenfeld & Winner 2014). These information flows will be discussed in further detail in Section 5 and Section 6.

2.4 AV Operational Use Cases

A recent study on automated driving was able to show that given a group of people, the perception of ‘driving’ an AV differed depending on context (Fraedrich,E & Lenz, B. 2014). As discussed earlier in the document, the Adaptive framework facilitates a better understanding of user interaction with the AV environment.

It is important to be very clear about the particular context of AV operation – discussing these issues in terms of easily described use cases is a good way to progress a common understanding. Undertaking a concept of operations discussion with key manufacturers, road operators and a range of other interested parties would greatly assist the understanding and implications of these use cases for all parties.

The non-exhaustive set of selected use cases outlined in Table 2.3 is presented to cover the range of functions from driver support systems through to completely driverless vehicles (with no human driver input). Please note that the use case names are used in a generic context and are not referring to any product or brand names. It is important to note that these use case names have been used in a variety of ways across the industry which can cause some confusion. A detailed consideration of the implications of the associated descriptions is required.

Table 2.3 Example AV use cases

Use Case	Description	Benefit
Highway (freeway/motorway) pilot[1]	The vehicle is able to perform the driving task on freeways/motorways. The vehicle is able to execute tasks such as navigation, path tracking, and control as well as a safe handover to a “minimal risk” situation. The AV takes over the driving task when it enters the freeway/motorway, after the driver indicates a desired destination and performs handover. The AV executes all driving processes until the exit from or end of the highway is reached. At the end of the driving period, a handover process occurs. If the driver does not meet the requirements for a safe handover, the AV transfers the vehicle to the minimal risk state in the emergency lane as it exits the freeway/motorway.	At level 3 automation and above, the driver becomes a passenger during this automated journey and can pursue other activities without need to provide oversight to the driving task. This alternative use of time is perceived as a boon to the traveller, who can re-direct his/her effort from the monotony of driving to potentially more productive pursuits. Potential safety benefits, particularly with addressing run-off-road crashes.

3 https://www.adaptive-ip.eu/index.php/objectives.html

Use Case	Description	Benefit
Traffic jam assist [2]	The Traffic Jam Assist system provides vehicles with some automation in slow-moving congested traffic including automation of the “stop-go” driving function. The vehicle autonomously follows the vehicle in front at a safe distance and maintains its lane position (without requiring any communication with other vehicles). Control may be given back to the driver if lane changes are required or if obstacles are detected or if the driver takes control.	Reduce driver stress in highly congested (but controlled) environments Potentially safety benefits, particularly in addressing rear-end and lane-changing crashes.
Autonomous valet parking [1]	Once the driver has reached the destination, he/she stops the vehicle, implements the automated parking function and exits the vehicle. In this use case, the vehicle may be owned either privately or by a car sharing provider. The AV may drive to an assigned parking spot or interface with a local government application to identify the nearest available parking. Once the traveller is ready to be picked up, he/she indicates a pick-up location to the AV. The AV drives to the pick-up locations and stops, waiting for the driver to take over the driving task. Particularly applicable to densely populated urban locations.	The vehicle is able to park itself after the driver, passengers and cargo have got out and to return automatically from parking to a desired destination. The driver saves time searching for a parking vacancy. Departure may be co-ordinated with the vehicle, such that it is ready and available for pick-up as the traveller exits a building. Parking spaces outside the CBD or entertainment district may be utilised more equitably.
Heavy vehicle platooning[3]	One Potential Lead Vehicle (PLV) and one Potential Following Vehicle (PFV) indicate that they wish to initiate a new platoon. The PLV driver is properly trained for HV platooning. Back office systems may be used to generate financial transactions around this agreement and to guide the Leading Vehicle (LV) and Following Vehicle (FV) to connect with each other. To maintain the platoon, speed, and positioning have to be periodically adjusted. When an LV or FV wishes to leave the platoon, they indicate their intention to leave. The leaving vehicle reverts to manual control. The platoon still exists after an LV or FV exits, as long as another vehicle steps forward to take the place of the LV. If this does not happen, the platoon must be dissolved. A platoon may be dissolved when: An LV indicates an intent to leave in a controlled manner. An FV indicates an intention to leave in a controlled manner, but leaves behind other FVs. The platoon exceeds a safe capacity, Other vehicles (not HV) become part of the platoon. There is an emergency.	Drivers of the following vehicles may utilise their time in other tasks or in resting to avoid fatigue. Decreased fuel consumption and/or emissions. Increased road capacity utilisation
Vehicle on demand[1] (Including automated bus)	An automated vehicle receives the requested destination from occupants. The AV proceeds in a highly automated mode to the destination. There is no option for any of the occupants of the vehicle to take over the driving task. The traveller can only provide destination input or opt to take a safe exit. This vehicle could operate as a taxi, an automated bus (on a pre-set route) or a shared vehicle.	The AV is potentially capable of being available at any requested location or patrolling an in-demand route during peak times. The AV can drive with or without occupants and cargo. Passengers have free time to pursue other tasks. Transportation services can be transported 24/7, barring a need to re-fuel or re-charge.

1. Wachenfeld & Winner 2014
2. Bosch 2016
3. Bergenhem et al 2010

2.5 Timeline for Deployment

Accurately predicting the degree of AV penetration in the vehicle fleet is difficult given the number of variables which could influence introduction. There are various opinions on a timeframe for deployment of AV technology. These opinions are often mixed with marketing 'hype' and industry agendas. Road operators have noted interest in the length of transition from a low proportion of the vehicle fleet through to a homogeneous highly automated vehicle fleet on some or all infrastructure. It is not possible to accurately forecast the timing of such a transition at present. However this will continue to be a point of focus for road operators in the immediate to medium term.

There are three major issues which will affect the widespread introduction of AV:

1. Availability of AV technology at an affordable price.
2. Appropriate legislation and regulation to ensure safe introduction and use of AV technologies.
3. Societal acceptance of the benefits of AVs and other changes to transportation and technology which could change the use of and turnover of the vehicle fleet. These issues are discussed in further detail in Section 3.

Figure 2.6 outlines one view of the potential introduction of a range of AV applications to Australia, developed by Austroads. The left hand side outlines the level of driving automation based on the SAE nomenclature outlined in Figure 2.1. It should be noted that this diagram focuses on a wide range vehicle operation on public road but does not specifically consider low-to-mid speed vehicles operating on dedicated routes (e.g. level 4 shuttle buses) that may be exempted from complying with many regulated vehicle standards. It should also be noted that this diagram was based on feedback and knowledge that was available at the time, and the timings would likely be forecast differently if the diagram was to be updated.

The thin vertical blue line indicates the current day (2016) at the time it was drafted. The horizontal bars indicate the earliest forecast date of introduction (left hand side of each bar) and the graduation in shading shows increasing penetration of these technologies over time. The acronyms outlined in the diagram are outlined in the Glossary.

2.6 Summary

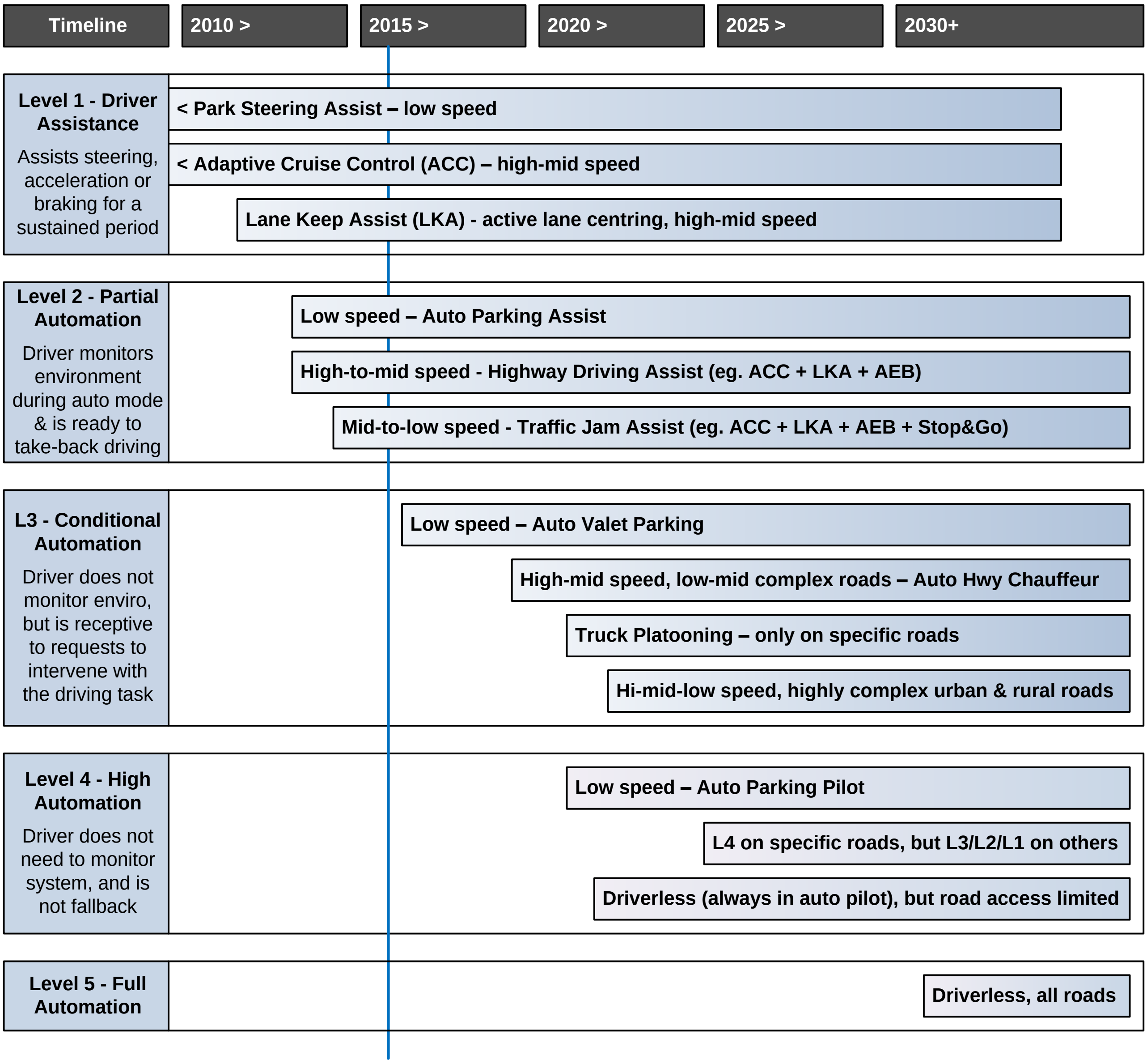
Clear frameworks are needed to consider the complex interactions between AVs and the environment. This section has outlined three different levels of a framework for consideration:

1. **Automation:** The definition of an AV is still under consideration by various regulatory bodies worldwide. The SAE Taxonomy has been suggested as a guide to defining the levels of automation within vehicles.
2. **Complexity of road environment:** It is clear that vehicles with greater levels of automation have different needs from the road environment. The European *AdaptIVe* project has developed a model as a base to consider AV interaction with the road environment.

   An issue that has emerged is the fact that the road environment also needs to be defined in terms of its complexity for AV operation. To achieve this, use cases should be defined for the road system, possibly using a Concept of Operations approach.
3. **Strategic Road Hierarchy and Land Use:** AV use cases also need to be considered to understand more strategic aspects of operation. This could be done as part of Network Operating Plans, in a similar way to how we would consider other road users. The concept of "Movement and Place" also needs to be considered as part of a framework to consider land use alongside considerations of mode of travel and road hierarchy.

A sample of use cases and a potential timeline for deployment has been outlined in this section.

Figure 2.6 Possible timescales for AV introduction



Source: Developed by Austroads following a wide range of discussions with vehicle manufacturers and wider industry (2016)

3. Influences on AV Uptake and Usage

Before considering the potential impact of AVs further, it is important to consider the wider technology and mobility trends which could influence the impacts of AVs. In his opening address to the ITS World Congress in 2015 the Chairman of ERTICO Cees De Wijs noted the three key trends of “Electrification, automation and the shared economy” as influencing transport moving forward. These are often described as “disruptive” and there is significant interplay between these trends and they cannot be considered in isolation.

This section will illustrate the complexity of trying to predict the societal circumstances, mobility trends and technology uptake that will be experienced with the disruptive trends as outline by Cees De Wijs. It is important to understand there is no single-point future prediction. There is a range of outcomes that may eventuate. AVs have the potential to facilitate changes in our communities in the way we move, connect, work and play. These societal changes may be beneficial or detrimental, depending on the diffusion of the technology and adaptive changes of the collective community.

This section develops the following concepts:

- movement and place
- mobility in an automated vehicle world
- potential positives and potential negatives of AV usage.

Building on these concepts the possible broader interventions by regulators are briefly discussed. These include:

- pricing and taxation
- vehicle parking
- provision of public transport services
- planning and modelling for AVs
- regulation.

3.1 Movement and Place

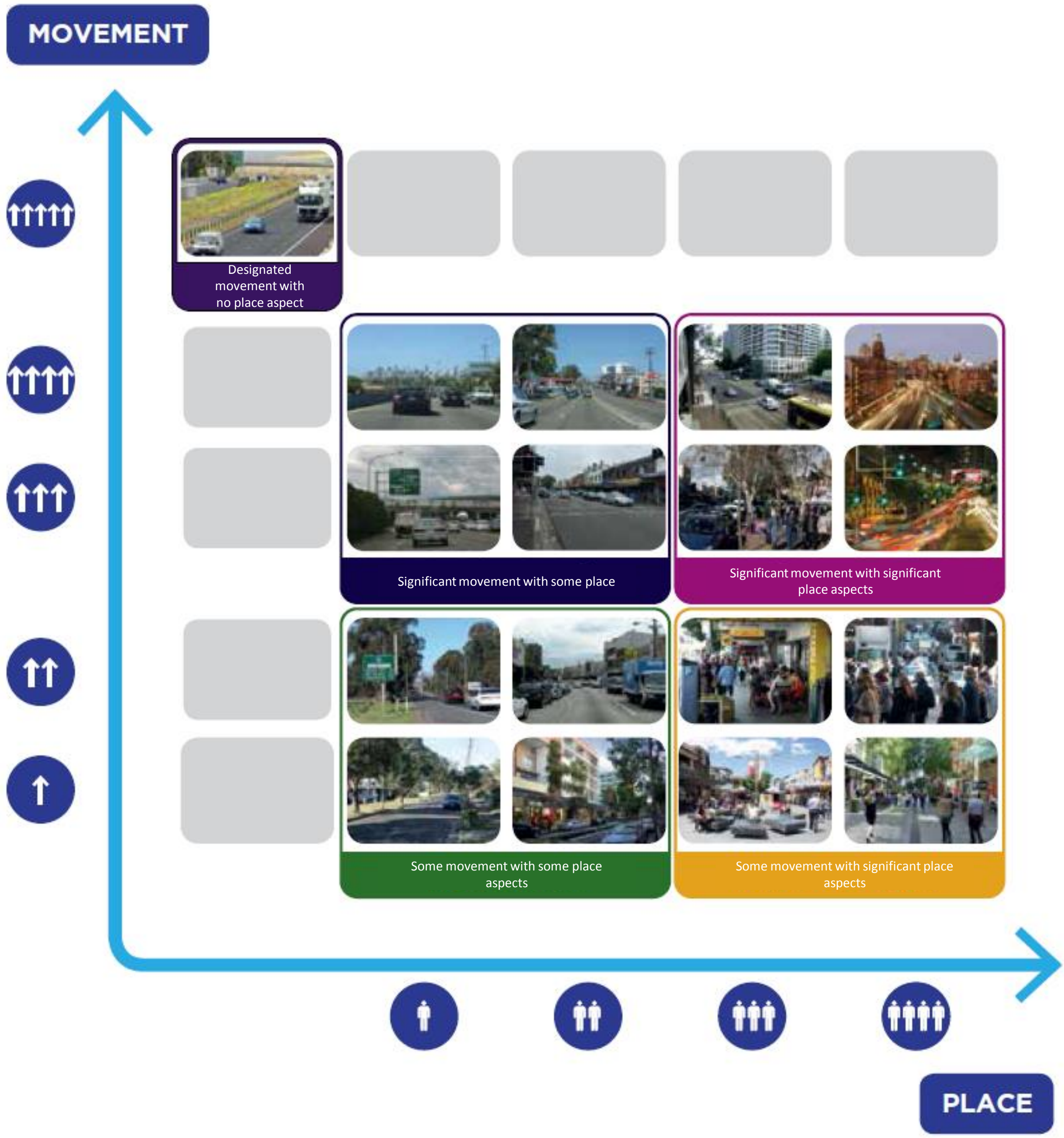
“Movement and Place” or what is sometimes referred to as “Link and Place” is a concept and framework which is being adopted by many government authorities internationally to consider and plan our road network and urban environment. The Movement and Place Framework identifies the role of each road through a movement and place matrix (as shown in Figure 3.1). This is based on the strategic significance of the road to move people and goods and the strategic significance of the land use interacting with the road. (Austroads 2016a)

The model is simplistic but is a useful instrument to allow stakeholder discussions about what outcomes we are seeking for our urban environments.

A Network Operation Plan (NOP) is a detailed assessment process that has been adopted by numerous authorities across Australia and New Zealand. The use of NOPs is outlined in the *Guide to Traffic Management Part 4: Network Management* (Austroads 2016a). The development of a NOP allows development and integrated operation of our road transport network. It considers land use but only in terms of access to and impact on the transport network. This is discussed in more detail in Section 3.2.

Given the different nature of operation of highly automated vehicles (operating at SAE levels 3, 4 or 5), it is important that we consider the impacts on "Place" as well as impacts on transport networks to ensure optimised outcomes from a whole of community perspective. This is discussed in greater detail in Section 6.

Figure 3.1 Movement and place framework



Source: Austroads 2016a

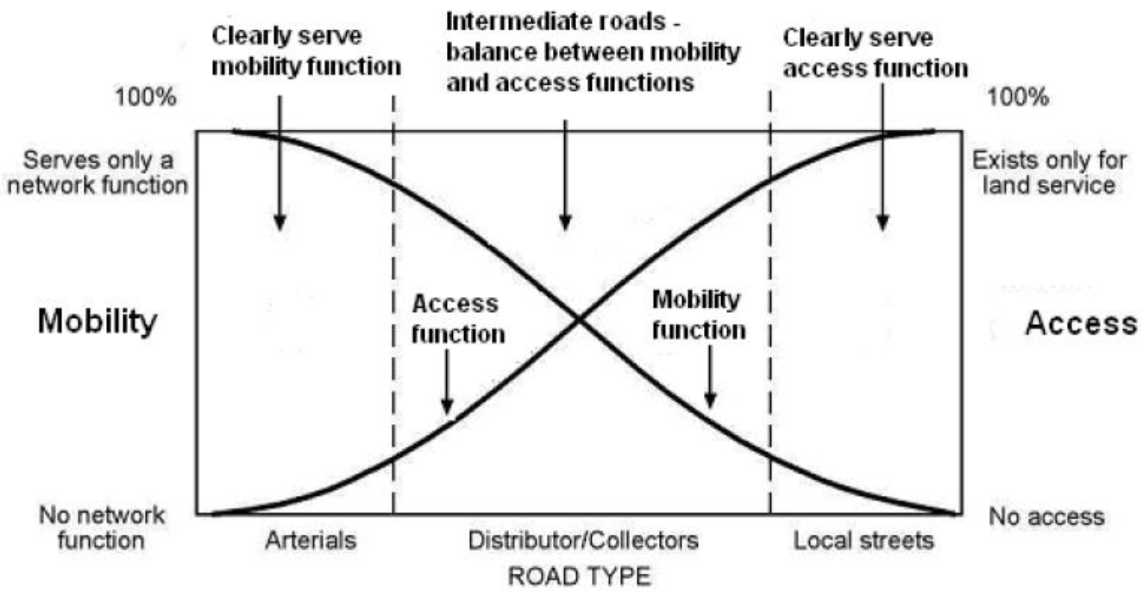
3.2 Network Operations Planning Framework

As discussed above jurisdictions in Australia and parts New Zealand have adopted an approach called Network Operation Planning (NOP). This framework outlines the important role of network operations in terms of increasing the efficient use of road network assets. It goes beyond traditional paradigms of the provision of road infrastructure and looks more holistically at the road asset as an operational system for multiple transport modes. Overall system performance and efficiency of the road network as the ultimate goal. Looking at the needs of road users, determining the right mix of infrastructure and non-infrastructure solutions, and focusing the prioritisation of interventions are examples of considerations of the NOP process.

One particularly important part of the NOP process is the development of the road hierarchy beyond a simple two dimensional model of classification, for example arterial road vs local road. NOP seek to recognise the additional dimensions to road hierarchy. That is different modes, use types and time of day considerations.

Figure 3.2 outlines how certain road types provide a certain mix of mobility and access function from 100% network or movement function (freeway) through to 100% access to a land use function. This concept has been central to the development of our road networks globally over many years.

Figure 3.2 Road type and function



Source: Brindle 1987

The process of NOP and similar concepts adopted in other countries has been well received by many planners and engineers because it provides a mechanism for a more transparent consideration and discussion regarding our use of roads as an integrated network. NOP enhances our ability to consider balance between transport and access. NOP promotes a focus on moving people and goods not vehicles and allows recognition of transport as supporting broader community goals.

3.3 Mobility – Providing for or Containing the Increased Travel Demand

Mobility will be greatly increased with the rollout of automated vehicles, with car access no longer limited to those willing and able to safely operate a vehicle. This will lead to an increase in the mobility options of members of society who currently cannot readily access private vehicle services, including the young, elderly and disabled.

Automated vehicles may also impact mobility by further encouraging the implementation of functional ride sharing systems. Assuming an automated vehicle future which sees vehicles constantly connected, ride sharing can be further integrated by combining two discrete trips if they share similar origins and destinations. There are numerous ways this behaviour can be encouraged, but to be successful on a wide scale it will require data to be shared near instantaneously, widely, and securely. It is important that the Disability Discrimination Act (DDA) issues and inclusiveness of all people are considered with the update and encouragement of these services, particularly if they are being viewed to provide public transport services.

In a scenario where we have a homogenous fleet of highly automated vehicles the capacity of roads could be increased without increasing the road footprint in the future. This could be achieved by the potential for AVs to safely maintain smaller clearances between vehicles both ahead, behind (i.e. headways) and lateral clearances. Connected AVs may also be able to dynamically reallocate road space based on demand, allowing for a greater ability to cater for heavy peak directionality demands on roads, or prioritise the movement of certain vehicle types. This is discussed in greater detail in Section 5 and 6 of this report. It is important to note that in a mixed fleet scenario these benefits may not be as achievable, except where capacity is available for AV specific use (potentially including at intersections and interchanges).

In certain scenarios highly automated vehicles could allow for reduced trip times and enable passengers to be productive during their trips. The combination of these factors may result in a greater ability for people to live further from their jobs and activity centres, which will in turn put increased pressure on the urban fringes of cities, and increase utilisation and demand on road assets by increasing the aggregate VKT of the fleet.

3.4 Potential Positives and Potential Negatives of AV Usage

Any assessment of the impacts of automated vehicles should be considered through the lens of the uncertainty around what the AV future will look like. As highly automated vehicles become mainstream, they will catalyse many changes broadly throughout society. From a road operator perspective these changes have the potential to be both positive and negative depending how AVs are utilised and how society adapts to their application.

For example, in a scenario where private vehicle ownership rates are low and ride sharing is high, the productivity of the combined vehicle fleet may be improved. This in turn would have a positive outcome. Another scenario involves a situation where private ownership remains high, and vehicles begin to make driverless pick up and drop off journeys. In this case fleet productivity is reduced with negative impacts experienced from the decreased vehicle utilisation.

These two scenarios are simplistic representations to demonstrate extreme (though unlikely) impacts AVs may have depending on the diffusion of the technology into society. Table 3.1 provides further detail regarding the contrasting future visions as they relate to technology, mobility and societal impacts only and not safety implications which have already been widely discussed and documented.

Table 3.1 Key attributes of contrasting future visions

Attributes		Pessimistic Scenario	Optimistic Scenario
Technology	**AV operations**	Lack of continuity and consistency regarding when highly automated modes are available and inconsistent handover between manual and automated control	No driver inputs required in nearly all scenarios in the future. In the short term the availability of highly automated modes and handover is highly predictable and reliable
	AV Interoperability	AVs are autonomous and not interoperable with AVs supplied by different operators	AV data is able to be exchanged in a format which is readily understandable by other system providers, vehicle manufacturers and road operators
	AV connectivity	AVs are not connected to other AVs or a wider network and key information cannot be shared	AVs are connected to wider network, increasing network performance through vehicles across a network. Vehicles are also a source of information to help manage infrastructure and operations
Mobility	**Vehicle ownership**	Vehicles are mostly privately owned	Vehicles are mostly owned by businesses or other mobility service providers.
	Vehicle usage	Low percentage of shared rides, likely only between family, friends and colleagues similar to today	High amount of vehicle sharing
	Public transport	Public transport usage limited, with decreased services due to popularity and affordability of private AVs.	A wide range of commuter services are available which are fast, reliable, and competitively priced. Automated vehicles able to provide a range of solutions including first and last mile solutions.
	Other road users	Cyclists and manually operated vehicles including motorcycles banned or have very limited use on some sections of road due to provision of AV only infrastructure. This may be more focused on meeting the needs of Level 4 AVs which could require more controlled environments to be operating without driver fall back and need to drop back to minimal risk condition if the driver is not available for handover of control.	AVs capable of operating in mixed vehicle environments. Decrease in overall VKT allows for road space to be reallocated to other road users encouraging active transport modes
	Pedestrians	Pedestrian crossing of some thoroughfares restricted to ensure safety operating conditions which impact on pedestrian amenity.	On main routes pedestrians operate much like today's society. Decrease in overall VKT allows for road space to be reallocated to pedestrians
Societal impacts	**Mobility of vehicle users**	Inequity of mobility for people that do and do not have access to AV technology.	Increase in mobility as all people are now capable of utilising an AV, as opposed the existing situation where only drivers are able to operate vehicles
	VKT	VKT increasing due to the commute distances from urban sprawl, lack of trip linking, and lack of ride sharing. This has resulted in increased congestion and travel times.	VKT has either stayed the same as today's society or decreased, and congestion and travel times are improved due to, reduced vehicle headways, better throughputs limits to urban sprawl, and the reduction in accidents providing greater reliability.
	Road capacity	Government is required to increase the road capacity due to the significant VKT increase.	Road capacity needs have decreased, allowing reallocation of road space

Attributes		Pessimistic Scenario	Optimistic Scenario
Societal impacts (cont')	**Parking**	Parking needs have generally stayed the same as the demand is similar to existing private ownership models. Parking spaces may be re-located due to ability for vehicles to park themselves remotely after usage. Parking pick up / drop off is substantial.	Parking needs have decreased substantially due to the reduction in single occupancy vehicle/privately owned vehicles Parking pick up / drop off is ubiquitous.
	Access and Movement and place	"Rat-running" more prevalent due to increased congestion, eroding amenity of places	AVs operating in an appropriately designated road use hierarchy and with recognition of Place, which will restrict rat running through inappropriate areas. AVs only operating in residential areas for first and last mile of trips. Care taken to manage pick up and drop off to mitigate impact on Place
	Transport accessibility	Demand for public transport is reduced resulting in a lower level of service provision. Low income individuals have fewer public transport choices and services available to them which may be focused around areas which have a sustainable demand level.	Low income individuals have excellent access to mobility options, using both public transportation and other shared AV rides.

3.5 Pricing and Taxation

In order to provide some measured influence over the potential effects of AVs, regulatory and financial incentives and disincentives could be used to guide and influence behaviour. Tax and fee structures relating to vehicle ownership, usage, and parking could be adjusted to promote desired vehicle usage and behaviours. Examples of these include:

- sales tax on private vehicle purchases
- tax on vehicle kilometres travelled combined with some measure of the impact of those kilometres
- variable vehicle registration fee based on level of sharing/use
- variable insurance based on usage
- high fees for public parking and high taxes for private parking
- reduced or subsidised costs for shared ride services
- reduced or subsidised costs for bike share, shuttles, and other solutions proving "last mile" access to transport nodes.

3.6 Vehicle Parking

Parking needs may be impacted with the introduction of AVs. If consumers own their vehicles and rarely share them, the parking needs will probably remain similar to today. On the other hand, increased vehicle sharing could significantly reduce the parking requirements. Parking policies can be established to minimise and manage dedicated parking facilities. Examples and other opportunities include:

- Eliminate or reduce minimum parking requirements in planning laws.
- Restrict or limit the number of parking spaces allowed in residential developments (and reduced even further if along public transport corridor) (and encourage/require those spots to be dedicated to car sharing providers).

- Require developers to develop parking management plans that outline how parking requirements can be minimised. This would include details about how pick up and drop off access will be facilitated.
- Developers must pay for the right to develop parking spaces and the government can use that funding to pay for parking in designated (and possibly remote) locations.
- Establish a city-wide parking space cap.
- Dedicate parking space to car sharing companies or shared vehicles. Additionally, car sharing companies may have exemptions for parking time limits or unlimited access to street parking.
- Institute variable priced parking to proactively manage how parking spaces are used.
- Reduce the size of parking bays in areas where vehicles can self-park. There will be no need for people to open doors. This is seen as an advantage in compact house design where home garage space is limited.

3.7 Public Transport – Changing Demands

Public transport's role in social access and mobility could come into question when highly automated vehicles are able to provide a greater level of amenity to users at a comparable cost. At this time public transport agencies will need to determine the appropriate level and the location of services. For example, the use of smaller vehicles for public transport services on a more dynamic basis may reduce the costs and increase utilisation of the service. This may enable public transport to compete more readily with private ownership and other mobility providers.

It is important to consider that an AV on-demand service forms an important social mobility role, and should be accessible to all users and not completely market driven. Government may need to consider how to work with private mobility providers to ensure equitable, fairly-priced mobility options for everyone. This may include community delivery of transport focused on relatively small geographic areas. This is particularly important in outer suburban areas. As noted in the recent *Smart Cities Plan* [Commonwealth Government 2016, pg 11]:

> *"these outer suburbs are often further from choices in education, transport and essential services. In the absence of good planning, growth can create isolated communities with limited access to opportunities to realise their full potential".*

Public transport operators will need to re-evaluate their fleet management plans in order to incorporate automated vehicles into their fleet. This will have significant implications for labour requirements, maintenance facilities, maintenance workers, and the safety and security of passengers.

3.8 Planning for and Modelling Impacts of AV

As more information becomes available about AV and their uptake increases, travel demand models will need to be updated to take account of these effects. The travel demand models should ideally reflect updated information regarding where people are living and working, how many trips they are taking, and what level of shared rides are occurring. The nature of these trips will be determined by a range of vehicle ownership approaches. It should also capture any changes associated with freight delivery. All of these factors are likely to impact travel behaviour. Modelling these impacts will likely be refined as the technology is developed further.

As has been described in the above section there are a wide range of potential assumptions that could be made about the future mix of parameters that need to be understood to allow accurate modelling. Many in the transport planning and forecasting industry recognise the need to consider integrated land use, public transport, private, and active transport options in a holistic manner. Bain (2009) notes that there are two key aspects we should always consider when making a forecast: firstly the need for transparency about what the model is being designed to do: its purpose, and secondly the need to clearly articulate and state the assumptions, in particular about the "future case" model being developed. This can allow a sensible discussion about these future scenarios and test some of the underlying considerations outlined above. Greater engagement is needed with the modelling community about the importance of these issues and the need to respond to these challenges. The lack of transparency of modelling assumptions for future year forecasts has already been recognised as a critical failing in some of our largest infrastructure projects (particularly toll roads (Bain 2009)) and could be further exacerbated by layering of the other aspects noted above. The transport and land use modelling community is able to develop simple and transparent ways of allowing policy and strategy makers to test a wide range of assumptions. This could be a very useful step in considering the range of future outcomes. Such a tool would be valuable in engaging wide ranking government, community and private industry stakeholders in these important discussions. It is important to note that this is the key benefit rather than the outputs themselves, as these tools and models could well serve as a platform to consider significant policy changes to meet the needs of our changing communities.

3.9 Governments and Regulators

Automated vehicles have the potential to impact State/Territory and Local Governments in a number of ways. This can be broadly grouped into two categories:

- impacts on existing operations
- impacts on governance frameworks and policies.

Operational impacts include changes that may cause adjustments of current operations. Some examples include:

- increases in traffic congestion, through changes in vehicle usage
- taxation revenues that may increase or decrease with changes in fleet ownership and levels of electrification
- changes to provision of public transport and parking services in response to changing needs.

Governance impacts include the requirement to establish new frameworks or policies to ensure the impacts of AVs are aligned with the needs of the community. The increased mobility provided by highly automated vehicles will lead to significant challenges and opportunities that will need to be managed. The requirement for governance frameworks will span across government jurisdictions and departments. This will require significant collaboration across a wide range of government and private stakeholders. This will be discussed in further detail in Sections 6 and 7.

3.10 Summary

Road operator actions to support AVs will be influenced by societal uptake and usage that are as yet unknown. Potential impacts and operator actions given these unknowns are summarised below:

- Frameworks and guidelines to plan and operate road networks will need to change to take account of the introduction of AVs. This will bring a focus on the need to consider the concept of 'place' as part of Network Operating Plans.
- Travel demand models will also need to change to take account of the impact from AVs. AV introduction will result in increased mobility and the ability to more productively use our travel time could result in a large increase in VKT if not appropriately managed. The impacts are currently unclear. There is a need for transparency of key assumptions being used in these models.

- Emerging mobility services such as on-demand mobility services will have a significant impact on VKT and could have a significant impact on ownership models which would encourage earlier AV take up.
- Public transport services, particularly, local bus services could be impacted by last mile AV services. Care will need to be taken to ensure that access and mobility is being enhanced and that DDA is being well considered.
- Vulnerable road users could gain significantly from AV introduction depending on how AVs are deployed. A strong focus on cyclists, motorcyclist and pedestrian interactions is required to ensure an optimised outcome.
- There will likely be a need to change parking requirements as a result of AV take up in the more distant future, particularly with highly automated vehicles. This is likely to result in a decrease in the need for city centre car parking spaces. More importantly it is likely that highly automated vehicles will result in a substantial change in pickup and drop off activities, which will need careful consideration in planning, development, and operations.
- Governments may need to consider changes to regulatory fees if they wish to influence the ownership (private v fleet) and usage (e.g. shared use) of AVs.

In addition to the above we note that there will be significant change to operations which will result from the uptake of AV. These issues will be considered in detail in Section 6.

4. Physical Infrastructure

4.1 Introduction

This section will outline AV interaction with physical infrastructure and identify how AV deployment could affect:

- In the short to medium term (1-5 years), the way in which we will design and maintain existing infrastructure in a mixed traffic fleet scenario (depending on the particular route).
- In the medium to long term, on changes to the way in which we design and maintain infrastructure, which is being purpose-built to cater for mixed fleets with an increasing proportion of AVs, in particular highly automated vehicles.

Two of the most important aspects are (i) the 'physical fabric' and (ii) the ability for AVs to read their physical environment, such as signage and line marking. As discussed earlier, AV operation is dependent on its ability to read the physical environment.

The physical road environment is a key consideration for vehicle manufacturers and the way vehicles interact with a roadway. Existing road infrastructure will need to support a mixed fleet of vehicles with differing levels of automation across a range of vehicle classes.

The scope of this section is for AVs that operate on roads accessible to the public, and not other types of AVs such as off-road shuttles or footpath delivery drones.

4.2 Australian and New Zealand Roads

In Australia roads are owned and managed by State/Territory government agencies, local government, and private operators. Federal government funding supports a range of priorities at both the state/territory and local levels. Each State/Territory government agency maintains its own network of freeway/motorway and arterial roads. Local government maintains local roads and there are several private road operators operating motorways. Most but not all of these privately operated roads are tolled.

Legal responsibility for roads in Australia is shared between the State/Territory and local governments and, in some cases other authorities established by the State/Territory Governments or the Commonwealth. In Australia funding for roads is shared between the three levels of government, with the Federal Government contributing funding to roads while not holding responsibility for operations and maintenance of public roads.

In New Zealand there is a similar regime with the federal NZ Transport Agency (NZTA) responsible for state highways, and other roads jointly funded by NZTA and local governments[4].

Roads are broadly classified in the following way, noting that all could be located in either urban or rural environments:

- freeways/motorways (major and minor) including roads known as freeways, motorways, expressways and tollways ('M' class roads) (Austroads 2015)
- highways and primary arterial roads (generally 'A' class roads)
- secondary arterial and minor roads (including 'B' and 'C' class roads along with local roads).

4 http://www.transport.govt.nz/land/land-transport-funding/road-funding/

In addition there are different categories of carriageway:

- dual (or divided) carriageway
- mixed carriageways
- single carriageways.

According to the *Australian Infrastructure Statistics Yearbook 2015* (BITRE 2015a) within Australia there are:

- 873,573 total km of roads
- 640,216 km of these are local roads.

In New Zealand[5] it is estimated there are:

- 94,496 total km of roads
- 83,621 km of these are local roads.

Some highways in remote areas of Australia and New Zealand are not sealed for high traffic volumes, and may not be suitable for AVs to operate in the range of weather conditions likely to be experienced. Following heavy rains, they may be closed to traffic for several days or weeks.

AV developments appear to be mainly focused on urban and freeway/motorway operation, with little focus on unsealed roads. In 2005, the ABS estimated that 56.8% of Australia's roads were sealed with bitumen or concrete (ABS 2005). Additionally, a significant proportion (65% in 2013) of annual fatalities occurred on regional or remote roads (BITRE 2015b). These factors are important when considering potential needs for AV infrastructure.

In a regional environment, the AV will be significantly more reliant on in-vehicle technologies to navigate the environment. For many rural areas there will also be less communications coverage. This is considered further in Section 5.

Due to the vast differences between regional and urban infrastructure, it may be that early AV deployments will be focused on urban freeways/motorways or high standard rural freeways and highways where a base level of acceptable infrastructure exists. Further to that, some early deployments would be best confined to controlled environments e.g. low speed off road scenarios such as university campuses.

4.3 Implications of AVs on Road Infrastructure

In Section 2 it was noted that in the longer term the nature of the motor vehicle would be likely to change. Feedback suggests that automotive manufacturers are developing AV technology with the goal of being able to safely operate on existing roads without the need to change existing road infrastructure (Gill et al 2015). The full benefits of Level 3+ AV deployment cannot be harnessed until AV technology matures to be able to correctly read the road environment in a highly reliable, predictable and safe manner. In very simple terms it is best to describe AVs as another road user with a particular set of requirements to interact with the road environment and other road users. As outlined in Section 2 we have suggested a framework to consider that interaction. We need to consider AV operation in terms of use cases.

The SAE J3016 standard (September 2016 update) outlines the need for highly automated vehicles to have the capability to bring themselves to a "minimal risk condition", which could be a complete stop. This could result in the need for laybys in tunnels and at the end of AV routes (e.g. at off-ramps).

As noted in Section 2, the mass market deployment of AVs with Level 3 or greater capability could have infrastructure implications for certain environments. AV deployment will ultimately redefine our infrastructure needs as the benefit from more prevalent AV operations overtakes the cost of infrastructure improvement. This will allow road operators to improve the safety and efficiency of our road networks (Gill et al 2015).

5 http://www.transport.govt.nz/ourwork/tmif/infrastructureandinvestment/ii002/

In the short to medium term, physical infrastructure required to operate in concert to support AV operation, can be considered in three broad categories:

1. Infrastructure which impacts on the AVs ability to position itself safely on the road or “read” the road environment. Examples include lane widths, vertical and horizontal curves (which impact forward visibility), intersection design, line marking, and signage.
2. Structural systems which support vehicle safety generally and may require some special consideration for unique AV characteristics (particularly heavy vehicle platooning). Examples include, pavement design, barrier design and bridge and culvert design. This is collectively described as pavements and structures.
3. Other road design elements or facilities required to support AV operation. This includes consideration for elements such as on-ramps/off-ramps (for light and heavy vehicle platooning operation), prevalence of emergency or pull-off bays, connector roads, merging lengths etc.

4.3.1 What Does This Mean for Existing Australian and New Zealand Road Signs and Road Markings?

Issues regarding the condition and consistency of existing infrastructure can be addressed by ensuring consistent application of the design and installation of national roadside signs. Vehicle and system manufacturer discussions held as part of this study indicate that international consistency in the application of road signs and road markings would be ideal. They also note that the provision of nationally consistent information would be a very helpful first step towards ensuring a more effective introduction of AVs in Australia and New Zealand. This could be met by consistent update to and adherence to existing **national** standards and guidelines by all road operators.

Many European countries are signatories of the Vienna convention for road signs which aims for basic and consistent sign features. Another approach is the Manual on Uniform Traffic Control Devices (MUTCD) used in the USA. To achieve national consistency in the long term Australia and New Zealand could consider using one or a combination of both conventions, as long as we do not add any additional signs. It is important to note that following a convention will not guarantee consistency. The Vienna convention does not cover all features that need to be addressed. The missing features include:

- traffic signal sequences
- specific information about the heights of mounting signs and signals.

Understanding the condition of current road infrastructure will aid AV technology by identifying areas of inadequacy. It is envisaged that ongoing monitoring and surveying of road infrastructure conditions will be required to maintain the condition of the road.

EuroRAP established a survey to address the practical use of road signs and marking in seven sample countries; Germany, Great Britain, Netherlands, France, Poland, Greece, and Serbia (EuroRAP 2011). The results of this study included:

- legal frameworks for prescribing signs and markings exist in all of the studied locations
- all of the studied countries had a “highway code” or other reference for drivers
- consistency in speed limits was exhibited when entering a speed zone (less consistency when exiting)
- “stop” and “no entry” signs are generally consistent between countries
- warning signs are generally consistent between countries.

Civil and structural design of roadways, bridges, and other associated infrastructure needs to be reconsidered in light of the changing usage scenarios.

4.3.2 Changing Our Use of Infrastructure

As highlighted in Section 2, the emergence of AVs, along with the new mobility services that AVs will support, will lead to a range of new use cases and scenarios. While industry feedback suggests that most AVs will be designed to operate on our roads as they are, it is likely that the emergence of these new use cases and scenarios may progressively bring with them changing requirements from our road infrastructure. This section discusses some likely changes on the horizon.

a) Road Certification

It will be prohibitively expensive to modify all existing road infrastructure in the short to medium term. One idea that is commonly raised is that road sections may be “certified” as being able to support certain AV use cases. Road certification would work by evaluating and defining roads that are suitable for specific vehicles and use cases. There is understandably significant interest in this topic, and the discussion has been evolving in a range of forums over the last few years. No detailed approach to road certification has yet been proposed.

Road owners or operators could be given the responsibility for developing roadway classifications and allocating certifications. Essentially, road certification creates a bias for or against particular vehicle use cases operating on particular roadways. This concept is similar to the method already defining heavy vehicle routes. It is quite possible that road owners and operators may choose to rule out the operation of certain use cases on a particular roadway, rather than certify the road for specific use. Certification may result in roadway owners assuming some level of responsibility for the “driving public” (Isaac 2016), and this matter needs to be considered further.

Requirements for certification would include clear road markings, appropriate and consistent signage on the network, and communication to users regarding use cases that can operate on that roadway (Isaac 2016).

Many of the stakeholders with whom we discussed the concept of road certification, noted that this could be too difficult to implement and cause road owners to assume unnecessary or unreasonable levels of liability. For this reason, some manufacturers are focusing on AV that can exist with our current infrastructure without modification, thus eliminating the reliance on new infrastructure (Isaac 2016).

The conference board of Canada has produced a report on the status of AV technology and likely social and economic impacts. It contends that no major infrastructure project should be undertaken in Canada without an “AV impact audit” to consider the viability of long-term investment decisions, in the context of the impending disruption from AVs. This is particularly significant given the long lifetime of road related infrastructure (Gill et al 2015).

These audits would have additional merit if the terms of reference could be extended to consider when proposed changes to future infrastructure would be most viable to implement. In particular, it would be useful to consider the tipping point when AV benefits exceed the infrastructure spend. The content of such an audit would need to be carefully considered to ensure the full range of potential impacts are considered and that key attributes are able to be measured in a meaningful and consistent manner.

Another potential model to consider is the Australian National Risk Assessment Model (ANRAM). It could be modified to take account of some of the infrastructure needs such as clear and consistent line markings and signs outlined in this document.

b) Speed Limits

It is conceivable that a 100% AV fleet will travel at or below the speed limit specified on roads as a key method of ensuring safer outcomes on our roads. Potential issues with speed differentials between AV and non-AV could be problematic in some countries if drivers are not generally law abiding. It should be noted that Google's self-driving cars are programmed to exceed speed limits by up to 16km/h. This is to account for the behaviour of non-automated vehicles. Google has found that when surrounding vehicles were breaking the speed limit, going more slowly could actually present a danger. Therefore the Google car accelerates to keep up in this context (SIBA 2014).

For roads that are available exclusively for automated vehicles it may be just as safe to have higher speed limits, especially on highways although this would be a long way into the future. While it is not considered likely that society will move to exclusively automated vehicles within the foreseeable future it is possible that the methods for setting speed limits will change over time (Isaac 2016).

The combination of Connected and Automated Vehicles allows for the possibility of dynamic variation of speed limits in response to demand, incident management, or congestion.

4.3.3 Changes to Design Standards and Guidelines

The table below outlines initial considerations for changes to standards to facilitate the introduction of AVs. It should be noted that it will still be necessary to ensure reasonable levels of passenger comfort and wellbeing is maintained when considering road alignment and stopping distances in addition to the vehicle / road interaction.

Table 4.1 Initial considerations for changes to design to encourage the introduction of AV

Design element	Key issues	Modifications AV may require
Alignment	• Stopping sight distance • Horizontal alignment • Superelevation etc.	• Improved ability to read the road with improved headlight technology (e.g. LED, laser light and infrared) and automatic braking systems will change stopping sight distances and vertical curve lengths. • Guidance systems could affect horizontal curve design.
Cross section	• Roadway width and shoulder width, median intersection design, turning lanes.	• Long term changes to vehicle design will change these key requirements e.g. reduced lane widths if vehicles are narrower.
Intersection	• Intersection sight distance models are based on driver behaviour rather than vehicle and roadway capacity	• In the short to medium term seeking to simplify intersection arrangements and interactions between vehicles. In the longer term if there is the greater potential for coordination between vehicles intersections could be made more compact
Structures	• Dynamic loading due to platooning vehicles	• May require a revision of design standards including loading assumptions. Note this may lead to greater numbers of heavy vehicles being attracted to a corridor or provide another reason to use a particular lane as well as decreased spacing between vehicles.
Pavements	• Loading due to platooning vehicles	• May require a revision of design standards including loading assumptions.
Freeways/motorways	• Design of certain aspects of urban freeways/motorways focuses on acceleration lanes, high-occupancy vehicles lanes, and entrance and exit ramps.	• In the long term homogenous fleets of AV will, improve throughput due to certainty of interactions and could require changes to ramp lengths depending on potential light and heavy vehicle platooning requirements. In the short term differences in the level of conservatism of AV operation will impact negatively on road operation, requiring at least current level of infrastructure provision.

4.4 Design of Road Infrastructure

There will be additional requirements from existing planning frameworks and operational guidelines to accommodate AV operations.

The design elements considered, relate to a range of road related infrastructure. It is vital to consistently apply local standards to achieve the best possible outcomes for AV. An area requiring more focused consideration is road works' sites due to the relatively unpredictable nature of these events.

Two key types of standards and guidelines need to be considered in the near future (within the next 10 years):

1. Provision of AV-readable, consistent infrastructure, such as static and electronic signage, and line marking (as well as lane widths). This should ideally be supported through national, and if possible, international standardisation wherever possible.
2. Appropriate infrastructure provision to cater for changes required to structures such as bridges, pavements and barriers.

In the longer term, when we have significant proportions of AV on the road network we are more likely to see more significant changes in the design of infrastructure to meet changes in vehicle design.

Based on experiences with both current vehicles and future vehicles that are being assessed, AV manufacturers have raised issues with the following in relation to Australian infrastructure. It is likely that some of these same issues would apply in New Zealand (Sage 2016):

- **Road signage:**
  - static signs (incl. fonts and spacing of characters, inconsistencies with the design and use of advisory signs, and inconsistencies with the use of words/conditions),
  - electronic signs (incl. refresh rates and readability of LED signs), and
  - sign location (e.g. service road signs adjacent to main carriageways have reportedly caused issues with some in-vehicle camera systems, and the height of signs)
- **Line marking:** including variability and visibility. This may also include accounting for the differentiation in driving behaviour required, based on double white lines, single lines or hazard markings.
- **Pavement condition:** including uneven pavement where bitumen has been used to seal cracks, cuts or drainage.

There have been significant efforts to standardise elements of road infrastructure in Australia and New Zealand over time. Austroads Guides and Australian Standards are primary technical references to ensure an appropriate level of national consistency.

Jurisdictions develop 'supplements' to identify where their practices differ, which take precedence. Standards for infrastructure are developed using a consensus approach with individual jurisdictions then choosing to extend elements of the standards to suit local conditions or a differing technical view regarding design.

This results in the creation of technical notes or additional guidelines which can then be cited in contracts for road operators as a mandatory requirement in suitably assessed cases. Some elements of infrastructure may be governed by international US or European design standards and guidelines, again on a case by case basis. This combination results in a wide range of approaches to infrastructure design which is a very unsatisfactory outcome from a vehicle manufacturer's perspective.

Some relevant standards are outlined below (this list is not exhaustive):

- Civil design (roads and pavement):
  - Austroads Guides (including the *Guide to Traffic Management Part 10: Traffic Control and Communication Devices* (Austroads 2016b))
  - American Association of State Highway and Transportation Officials (AASHTO) guides and manuals
  - *Highway Capacity Manual* (TRB 2010)
  - Australian Standard AS1742 *Manual of uniform traffic control devices* for signs and line marking
  - State based technical or guidance notes
  - Roadworks related Code of Practices and Guidelines (sometimes project specific).
- Structural design (pavements, bridges, containment barriers and retaining walls):
  - *Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2012)
  - Australian Standard AS3600 *Concrete Structures*
  - Australian Standard AS5100 *Bridge Design*
  - *AASHTO LRFD Bridge Design Specifications* (AASHTO 2014)
  - *Standardised Bridge Barrier Designs* (Austroads 2013a).

There will potentially be impacts on traffic signal and electronic road sign standards. Some of these issues are discussed in Section 5 (Digital Infrastructure).

There are a range of standards and guidelines applied to road operations, for example the US Transportation Research Board's *Transit Capacity and Quality of Service Manual* (TRB 2013). These are outlined in Section 6 (Road Operations).

4.4.1 Revision to Current Design Methods

Changes in the way we use our roadways may change geometric design as outlined in the section above. In addition to this we need to consider the implications of our roads being used in different ways as discussed below. A framework to consider these issues was outlined in Section 2.3.

It is important to note that national and international consistency in the way in which we design our infrastructure is vital to ensure the best possible outcome for AV deployment.

From discussion with a wide range of AV and equipment/sensor providers there is a very strong preference for:

1. Key elements of road side infrastructure to follow one international standard. This would appear unlikely in the short term.
2. If there is no international standard or even national standard, then consistency of design within a jurisdiction is the next best thing.

Other trends and elements to consider regarding future infrastructure design include:

- Major transportation infrastructure forecasting will need to start anticipating the arrival of AV on our roads. Design of infrastructure will need to start anticipating AV deployment and future-proofing projects to support AV technology (Gill et al 2015).

- The concept Simultaneous Vehicle and Infrastructure Design (SVID) was building some momentum around the year 2000 in the USA. This design approach works by aligning vehicle and infrastructure designers. This is done to identify synergies that allow the designers to improve the performance of both the vehicle and the infrastructure. This concept would appear to have more validity at present. Designing via a functional safety approach will provide a similar end result and is a useful model to consider development of design standards and guidelines. This is recognition of the whole road environment and the interaction of the human, roadside infrastructure and the vehicle being a system of systems.
- Three-dimensional (3D) and four-dimensional (4D) tools (which include the dimension of time) in highway design are becoming more prevalent (Fambro et al 1999). Technology advancements are changing the way engineers are approaching the design of transport infrastructure.

Uptake of automated vehicles will create greater demands on precision and currency of spatial information about our cities. As discussed earlier, mobility trends are likely to shift towards a more integrated solution to transportation. Therefore transportation will become complex, large, and interconnected systems.

AV makes it possible to use several transport modalities to create a collection of interrelated subsystems, strongly tied through feedback loops. However, this will also create reliance on accurate, current data. Designing infrastructure for AV requires designers to rethink the traditional model of usage and to embrace a more data driven design process.

Modelling will therefore become a fundamental activity to understand and simplify reality through abstraction. A holistic approach is needed to integrate and manage the various ITS solutions. A base modelling and simulation platform should incorporate some combination of a Geographical Information System for Transportation (GIS-T), able to cope with the spatial dimension, and a traffic simulation tool, able to handle the temporal dimension. The platform must be able to include other modelling tools as needed (e.g., environmental impact models, travel demand models). The basic requirements for such a platform would be (Ramos et al 2012):

- To support a broad digital Traffic and Environment database, and allow the integration of efficient data acquisition tools and the calculation of appropriate key performance indicators.
- To act as a decision support system by means of modelling, analysis and simulation capabilities that enables the comparison of different strategies.
- To provide tools to inform and involve stakeholders via intelligible, user friendly and realistic visualizations.

4.4.2 Design Considerations to Accommodate AVs

Different AVs will use different sensing technologies, have different functionality, and support different use cases. Given much of this is still unknown, designing future road infrastructure has its challenges. Some key design considerations are listed below:

a) Consistency of Lines, Signs, Pavements and Road Layout

As outlined above, vehicle manufacturers are concerned about these factors impacting the ability of their vehicles being able to “read” the roads in Australia and New Zealand. We need greater understanding of these issues before we make any changes to current practices, or at least ensure we consider a range of potential outcomes.

b) Context Sensitive Design Approach

Context Sensitive Design (CSD) is the art of creating public works projects that meet the needs of the users, the neighbouring communities, and the environment.

CSD uses a collaborative, interdisciplinary approach that includes early involvement of key stakeholders to ensure that transportation projects are not only “moving safely and efficiently,” but are also in harmony with the natural, social, economic, and cultural environment.

This is strongly related to evolving urban design principles, which are being promoted in some state and municipal authorities. Integrated land use and planning is the cornerstone concept.

This has more recently been simplified into a consideration of Movement and Place as outlined in Section 3.1, where link is the transport route and place is the urban environment where activities take place. These planning aspects are of vital importance to local governments. This has been recognised in the recently released *Smart Cities Plan* (Commonwealth Government 2016).

Integrated transport and land use planning considers our entire environment where: planning, implementing and operating a road should involve the whole of the road reservation from building line to building line (in an urban context). It is important to keep in mind that many road operators will only have had a need to focus road operation on kerb line to kerb line activities and not consider pedestrian issues, parking or access to adjacent developments. This is a constant tension between some state road agencies and local councils. AV will impact on land use and care will need to be taken about the impact of kerbside pick-up and drop off behaviour which is discussed further below an in the discussion in relation to road operations in Section 6.5.

c) Parking and Drop-off/Pick-up Locations

As vehicle capability changes, the way we use vehicles may also change; refer to Sections 2 and 3. It is quite possible that the increased penetration of automated vehicles may lead to greater sharing of vehicles rather than personal ownership. A shift may occur toward ride sharing options.

This shift in behaviour may lessen the need for car parks as vehicles continue on to perform a different task after completing the required journey. This will reduce the need for on-street and off-street parking.

Even in a situation where personal ownership remains strong, owners may opt to have their vehicles park themselves in remote locations. On face value, this would reduce the need for inner city / business district parking.

However a reduced parking scenario will be countered by a requirement for more passenger pick-up and drop-off facilities. If not appropriately managed, this shift could lead to congestion at these locations similar (or far worse than) current day taxi ranks.

Lastly, parking space sizes may change as vehicle size and shape adapt (Isaac 2016) to new requirements. Possibilities include, different sized parking bays for emerging vehicle classes; or narrower / stackable parking bays for empty AV storage, as there would be no need for people to walk to the parking bay and instead drop off or summon the vehicle, therefore cars could park closer together with no need to open the doors increasing the earning potential of parking areas and reducing damage to vehicles from minor car park collisions.

d) Intersection Design

It is highly likely that a fully automated vehicle society will create entirely new travel patterns. As a result, the local government may need to alter the signal locations and timings. Operators will continue to seek greater efficiencies from road operations, however these efficiencies need to be balanced with the function of the road as outlined in Section 3.2. There have been a number of innovative concepts put forward regarding future AV operation such as the slot based “Light Traffic” concept from the Massachusetts Institute of Technology (MIT) [6], the Swiss Institute of Technology (ETHZ), and the Italian National Research Council (CNR). This and other innovative approaches mention the potential to double intersection capacity. Care will need to be taken to consider non-automated vehicles and, most importantly, pedestrian and cyclist movements in any innovative design.

Local governments will continue to consider prioritising public transport and shared occupancy vehicles at intersections. AV technologies would be likely to become a part of the suite of technologies being considered in the future.

6 http://senseable.mit.edu/light-traffic/

e) Platooning

Platooning involves the linking of vehicles similar to a train and are not restricted to AVs. Both light and heavy vehicles are capable of operating in platoons, although heavy vehicle platooning can be considered a separate use case given the increased loads and dimensions of the vehicles involved. Some advantages of platooning include:

- Allows vehicles to reduce the following distances between vehicles and thereby enhances lane capacity usage.
- Creates potential for vehicles to obtain better fuel economy.
- Reduces driver fatigue. The lead vehicle is driven as normal (by a human driver, or in the future it may be an AV). In early versions of this practice the following vehicle driver is in control of steering, but allows the vehicle to control acceleration/braking when the system is in platooning mode (Florida Uniform Traffic Control Law 2016)[7]. Subsequent practices could allow automation of lateral and longitudinal control.

Road infrastructure constrains the implementation of platooning. Much of our current civil infrastructure was not designed to accommodate platoons (e.g. roundabouts, bridges and on/off ramps).

Possible impacts of vehicle platooning include:

- Changed load dynamics and increased road utilisation. This could result in:
  - increased loading on existing bridges and pavements (particularly increases in dynamic loads)
  - changes to bridge and pavement design standards to account for platooning.
- Changes to tolling technology to allow identification of each unit in the platoon as a separate vehicle.
- Changes to pavement design to account for new load volumes.
- Increased protection for barriers at critical physical infrastructure (e.g. protecting bridge piers in situations where there is a high speed road under a rail bridge)
- Operational problems for road authorities and other drivers in situations such as overtaking and entering and exiting on freeways/motorways.
- The following new standards or additions to old ones may be required for roads that support platooning:
  - line marking and signage
  - limiting side road access
  - need to reconsider minimum distances between on/off ramps and weaving in design
  - cellular coverage.

f) Special Use Highways

Special use highways are transportation facilities not available to the general public, for example, bus and high-occupancy vehicle (HOV) lanes. There has been some speculation that we may see separate facilities for large trucks and automated highways in congested corridors (Fambro et al 1999). It is likely that these developments would be promoted on an efficiency basis and be seen at locations with high levels of congestion and of strategic importance to freight. Some toll road operators such as Transurban has raised the prospect of having dedicated lanes in future that support AVs and allowing platooning/reduced headways (Wiggins 2016).

7 http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0300-0399/0316/Sections/0316.0896.html

4.4.3 Designs and Maintenance of Structural Elements

a) Pavements

The condition of current road infrastructure may inhibit introduction of AVs. To safely negotiate roads, AVs require sophisticated technology to address the varying physical conditions of the road environment. The following issues are thought to have a negative impact on AV performance:

- pot holes
- edge wear
- accident damage
- impact of debris.

Some aspects of AV functionality remain unclear. These include, how AVs read the roadway environment (EuroRAP 2011) and how they respond to visible road defects. For example do AVs plan to avoid debris on the road by gathering information ahead of time and then changing speed or direction? Alternatively, are the sensors good enough to provide information at the last moment and thereby avoid minor collisions?

Imperfections such as pot holes, edge wear and accident damage will require monitoring and maintenance once degradation has surpassed what is acceptable for an AV. This would ideally take into account the cost-benefit ratio of mechanical damage to vehicles versus cost of maintenance and repair of the pavement.

Regular monitoring of asset conditions is already becoming prevalent in some countries. For example, monthly visual inspection of road infrastructure is performed in the UK and critical defects are responded to in 24 hours.

Increasing use of machines during the inspection process is helping to identify how AV will likely read road conditions (Sage 2016). In the longer term, it may be possible to receive data about road conditions from AVs in near real-time. This could change the way these assets are maintained. This is discussed further in Section 6. As previously mentioned consistency in the ways this maintenance is approached will become more important as we see greater numbers of AV on our roads.

Another key aspect of pavement design that warrants further consideration is heavy vehicle AV platooning operation potentially resulting in increased rutting and surface wear as AVs may follow the exact wheel path of other vehicles. For pavements with high proportions of AVs this will need to be carefully considered and changes to design balanced against more traditional pavement asset management strategies. In addition there is some potential for AVs to reduce the impact on pavement if vehicles within a platoon (or all AV which use a given lane) were laterally offset from other vehicles. This may have implications for fuel efficiency of the platooning vehicles. Further evidence based research would be required to consider such trade-offs between design of pavements and operation of AVs.

b) Bridges

Contemporary bridge design standards make assumptions around the number of vehicles likely to be on the bridge at any one time along with other physical characteristics such as vehicle mix, axle spacing and loadings. The precise impact of AV platooning, particularly groupings of heavy vehicles (with small headways and little lateral offset) on these design standards needs to be explored further.

As well as a change to the design approach it is likely that there will also be a change in how these assets are managed. This is discussed in more detail in Section 6. The potential for technology to monitor the performance of key assets at very regular intervals or even in real time will become an important input to our consideration of road operation – to ensure the longevity of road operator assets (as well as the safety and efficiency of the network).

c) Barriers

Impact loads for barrier design may need to be reconsidered as a result of the changes related to truck platooning (small headways between vehicles). Although the likelihood of an accident may be decreased with the introduction of AV, the relative risk of impact to critical physical infrastructure needs to be considered.

4.4.4 Design and Maintenance of Road Markings and Road Signs

a) Line Marking

While some developers of AVs have stated they will not need lane markings (Motoring 2015), other manufacturers have suggested otherwise. Clear, consistent lane markings are paramount to the operation of this technology, as those AVs that place reliance upon lane markings may not be able to effectively operate in an automated mode if lane markings are faded or are otherwise physically degraded.

Tesla CEO Elon Musk has publicly complained that poor line marking is confusing Telsa's cars (Sage 2016). Further, consultations with Australian representatives from a number of vehicle manufacturers has confirmed that many current models with lane departure warning (LDW) and lane keep assist (LKA) applications are having issues with line marking in Australia. It is important to consider these implications when developing different line shapes (e.g. box dots), and potentially different colours (e.g. yellow lines being trialled at road works), the condition of lines, and unique lines/shapes (e.g. zig zag lines within lane) may all impact on readability of line marking. An example of the variability of marking visibility in different conditions is provided in Figure 4.1.

One example of this variation is the lack of application of uniform standards for line marking. As a result, many different materials have been applied to a variety of road surface and alignments causing the condition of line markings to vary. Due to different marking materials, methods of application and stages of the life cycle, there are significant variations in dry night visibility, wet night visibility, and skid resistance (Carnaby 2003).

Figure 4.1 Varying levels of line mark visibility in wet night conditions

Source: Carnaby 2003

Figure 4.2 Temporary Yellow line markings In Road Works Zone

AV technology will benefit from a consistent national approach to line marking to enable consistent and accurate reading of vehicle position on the roadway.

Similarly, maintenance and removal of lines also needs to be approached in a consistent manner. The trigger points to require repainting of lines varies significantly between jurisdictions. Maintenance practices regarding line removal also varies.

Black out of existing lines may be detectable by AV using grey scale images for lane detection, however, the reliability of this reading is not conclusive. In recent years, use of hydro-blasting techniques has led to the occurrence of “ghost markings” an example of which can be seen in Figure 4.3.

Figure 4.3 Ghost markings

Lane detection can be performed using grey scale image processing technology. Some limitations that have already been identified with this technology include (EuroRAP 2011):

- bitumen lines used to seal cabling or drainage in the roadway
- faded indistinct line on asphalt surfaces
- slightly faded lines on concrete road surfaces which present poor visual confirmation
- lane marking not in normal use e.g. unusual road markings at roadwork sites
- discontinuous markings.

Roadworks present another challenge, as physical line markings will likely have changed and/or been made redundant. Temporary changes may also render any digital map redundant temporarily. This gives rise to two important requirements:

- digital road map data used by vehicles must be regularly updated; ideally from a centralised source (e.g. cloud service accessed via cellular communications). Localised changes may also be updated via direct communications (e.g. VSLS broadcasting speed zone information). This will enable the AV to function from a point of truth when the real world differs unexpectedly from the maps used by the AV.
- Road operations processes will need to be updated to ensure agencies keep data about its physical infrastructure accurate and current.

Roadworks are discussed further in Section 4.5 and positioning in Section 5.3.

In the longer term, assuming lanes are marked appropriately, AVs could operate on smaller widths of local roads or highways. This may not be a necessity, but the reduction could increase the capacity of roadways, provide added space for bike lanes, and/or improve walkability (Skinner & Bidwell 2016).

Mercedes says the "drive pilot" system found in its recently unveiled luxury E Class 2017 sedans works even with no lane markings. The system – which incorporates 23 sensors – takes into account guard rails, barriers, and other vehicles to keep the car in its lane up to 135km/hr under "suitable circumstances."

Key Issues Identified by EuroRAP

The European Road Assessment Program (EuroRAP) has disseminated a consultation paper discussing what automotive manufacturers need to enable AVs to read the road reliably (EuroRAP 2011). Lessons learned from failure modes and limitations of lane keeping systems are especially valid for AVs as these systems also rely on greyscale images. The following key limitations (identified as being low, medium or high impact on vehicle operation) were identified:

- **High Factor:** Road surface condition (wet, ice etc.), worn out markings, multiple confusing road markings, old road markings not completely obscured even if blacked out.
- **Medium Factor:** Road gradient, road curvature, boundaries between multiple lanes.
- **Low Factor:** Lane width (too narrow, too wide), visibility (e.g. fog).

Vehicle manufacturers have also called for road markings to be a maintenance budget priority with road operators. The consultation paper identified that no European countries (including the UK), had proposed national standards for monitoring the condition of road markings. If implemented during normal maintenance and replacement cycles, these improved standards could be cost effective but need detailed consideration by road operators.

Mitigation Responses Proposed by EuroRAP

EuroRAP proposed that road markings be designated a maintenance budget priority so that all roads are properly marked and maintained. The end goal is to ensure lanes are clearly visible and not confusing. The following specific recommendations were made to road authorities:

- use retro-reflective markings that are visible under all weather conditions (the simple and memorable "150 x 150" standard). This is a minimum of 150 mm wide and minimum retro-reflectivity 150 mcd/lux/m²
- harmonise the colour and dimensions of lane and carriageway edge markings across Europe
- install continuous lines to delineate the edge of the carriageway.

b) Road Signs

A second example of variations in Australian road infrastructure occurs with road signage. Coding is the principle of presenting information in a standardised, recognisable form. Standard colour, shape, font, line spacing, and luminance contrast are used to make signage legible to drivers (Mitchell 2010). Spatially and historically the standard for coding has changed but outdated signs remain on the road network. This challenge to consistency applies to many elements of road infrastructure.

As discussed earlier, standardisation and consistency is very important in the short term. However, it will be difficult to achieve across the whole road network. AVs will need to detect the subtle differences in roadside asset characteristics, such as font size, asphalt colour and style of delineation. AV technology will need to have some tolerance outside of the values specified for roadside asset features prescribed in current design standards.

AVs detect the roadside signs using video cameras. Colour or shape based detection algorithms may be used to identify an approaching traffic sign before recognition algorithms process the information presented on the sign. These methods of detection and recognition assume certain sign characteristics in order to process the information. For this reason, signs should, wherever possible, conform to a defined standard (to ensure consistency) and must not be obscured (or misaligned) (EuroRAP 2011).

Factors impacting traffic sign detection and recognition for AVs are:

- inconsistencies in signage infrastructure
- obscured signage
- varying illumination
- lack of signage
- electronic sign legibility
- maintenance and vandalism.

Each factor is described in detail below.

Inconsistencies in Signage Infrastructure

Traffic signs have a number of inconsistencies that impair their automated detection and recognition. Damaged or uneven signage and variations in size, colour, and font complicate how AVs read traffic signs. Some vehicle manufacturers have also commented that they have issues with advisory speed signs (e.g. some have a circle/annulus around the number and some don't), and with signs with written words within or near the sign. Some systems struggle to read the hours of sign enforcement, or whether the sign is in force only for specific vehicle categories[8].

Lack of consistency in positioning and application of signs can be problematic, leading to uncertainty about how vehicles are expected to interact. One more extreme example of this is the use of four-way stop signs in some Australian states. The efficient use of the intersection is reliant on eye contact and gestures between drivers, which is problematic for AVs.

Temporary signs, such as those at traffic work zones, have also been identified as an issue. Examples of signs being placed in obscured zones, or out of a camera system's viewing range have been reported. A common view expressed to Austroads in consultations with AV manufacturers is that camera systems (either released or currently under assessment) have had difficulties with locations where a main carriageway is near a service road or on/off ramp. A common problem has been that the system reads the wrong sign due to proximity to the main carriageway (or vice versa) (Sage 2016).

Mapping services provided by third parties in our vehicle satellite navigation systems and phone applications already contain digital speed limit information. In the future 'digital signage' may become more dominant. Both physical and digital inputs will be used for the foreseeable future, with the information verified within vehicle systems. Where there is any uncertainty it is possible that the AV function be degraded (e.g. warn or hand back control to the driver).

Electronic Sign Legibility

Some AV manufacturers have noted significant challenges for AVs being able to read LED signs (including VSLS, VMS and LUM signs). This has been noted informally by some manufacturers to be due to the refresh rate of the LEDs used in the signs and general legibility problems caused by luminance levels from LEDs which can cause "bleeding" between characters making the sign incomprehensible. It is noted that the Australian Standard for electronic speed limit signs varies from the European standard.

Some authorities note the potential for direct communication between signs and vehicles rather than relying on the vehicle systems to have to "read" these signs using camera based systems. Such systems could improve the information flow to the driver, however at present the future availability and take up of such in vehicle systems is unknown and therefore it would not be sensible to assume that these issues can be resolved for automated driving systems with direct methods of communication. In addition it is important to note that some of the readability issues relating to VMS are also a problem for human drivers, which needs ongoing consideration.

8 Austroads, private correspondence, June 2016

Recent developments in full RGB LED technology and other technology improvements could improve sign readability in the future, however there is also greater opportunity to present bespoke and non-standard signs in ways that may be more meaningful to end road users. Further consideration of these new technologies is required, and any opportunity to test the readability of these new sign types would be advantageous to both the vehicle and sign manufacturers.

Maintenance of electronic signs also impacts on legibility, seeking methods to routinely check readability of signage would be a complex but worthwhile consideration.

Figure 4.4 New RGB sign (Hilton Digital)

Obscured Signage

Signage may be obscured partially by other vehicles, roadside infrastructure or vegetation. This needs to be assessed from an AV technology perspective and addressed to ensure adequate detection is possible. Graffiti impacts significantly on sign visibility, which will impact on AVs as well as human drivers. Signs close to the edge of the carriageway are often struck by passing vehicles which may not knockdown but reorient the sign face which may make it very difficult to read.

Lack of Signs

In Australia and New Zealand, default speed limits apply when there is no posted speed limit. As a result there are circumstances where there is an absence of speed signs. AV mapping data could help to account for lack of roadway speed signs.

Varying Illumination and Street Lighting

Weather conditions, including low light conditions, low angle sun and shadowing, hinder the ability of AV technology to detect and recognise traffic signs. Degraded retroreflective material will also impact the ability of the AV to read a sign at night. Road operators are interested to understand whether the provision of a consistent level of street lighting could impact on the ability of an AV to recognise road markings. Some AV OEMs have noted this is not an issue of significant importance for vehicle operations, with the vehicle headlights providing sufficient illumination at a range where the vehicle systems are looking to read the road markings. Vehicles will need to be able to operate in all sorts of conditions with and without street lighting being present. It is, however, noted that in very wet conditions where water is pooling on the surface of the road, reflections from the pavements are far more prominent and street lights could make the road markings harder to read for both AV systems and human drivers. This issue is worthy of further consideration in the context of the overarching need for street lighting. This AV need should be considered in the context of other street light requirements, including improving the visibility of pedestrians and cyclists.

4.5 Roadworks

During roadworks events, a roadway can change its lane widths and orientation several times a day. Roadworks are a significant interruption to normal service and can result in increased vehicular crashes.

There is not currently a uniform set of guidelines for traffic management and control for roadworks at a national level let alone within jurisdictions in Australia. Guidance for traffic management is often provided at a project level in some jurisdictions.

Information regarding route choice for satellite navigation systems currently come from a variety of sources, and may differ between different systems. Further consideration is required regarding the responsibility for route changes and mapping information currency. Some level of input should be obtained from road operators and key contractors.

4.6 Summary

Different AVs will use different sensing technologies, have different functionality, and support different use cases. Given much of this is still unknown, designing future road infrastructure has its challenges. In very simple terms it is best to describe AVs as another road user with a particular set of requirements to interact with the road environment and other road users. The following areas of physical infrastructure design and maintenance are likely to be impacted and require consideration by road operators:

- **Road pavement and structure:**
  - Loads on existing bridges and pavements may be greater than original design assumptions, particularly for use cases like heavy vehicle platooning, which may require restrictions or modifications.
  - Design of new bridges and pavements may need to have different loading assumptions.
  - Design of pavements may need to be considered differently with automated heavy vehicle operation potentially resulting in increased rutting and surface wear as AVs follow the exact wheel path of other similar vehicles.

- **Physical attributes:**
  - Vertical and horizontal curves of roads may need to be considered differently if the road is expected have AV operation in the future.
  - Barrier design should consider impact loads from platooning vehicles, based on a risk assessment for the road.
  - Intersections – there is potential for coordination between vehicles. Intersections could potentially be made more compact in the future.
- **Static and electronic road signs:**
  - Static signs – the standards for static signs (speed zone, advisory speed, give way, etc.) need to be consistently adopted nationally. Variations should be avoided.
  - Electronic Signs – consideration needs to be given to the specifications of these signs to ensure that all road users (including AV) can read these signs.
  - Care in locating and orienting signs is just as important as the information on the signs.
- **Line marking:**
  - Consistency is vital and noted to be problematic for some vehicle manufacturers at present.
  - Material used for line marking should ideally be able to be completely removed to avoid “ghosting” and confusion caused by outdated line marking.
- **Road certification/risk rating:**
  - Evaluation and definition of roads may be required to define roadways that are suitable for specific vehicles and use cases.
  - Requirements will include clear road markings, appropriate and consistent signage on the network and communication to users regarding what vehicles can operate on that roadway. Special use highways may be required to accommodate certain types of AV traffic such as platoons of heavy vehicles.
  - An alternative approach to certification is to provide some guidance or framework, outlining where certain AV use cases should or should not operate (e.g. by using Network Operating Plans as outlined in Figure 2.4).
- **Maintenance:**
  - Need for regular and consistent maintenance (including trigger points) are particularly important to AVs given their reliance on delineation and signs.
  - New vehicle use cases, particularly heavy vehicle platooning, will require a different consideration of maintenance regimes for structures and pavements.
- **Roadworks:**
  - There is a need for consistency in the treatment of these environments. There are currently significantly different approaches between projects and across different jurisdictions.

5. Digital Infrastructure

5.1 Introduction

A variety of definitions exist for digital infrastructure, although a common theme with the definitions is that it involves data and the ability to store, manage, and exchange data with information and communication technology (ICT) systems. This Section outlines the concept of digital infrastructure, how it is required to support the operation of AVs, and raises issues with digital infrastructure that may require action from road operators to address.

As described in Section 2, an AV will rely on a range of systems to operate effectively and safely. This includes not only a range of on board systems and sensors that capture data about a vehicles immediate environment, but it also includes the use of data from other sources external to the vehicle.

While different vehicles may use different technologies and approaches to enable automated driving, the following key forms of digital infrastructure appear to be directly relevant to the effective and safe operation of AVs, and should be considered by road operators in their planning for AVs:

- **Data management and access:** this refers to the data required by an AV to effectively and safely operate. This includes not only data about the physical road environment (e.g. mapping data attributes) but also road traffic condition data, and other data required to support operation of the vehicle's systems such as software updates, security certificates, diagnostics, etc.
- **Positioning services:** this refers to wireless services that enable a vehicle's driving system to know its absolute position, which it may then use to match against a map representation of the road network, and/or to fuse with relative positioning data that it receives from its on-board sensors. Absolute positioning services are commonly satellite-based services, but could also include terrestrial services.
- **Communications technologies:** this refers to the use of wireless communications technologies, such as cellular, DSRC, RLAN/Wi-Fi, radio broadcast, satellite, etc. This digital infrastructure will be necessary to facilitate the reception and exchange of a range of data required by AVs.

The following sections will explore these categories of digital infrastructure in further detail, and identify key issues that road operators may need to consider and address.

5.2 Data Management and Access

Data management and access encompasses all data required by an AV to operate safely and effectively. Data management includes items such as positioning data, road map attributes, information recorded from sensors regarding the external environment, data shared between vehicles, software updates, security certificates and diagnostics.

Road Operators have a role in data management and access through the provision and management of relevant data and/or making this data accessible to the vehicles, directly or via third party service providers. Some examples of this include:

- **Map and road condition data:** AVs in the majority of cases will obtain map data from one of the major data providers. 'TomTom' and 'Here' are two examples of these providers. Some AVs may also use their own created map data using proprietary mapping data that is unique to that vehicle supplier. It is unlikely a road operator will have a direct role with the creation and updating of map data to a vehicle. However, there may be data attributes for which a road operator is the authoritative source. Examples include speed zone changes, road closures, road works, changed lane use arrangements, permits, and restrictions. Vehicle manufacturers and map data providers have confirmed an interest in road operators providing this data in real time into the data supply chain. Road operators will need to consider how they support these potential requirements. Another key aspect for road operators to consider is to allow mapping of soon to be opened road infrastructure by services providers so that the physical and digital road opening can be undertaken simultaneously.
- **ITS roadside infrastructure:** Data could be provided from the Road operator in regards to roadside devices. For example, message data from variable message signs, lane closure information from lane use management signs, ramp metering data and roadworks restrictions. It is likely that this data will not have a direct impact on automated driving systems in all cases, but will be data that may fuse with other data captured by the vehicle, and add to redundancy of safety applications. On this basis there will be a need for national consistency in terms of the provision of this data.
- **Security certificates:** It is yet to be determined what role, if any, road operators may have with supplying, monitoring, or revoking a vehicles security certificates using roadside ITS. It is something which should be considered and international developments in this area will continue to provide direction on the future approach to this issue.
- **Data collected from AVs:** The data collected from AVs also provides a valuable resource for road authorities. Currently road authorities spend significant resources on the collection of information such as flow rates, headway and occupancy on motorways, origin destination information, time of day and seasonal traffic movements, queue lengths for traffic signal operation, road safety information and driver behaviour trends. This list is not exhaustive, and the optimisation of existing resources is becoming the focus of road authorities as existing capacity becomes more constrained. The availability of data collected by AVs provides an opportunity to provide this data, with a high level of resolution with potentially a lower infrastructure commitment by road authorities. The potential downside to this may lie in the fact that this data may be proprietary to third party suppliers and may require a licensing fee to access it.

Work being completed by Austroads on Road (Asset) Metadata Standards is also relevant to the discussion of data requirements. This project seeks to produce a Standard that addresses harmonisation of road data information and language across Australia and New Zealand. It also seeks to develop a business case for adoption of a standard and identify implementation plan to support wide-spread adoption of the standard across Australia and New Zealand. The standard covers road assets owned by State or Local Government agencies, this includes the road itself plus roadside infrastructure, e.g. ITS, structures and street furniture etc. that are part of the road asset owner's asset portfolio. This could be extended to include digital infrastructure associated with AV operations.

Australian road operators may also consider the implications of the development of the National ITS Architecture regarding the management of data.

5.3 Positioning Services

The ability for an AV to know its absolute position on the ground, and its relative position to physical attributes within the road environment will be critical to its ability to safely automate the dynamic driving task. As described earlier in Section 2, AVs will use a range of different on-board sensors to determine its relative position. Different vehicles may use different sensors, and may take different approaches to determining a vehicle's position. Due to the complexity of the nature of the task, no single sensor can perform all tasks required for a vehicle to "see" and interact with its environment and safely navigate the road. Some road environments will be complex, such as urban roads that involve traffic lights, pedestrians, and varying road rules. In order for an AV to successfully drive on the roads it must have a sensor system capable of navigating through this environment or having "localisation".

Figure 2.3 outlines the Bosch model for localisation, and provides a good basis for appreciating the localisation challenge. Under this model a combination of many data sources is brought together to build a model of the road environment and facilitate control within that environment. Key elements to the localisation process include:

- **Development of the digital map database to allow the vehicle to navigate the road network:** A combination of accurate street maps with accurate feature maps will be required by most AVs. These maps must be current and may require some management. A current challenge of road operators is to have roads opened digitally and physically at the same time, e.g. to have asset/map bases updated for 'day 1' of a new road. For those AVs that require digital map data, the data attributes will likely be updated and accessible via a cloud service. Road operators are expected to have a role in forming or contributing to these databases.
- **Localisation within the digital map environment:** For most this will be through GNSS, with some supplementing this with terrestrial positioning services. With mass market AV, it appears that emerging vehicle positioning requirements are being met by a Space Based Augmentation System (SBAS). This will be discussed further in section 5.3.1.
- **Sensing of the local road environment to add physical features to the digital map environment:** Cameras, LIDAR, radar, and ultrasound devices are utilised to log features within the local road environment.
- **Adaptation and response to the road environment based on the live road environment:** Simultaneous location and mapping (SLAM) technology allows for the construction or updating a map of an unknown environment while simultaneously keeping of the vehicle within the map.

5.3.1 Requirements for Absolute Positioning

In the short to midterm it is likely that the majority of AVs will be able to operate sufficiently well by utilising GNSS which is readily available as a primary method of absolute positioning; as noted earlier AVs will primarily be reliant upon on-board sensors for relative positioning. This will be combined with vehicle mounted sensors to help determine relative positioning and potentially allow vehicles to operate for periods of time without GNSS coverage where it is either unavailable or not sufficiently accurate for the driving situation.

There are a wide range of industries (including automotive) reliant on absolute positioning that will have stringent requirements for accuracy, coverage and integrity of positioning. Many AV developments internationally are using an SBAS-enabled GNSS receiver to meet their absolute positioning requirements. The SBAS augmentation signals are freely available in some jurisdictions, and while the signal formats are internationally consistent, the augmentation signals are unique to different international regions.

In contrast to many regions in the northern hemisphere, Australia and New Zealand do not currently have an existing SBAS service freely available for use. This lack of free access to an SBAS could potentially act as a barrier to some AVs being introduced to our market or some cases/applications being supported. Vehicles developed for the major markets of Europe, Asia, or the Americas will likely be developed to utilise the positioning technologies available in those regions. For example, Europe has the Geostationary Navigation Overlay Service (EGNOS) and North America has the Wide Area Augmentation System (WAAS).

In Australia and New Zealand, in the absence of a compatible SBAS service there may be a requirement for hybridised systems using existing GNSS and ground based positioning technology. These may require different hardware to be fitted unique to the Australian market, which could present commercial and manufacturing barriers that may not be feasible for mass market production vehicles.

In addition to this limitation there are also a number of other specific positioning challenges to be overcome with road transport applications. Examples of these include:

- tunnels
- urban canyoning and multilevel car parks
- spoofing
- tampering or jamming signals
- solar flares
- GNSS vulnerability to outages.

There are a number of possible technical solutions that could be used to implement positioning solutions to overcome the problems listed above. Some solutions utilise additional terrestrial-based systems to supplement, enhance or as a substitute to GNSS positioning. Solutions such as Differential GPS (D-GPS), Real Time Kinematic (RTK) systems, and Precise Point Positioning (PPP) are examples of these. Key challenges in adopting these other potential solutions is that it may not be feasible for vehicles sold in Australia to have equipment fitted (e.g. GNSS receiver) that is unique to Australia, and commercial positioning services that have an ongoing subscription fee may not be supported by vehicle manufacturers or the market.

Absolute positioning is also an important requirement for many C-ITS applications. A summary of potential positioning technologies to support C-ITS is shown in Table 5.1, which was developed as part of the Austroads study *Vehicle Positioning for C-ITS in Australia* (Austroads 2013b), which is also highly relevant to consideration of AV needs.

The role for road operators in the provisioning of positioning infrastructure is not yet clear. Further investigation and development of Australia's GNSS and SBAS capability is being undertaken by Geoscience Australia through the National Positioning Infrastructure project (GA NPI project)[9]. The outcomes of this project will further define the potential future of SBAS in Australia.

In unique circumstances, such as tunnels, there may be a requirement to provide dedicated positioning infrastructure. There has been some work undertaken internationally exploring potential solutions, including with GNSS repeaters and Bluetooth beacons. Multipath issues appear common due to the closed environment of tunnels. At this stage it appears unclear what in-tunnel positioning requirements might be for AVs.

9 http://www.ga.gov.au/scientific-topics/positioning-navigation/positioning-for-the-future

Table 5.1 Vehicle positioning for C-ITS in Australia

Hybrid positioning systems	Media	Standards	V2X	Comments
Low-end GNSS receiver + low end on-board sensors	5.9 GHz DSRC GNSS broadcast signals	SAE2735, IEEE 802.11p, WAVE IEEE 1609, GPS navigation messages	Satellite to Vehicle V2V	Available anywhere in Australia. This is the easiest solution available for C-ITS roll-out now however it has limitations associated with not having SBAS coverage for Australia.
Low-end GNSS/SBAS/ Locata receiver + low-end on-board sensors	L-band satellite communication; GNSS and SBAS broadcast signals, 5.9 GHz DSRC	SBAS messages, SAE2735, IEEE 802.11p,WAVE IEEE 1609	Satellite to vehicle V2V	SBAS signals are not available in Australia. Development efforts are required to make this solution available. The solution avoids user operational cost due to cellular communications.
Low-end GNSS/Locata receiver + low-end on-board sensors + mobile data link	Cellular network: 2G, 2.5G, 3G and 4G, 5.9 GHz DSRC	SBAS,SAE2735, IEEE 802.11p, WAVE IEEE 1609, NTRIP	V2I, I2V, V2V	Available in the CORS and 3G14-G overlap areas. Implementation can start any time.
Dual-frequency GNSS + high-end on-board sensors + mobile data link	Cellular network: 2G, 2.5G, 3G and 4G,5.9 GHz DSRC	RTCM 104 3.0, SAE2735, IEEE 802.11p, WAVE IEEE 1609, NTRIP	V2I,I2V,V2V	Available in the CORS and 3G overlap areas. Implementation can start any time.
Dual-frequency GNSS/ Locata receivers + mobile data link	Cellular network: 2G, 2.5G, 3G and 4G,5.9 GHz DSRC	RTCM 104 3.0 SAE2735, IEEE 802.11p, WAVE IEEE 1609, NTRIP	I2V, V2I,V2V	Available in the CORS and 3G overlap areas. Implementation can start any time.

Source: Austroads 2013b

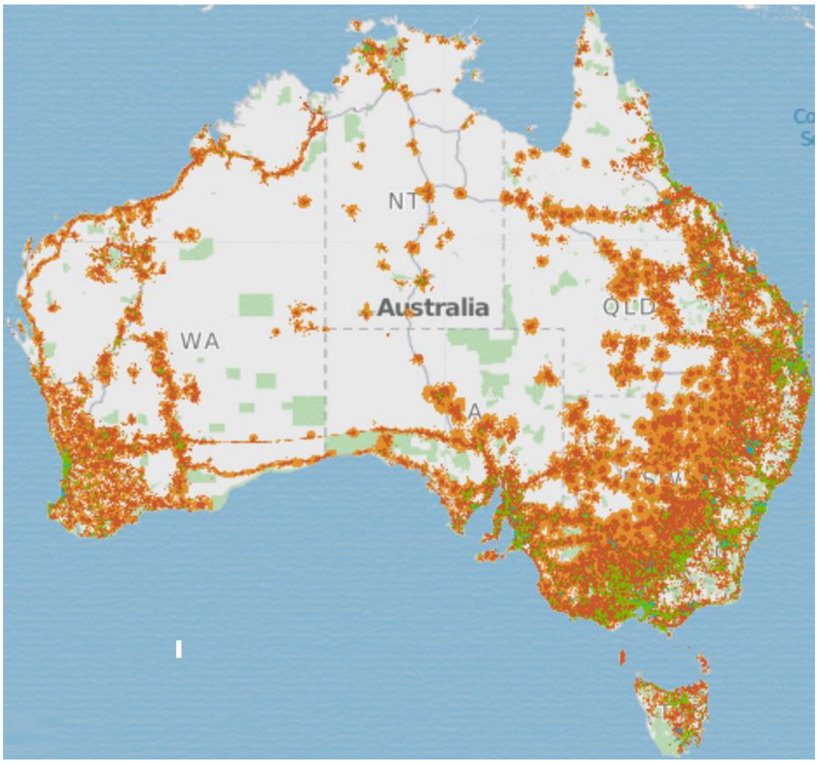
5.4 Communication Technologies

Communication technology refers to the use of wireless communications technologies, such as cellular, DSRC, RLAN/Wi-Fi, radio broadcast, and satellite. This digital infrastructure will be necessary to facilitate the reception and exchange of a range of data required by AVs. These technologies are outlined in further detail in Table 5.2 below. It is noted that it is currently uncertain which technologies will play a role in providing connectivity for AV. It is likely that all technologies will be used to some extent (with the exception of WiMAX at present) in Australia.

Cellular services will play a critical role with AVs in future, as they are beginning to with many vehicles now supporting the GSMA Embedded SIM Specification. Gartner Research estimates by 2020 one in five vehicles will have some form of wireless connectivity (Gartner 2015). As outlined in Table 5.2 there are a number of applicable cellular services available now or under development. While cellular coverage is available for approximately 99 per cent of the Australian population[10] this statistic is somewhat misleading as it leaves a large proportion of the Australian land mass without coverage, and within coverage areas there are black spots with no or limited coverage[11]. This is illustrated by the coverage of Telstra's network, shown in Figure 5.1. This is an issue for AVs and CAVs operating on roadways which may need to operate in a degraded mode in the absence of communications. Off-road AVs such as agricultural machinery relying on cellular coverage are anecdotally impacted, though these uses are outside the scope of this report[12].

10 Mobile services and coverage, Department of Communications and the Arts https://www.communications.gov.au/what-we-do/phone/mobile-services-and-coverage
11 Mobile Black Spot Programme, Department of Communications and the Arts https://www.communications.gov.au/what-we-do/phone/mobile-services-and-coverage/mobile-black-spot-programme
12 Austroads, private correspondence

Figure 5.1 Telstra coverage map in Australia



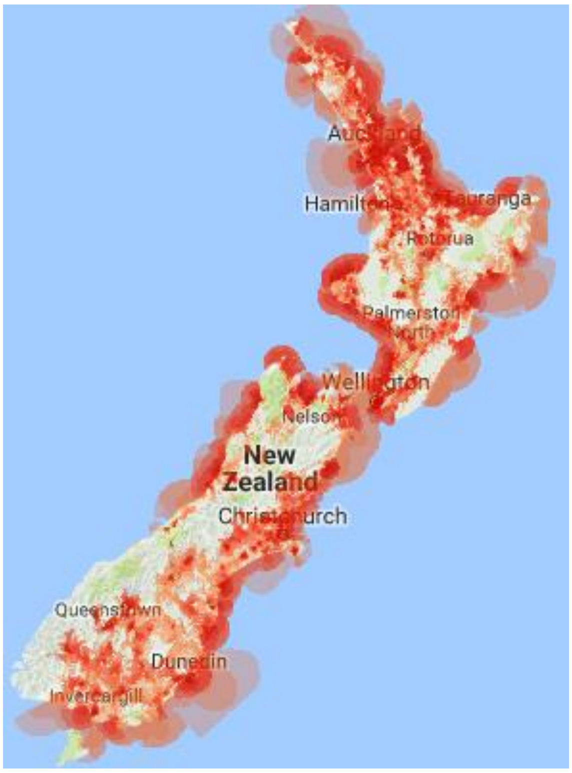
Source: Coverage Map, Telstra (retrieved 30 June 2016) https://www.telstra.com.au/coverage-networks/our-coverage

Figure 5.2 New Zealand coverage maps

Spark

Source: Spark cellular coverage map http://www.spark.co.nz/coverage

Vodafone



Source: Vodafone cellular coverage map http://www.vodafone.co.nz/network/coverage/

Table 5.2 Communication technologies

Digital Infrastructure Technology	Description and Abilities	Coverage/ Availability	Limitations
DSRC (Dedicated Short Range Communications)	DSRC was developed with the primary goal of enabling technologies that support safety applications and communication between vehicle-based devices and infrastructure to reduce collisions. DSRC is the only short-range wireless technology that provides: **Designated licensed bandwidth** In Australia the ACMA is currently progressing a formal allocation process and device licensing for the 5.9 GHz band for use by ITS vehicle safety and mobility applications. This provides secure and reliable communication to take place. **Fast Network Acquisition** Active safety applications require the immediate establishment of communication and frequent updates. **Low Latency** Active safety applications must require a high level of link reliability. DSRC works in high vehicle speed mobility conditions and delivers performance immune to extreme weather conditions (e.g. rain, fog, snow, etc.) **Priority for Safety Applications** Safety applications on DSRC are planned to give priority on non-safety applications. **Interoperability** DSRC will ensure interoperability, which is the key to successful deployment of active safety applications, using widely accepted standards. It supports Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. **Security and Privacy** DSRC is planned to provide safety message authentication and privacy. DSRC enables reliable, high speed vehicle-based technology for crash prevention safety applications. DSRC based communications serves as the basis for connected vehicle safety and mobility application integration.	Coverage varies depending on transmitter power and receiver sensitivity. However, generally this type of communication is best suited for one-way or two-way short to medium range wireless communication. Because it is a dedicated wireless transmission method (based on IEEE802.11p standard) it works independently of cellular networks, Wi-Fi networks and satellite availability.	The limiting factor of DSRC is that it was specifically developed for short range communication between Vehicle-to-Vehicle and Vehicle-to-Infrastructure. Only supports relatively small data messages. Focus to date has been on enabling warning applications, not automation.

Digital Infrastructure Technology	Description and Abilities	Coverage/ Availability	Limitations
3G Cellular (Third generation cellular network or Universal Mobile Telecommunications Service – UTMS)	The 3G cellular network finds applications in wireless voice telephony, mobile internet access, fixed wireless internet access, video calls and mobile TV. The 3G network operates on the UMTS platform which utilises Wideband Code Division Multiple Access (WCDMA) for both downlink and uplink data transfers.	There are several 3G networks operating in Australia with frequency bands listed below: • 850 MHz (B5) – Telstra • 900 MHz (B8) – Optus, Vodafone • 2100 MHz (B1) – Telstra, Optus, Vodafone Coverage is dependent on the distance from the nearest cellular tower and can vary between carriers. Capacity on the network in terms of usable data rates can vary significantly depending on congestion and the number of devices connected to any individual base tower. The peak data rates published by the service providers are listed as peak values.	A limitation of cellular technologies is that they require additional antennas at each base station in order to increase data transmission rates. Being a public cellular network which is not dedicated for sole use by AVs it is prone to be unreliable in terms of capacity and availability as data rates may be significantly less than the peak data rates and service outages may be experienced by the service provider. Coverage is affected by obstructions (i.e. buildings, vehicles, trees and hills) which act to reduce the signal level available at the mobile device. Requires a data plan
4G – LTE (Long Term Evolution) (Fourth generation cellular network)	The 4G – LTE is an easily deployable network technology, offering high speeds and low latencies over long distances. Typical range from a base station is 5km which will still have adequate signal strength to enable communication. The Quality of Service (QoS) provisions permit a latency of less than 5ms in the radio network which is excellent for AV latency requirements. LTE uses two different types of radio links, one for downlink (from tower to device), and one for uplink (from device to tower). By using different types of interfaces for the downlink and uplink, LTE utilises optimal wireless connections both ways, which makes a better-optimized network. The 4G network operates on the LTE platform which utilises OFDMA for the downlink and SC-FDMA for uplink data transfers. The 4G network supports peak speeds up to 100 Mbps (downlink) and 50 Mbps (uplink). 4G bands currently used in Australia are: • 700MHz, 850 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2300 MHz. Supports both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) and both can be utilised simultaneously to boost peak downlink and uplink data rates. LTE-TDD & LTE-FDD operate on different frequency bands.	LTE supports deployment on different frequency bandwidths as noted. Allows high-speed data communication (reception: 100 Mbps or higher and transmission: 50 Mbps or higher). Low-delay transmission (less than 5ms). LTE is suited for audio communication, moving picture distribution, and online games.	Requires additional antennas at the base station locations for increased data transmission. Infrastructure Coverage is affected by obstructions (i.e. buildings, vehicles, trees and hills) which act to reduce the signal level available at the mobile device Additional handshakes required across cellular services could possibly result in some latency issues – will need to be considered. Requires a data plan

Digital Infrastructure Technology	Description and Abilities	Coverage/ Availability	Limitations
5G (Fifth Generation cellular network)	The 5G network is based on the 4G LTE network but with enhanced peak download and upload speeds and lowest latency. Increased peak data rate, 3 Gbps (downlink) and 1.5 Gbps (uplink) Low latency (1ms) and high capacity (3 Gbps). The radio frequencies that our 3G and 4G networks operate on are overcrowded. With more and more people and devices likely to be connected over the next five years or so – 5G will likely be the network that has to handle numbers of AVs on our roads ETA on 5G network roll-out is 2020.	This technology is not currently deployed and the expected roll-out is in 2020. However small scale pilot deployments are anticipated in Australian capital in 2017-2019. Expected to be trialled at the 2018 Commonwealth Games on the Gold Coast[13]	Cost of infrastructure could be high initially. Technologies are still evolving Requires a data plan
LTE Direct	LTE Direct is a device-to-device technology that utilizes licensed LTE spectrum for proximal discovery of friends, services, offers, and other relevant value. It leverages the global LTE standard as part of 3GPP release 12. LTE Direct works seamlessly with LTE, setting aside a small percentage of sub-frames for efficient discovery. It leverages the LTE network for timing, resource allocation, as well as user authentication. LTE Direct can be efficiently integrated with existing LTE Advanced services and networks.[14]	Commercial reality not yet apparent – could be cells of approximately 500m width	Requires changes to end user devices – will take some time to come into common use Requires a data plan
LTE Broadcast	LTE Broadcast enables multiple users to receive the same content simultaneously. LTE broadcast can deliver the same content to multiple users with the capability to support a virtually unlimited number of users simultaneously, thereby maintaining efficient use of spectrum and network investments.[15]	Limited trials undertaken by Telstra at sporting events	Requires a data plan
WiFi	Wi-Fi or wireless LAN (WLAN) network, mainly using the 2.4 gigahertz. Wi-Fi is based on the (IEEE) 802.11 standards	The technology is ubiquitous in in most urban areas in Australia with wireless hotspots formed in homes and business across Australia. The range of these networks is very limited (perhaps to within 10–20 meters).	Range, latency and issues with contention are problematic for Wi-Fi. However if connection are not safety critical and are only needed for high volume / low criticality updates such as mapping this could be a useable form of communications
WiMAX (Worldwide Interoperability for Microwave Access)	WiMAX is a family of wireless communications standards initially designed to provide 30 to 40 Mbps peak data rates. In 2011 the downlink peak rate was increased to 1 Gbps for fixed stations. The WiMAX network when launched was in direct competition to the 4G (LTE) network and the technology was not adopted for use by the public in Australia. WiMax operates at a wide variety of frequencies internationally from 2.3 to 5.8 GHz	There are currently no WiMAX service providers covering all of Australia, with some isolated coverage only e.g. offered by iiNet in South Australia to cover fixed line blackspots[16].	

13 Network review complete, https://exchange.telstra.com.au/2016/05/02/network-review-complete/
14 LTE Direct, Qualcomm https://www.qualcomm.com/invention/technologies/lte/direct
15 LTE Broadcast, Ericson https://www.ericsson.com/ourportfolio/telecom-operators/lte-broadcast?nav=marketcategory002
16 iiNet website, https://www.iinet.net.au/wimax/

5.5 Summary

Digital infrastructure is a key area for consideration in supporting the operation of AVs. Data management, positioning services and communication technologies are important areas to be considered, and there are many issues to be addressed to support the rollout of AVs across the road network.

Pertinent issues requiring attention include:

- **Road data management** – It is anticipated that many AVs will rely on road map data to operate. These map data products will be provided by service providers. However, there may be some road data attributes for which road agencies are the authoritative source (e.g. speed zone changes, road closures, road works, etc).
- **Positioning services**: It is clear that many AVs will be reliant upon availability of absolute positioning services. Compatibility of positioning systems with major global vehicle markets such as Europe, North America and Asia will be important to allow mass produced vehicles to be used on Australian and New Zealand roads. There may be a role for road operators to provide or to facilitate positioning technology in certain locations or scenarios
- **Communication services**: Availability of communication services, typically cellular, has the ability to enable or preclude AV operation. Road operators typically traditionally do not have to play a role in this space however may need to be more proactive should market forces not provide appropriate services (for example rural areas) or be required to augment services within areas of restricted coverage (e.g. in tunnels or valleys).
- **Data ownership:** What is the government role in collecting data and how will they share this data? Some companies are proposing the use of open data protocols others are continuing to promote highly siloed vertical integrations, intent on controlling data streams.
- **Support for proprietary models:** A key concern for road authorities is whether support should be provided for proprietary digital infrastructure. For example, if OEMs are to use their own 'clouds' (Volvo, BMW, etc.), will there be something road authorities (or other stakeholders) need to do to support these modalities?
- **Standards and guidelines for data are currently non-homogenous in the AV context:** Standardisation and consistency is very important from a manufacturer's perspective to support AVs.
- **Road authority regulatory framework in a digital environment:** Road authorities currently manage many regulatory issues such as speed limits, access permits, roadworks, heavy vehicle restrictions, over height restrictions etc. The transition to integrate and maintain this regulatory environment within real-time digital context will be challenging as it may require a significant overhaul of existing systems as well as new skills and changed organisational culture to provide the level of real-time information required. Real time information in regards to roadwork would be highly valuable.
- **Privacy and surveillance regulations:** Road authorities and other organisations involved in the information supply chain will need to be judicious in regards to the collection and management of data. All data collection, storage, distribution, and utilisation will need to be in accordance with relevant laws.

6. Road Operations

6.1 Introduction

This section considers the implications to road operations of AV use on our roads, and what changes road operators may need to consider to:

1. support the use of AVs, and
2. in the longer term, consider the opportunity to optimise and improve the performance of our road networks with the introduction of these vehicles.

This section discusses the following elements:

- outline of current approach to road operations
- application of existing standards and guidelines for AV
- outline of AV needs for road operations
- potential opportunities for road operators to improve operations
- road works and special events
- specific operational support.

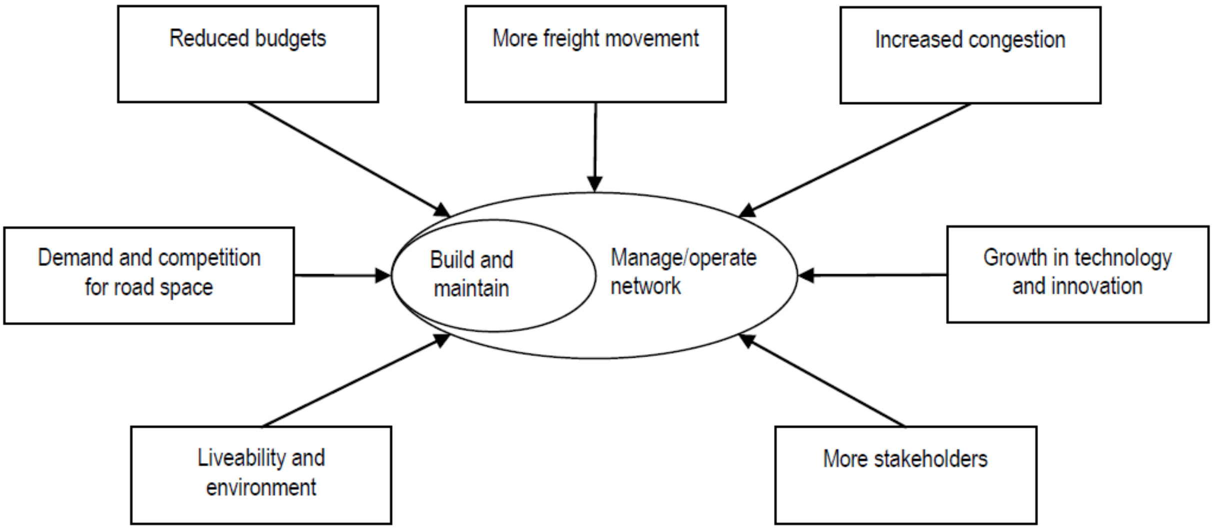
6.2 Current Approach to Road Operations

Road operations is a broad term given to the operational aspects of successfully operating road based transport network. It is a distinct activity from other road agency roles such as planning, design, and construction of road assets. The World Road Association's *Road Network Operations Handbook* (PIARC 2003) defines the following broad areas for network (road) operations:

- **Network monitoring:** observing, gathering information regarding network performance and undertaking interventions as appropriate.
- **Maintaining road serviceability and safety:** undertaking maintenance as required to restore normal road conditions.
- **Traffic control:** control of traffic to optimise and control traffic flows, for example markings, signs, traffic signals, ramp metering, and speed control amongst many others.
- **Travel aid and user information:** providing timely accurate information on road conditions and known events to inform commuters.
- **Demand management:** establishment of mobility policy to achieve outcomes aligned with agreed strategy of asset usage.

All of the above aspects have relevance with regards to AV operation on our road networks. Most pertinent in the context of basic AV operation is the ability of the AV to safely navigate the road network. Once we move beyond the provisions of the basic road pavement, traffic control becomes the key aspect to allow a vehicle to safely navigate the road. This concept can be broadened with traffic control utilised on a collective basis defined by the concept of network management (Austroads 2016a). Road operators will need to understand the implications of AVs at a network level, and at more detailed operational levels to ensure that they can safely traverse the network. Figure 6.1 demonstrates the needs for network management and is applicable to the consideration of AV operation. The core focus for road operators is to manage and operate road networks, aspects of what needs to be built, and how it is to be maintained has been discussed in Section 4.

Figure 6.1 Drivers for increased emphasis on network management



Source: Austroads 2014

6.3 Application of Existing Standards and Guidelines for AV

The following section outlines existing standards and guidelines relevant to road operations. They list out the practices and guidance that enables road operators to undertake daily activities of operating a road network. Relevant publications are as follows:

- Austroads *Guide to Traffic Management* Parts 1-13
- Austroads *Network Operations Planning Framework* (Austroads 2009)
- *Manual of Uniform Traffic Control Devices* (AS1742)
- Relevant State legislative frameworks for example:
  - Transport Operations Act in QLD
  - Road Transport Act in NSW
  - Road Management Act in Victoria
  - Land Transport Management Act in New Zealand
- Commonwealth Privacy Act and state based acts and guidelines including Devices Surveillance Act. In New Zealand there is Privacy Act.
- Relevant Information management standards and guidelines including consideration of Critical Information Infrastructure (CII)

The rollout of AVs onto the network will have an impact on these standards and guidelines, and as such they will need to be updated to reflect these changes over time. The frequency of review and modification may need to be increased to reflect the changing environment created with AVs.

6.4 AV Needs for Road Operations

There are three levels of operation where AV needs must be considered, which are outlined in the subsequent subsections below:

- Strategic road hierarchy and types of roads applicable to a certain AV use case.
- Network management – providing guidance to the vehicle throughout the journey.
- Road works and special events. This is a special circumstance that requires further consideration.

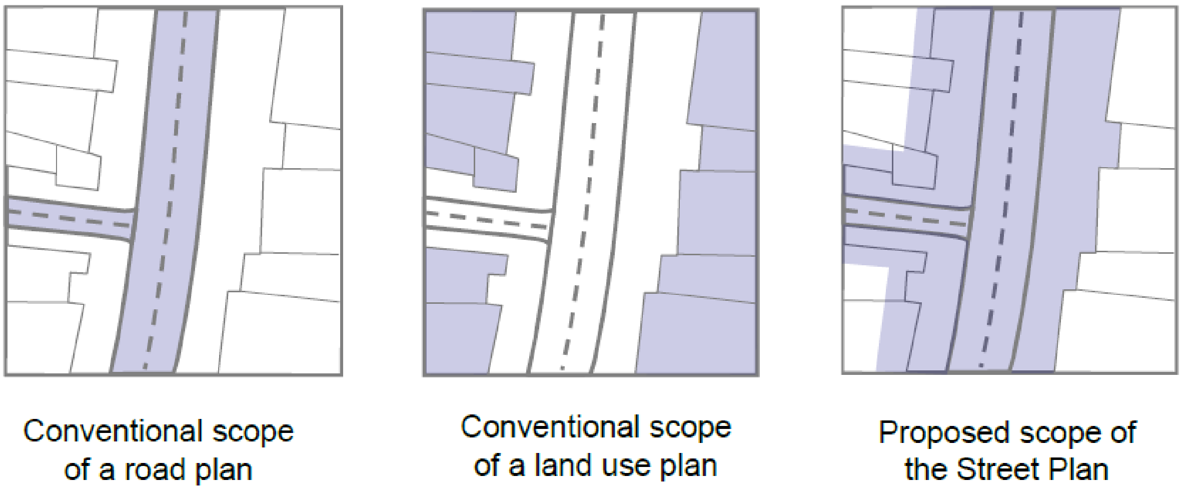
In addition to this it is worth considering the opportunity for road operators to improve the efficiency of road operations with interactions with AV. This is discussed in Section 6.6 below.

6.5 Reinforcing Strategic Road Hierarchy and Land Use

The concept of the network operating planning framework was discussed in Section 3.2. The network operating plan (NOP) road hierarchy framework provides many benefits however it is still focused primarily on road usage perspective and not a land use oriented view. Land use concepts have been added to the discussion. There is potential to use these frameworks to reinforce the use of the road network for AVs in line with these strategic goals

From a land use perspective the majority of our public space in urban environments are streets. Streetscapes closely reflect the character of cites and as a result can be formed to change and enhance the character of cities. Figure 6.2 describes the combination of the more traditional traffic/transport oriented view and the combination with a land use view to get the combined view of a street plan.

Figure 6.2 Consideration of land use



Source: Jones & Boujenko 2009

This land use oriented view of our cities has more recently been described as a focus on place. This was first articulated in the UK Guide *Manual for Streets* (Department for Transport 2007) and is discussed in detail in section 3.1. Having a combined framework to consider Movement and Place is important to the consideration of AVs because we know that there is potential for highly automated or driverless vehicles to impact on adjacent land use.

In summary the considerations for road operators could be noted as follows:

- In the short term: Restricting or changing access to city areas:
  - Restricting access of certain vehicle types and use cases in certain areas: e.g. no trucks platooning through strip shopping centres as an extreme example of the potential need for new localised traffic management solutions in the case of automated shared taxi drop-off / pick-up.
- In the medium to long term: Structural change to urban form:
  - Different needs for pick up and drop off and displacing needs for parking, and potentially lane widths, in the medium to long term, with highly automated vehicles.

Some of these interactions were discussed in greater detail in Sections 2 and 4.

6.6 Operational Needs of an AV: Providing Guidance through the Journey

AVs require consistent information to allow them to safely and efficiently traverse the road network. The greater the consistency, the greater potential for operation across a wider range of roads. For the short to medium term highly automated vehicles will not be ubiquitous across all roads as discussed in Section 2. We are likely to see particular AV use cases deployed on a specific sub-set of routes and some road operator involvement in discussion as to where AV should or should not operate. Clear definition of the use cases could be achieved through development of a concept of operations.

A number of road operation scenarios/use-cases have been identified as required to support AVs, which were considered in Section 2. Some examples of this include:

- complex intersections (e.g. hook turns in Melbourne)
- u-turns in a variety of environments
- green wave and vehicle prioritisation: impact on traffic signal operation
- dedicated AV lane operation
- heavy vehicle platooning
- pick up and drop off in city centres
- automated bus or taxi operation
- roadworks (see Section 6.7)
- incident clearance: broken down AV, how to control and remove or bring AVs to a “minimal risk condition” on our roads
- non-responsive driver: AVs brought to a “minimal risk condition” should a human driver not take over when requested
- any use cases or scenarios requiring interaction with vulnerable road users. Adjacent bicycle lane off set (1 metre clear), unusual or uncontrolled crossing scenarios
- public transport operation: traffic management considerations and need to ensure DDA compliance for pick up and drop off

Discussions about the above scenarios: key issues, differences between states, and an opportunity for a consistent approach needs to be explored, potentially through development of Concept of Operations. It is important to note that whilst the development of Concept of Operations has been used by some state and regional road agencies, it has not been commonly used by all, or by local government road operators. Local government will be a key stakeholder for many of the items listed above.

6.7 Road Works and Special Events

There is a specific need to consider road works and other special events. When the layout or access to the road network has changed accurate real time indication of the current and future availability of lane space is required as well as consistency of traffic management around work zones. Some of these aspects were discussed in Section 4. Clear, consistent communication with all road users including AVs is necessary to ensure safe and timely movement through work zones and areas disrupted by other special traffic events.

Road works and special events provide unique needs for interaction with a (human) traffic controller in work zones and police and emergency services at other special events. There are complex edge cases where it is likely that AVs will seek to degrade the level of automated control and hand back to the driver in the short term. However in the longer term there will be ways in which AVs could be better controlled. One aspect has been raised in the European Managed Corridor project is the idea that Traffic Controllers who have been appropriately trained could be uniquely identified by wearing a particular safety vest, so that an AV would only seek guidance from these individuals. Any view of developing a different interaction with a traffic controller, police or other emergency services would need to be undertaken in a highly coordinated manner and from a manufacturer's perspective at an international level if possible. For example, recognising hand signals, gestures, and manual signalling by controllers or police.

At times new operational requirements arise that result in a new approach to traffic management on the road network. These are far more commonly seen in road work sites. The use of yellow temporary line marking in work zones as described in Section 4 is one example of such changes. These marking have been shown to be effective in reducing harm to workers and providing clear information to the travelling public. In the future measures such as these will need to consider the impact on AVs in a similar way to how we consider impacts on any other class of road user.

There are currently a number of traffic management standards, Acts, and guidelines applicable that vary across state authorities. Important documents include:

- *Manual of Uniform Traffic Control Devices, Part 3: Traffic Control for Works and Roads (*AS1742.3 – 2009)
- Occupational Health and Safety Regulations 2007
- Various State Transport Acts (e.g. Road Management Act Codes of Practice)

At the time of writing this document Austroads had engaged in a major review of traffic management procedures. It is focused on getting consistent road works practices across Australia and New Zealand. Key aspects include:

- AS1742.3 review
- update of and greater focus on Austroads guidance material
- guidance to be updated on a yearly basis
- consideration of the role of technology in improving work zone safety and providing better information to road users. Consideration of the opportunity to provide consistent information to connected and automated vehicles could be considered as part of these technologies.

6.8 Opportunities for Improved Road Operations

AVs provide the opportunity for greater consistency in the way in which we manage our roads through discrete traffic control devices, at roadworks, parking, and unique AV use cases as discussed in Section 2.

It is also important to note that the interaction between vehicle and infrastructure systems which could be available from AV operation that provides a range of other opportunities for road operations to better manage and optimise traffic networks and infrastructure. Some of these potential opportunities are outlined below:

- **Reinforcing road use hierarchy:** this can be considered at a number of levels:
  - Firstly at a whole of trip level e.g. movement of vehicles across a city where a vehicle may have its route informed by the hierarchy as well as the real time impacts on capacity (significant road works or event) and congestion. OEMs have indicated an interest in being given direction about this hierarchy from road operators
  - Secondly at a local level at one end of a trip where the vehicle needs to stop to park or pick up and drop off passengers (or freight) there is need for consideration of the impact on adjacent land use and local traffic flow. A state or local government road operator (depending on the specific location) would like to control these activities in a similar way to taxi ranks and loading zones are managed at present.
- **Focus on data gathering:** information provided from vehicles regarding their position as AV and connected vehicles act as “probes” on our networks. Data from vehicles connected can provide real time or non-real time information about vehicle location, speed etc., and information about the vehicles interaction with other vehicles or particular roadside infrastructure. There is significant value to road operators in this data and these elements warrant further consideration.
- **Effective traffic management:** influencing or controlling traffic flow to ensure more coordinated and efficient interaction between vehicles e.g. direct communication of traffic signal information to allow better traffic signal optimisation on freight corridors or more efficient merging on freeways/motorways. Some Australian and road authorities in other countries are trialling or implementing C-ITS to improve network efficiency. There is strong interest in how managed motorways control systems could be enhanced with AV optimisation. Highways England and a range of USA road operators are currently developing concepts of operation which will promote the introduction of these schemes. Developing such concepts is an important next step to understanding the potential benefits and challenges of system deployment. It is important to note that the transmission of information direct or via cellular means from road side devices (traffic signals or a VMS) to a vehicle is certainly possible however the potential implications for the safe operation from a vehicle manufactures perspective need to be considered.
- **Optimisation of roadside infrastructure:** road operators are increasingly focusing on moving towards a more proactive mode of managing roadside infrastructure and away from reactive maintenance. Proactive asset management will provide the opportunity to better manage the most expensive and most critical elements of infrastructure, bridges, and tunnels being the most obvious examples and are often a focus when considering network resilience. In addition in the medium to long term there will be opportunity to rationalise investment (capital and ongoing operating expenditure) in ITS field based technologies e.g. VMS and permanent sensors given greater opportunity to monitor and inform road users on the network with the availability of AV, connected vehicle, and other technologies.
- **Monitoring of heavy vehicle impacts:** infrastructure is equipped with sensors to monitor impacts from heavy vehicles. Weigh in Motion is an example of such a sensor, a whole new range of sensors are now available to monitor stresses and deflections infrastructure such as pavements and bridges. AV operation (in particularly heavy vehicle lane allocation and platooning) could be influenced to lessen the impacts on bridges or even to ensure a better spread of load on road pavements where required. Similar systems already exist with the Intelligent Access Program (IAP) where vehicle routes are agreed and travel monitored.
- **Monitoring of other road conditions:** AVs have the potential to provide a much richer set of data regarding the condition of the road network in the future. This information will allow a level of proactive asset management not currently possible. Key examples are likely to include monitoring signs, line marking, and general pavement conditions potentially such as roughness, locations of potholes, or other issues with road surface which could impact on AV operation or vehicle operation. This data is of significant value to road operators to help proactively maintain AV infrastructure
- **Optimisation of tolling infrastructure:** following discussions with a number of private toll operators it is clear that there is strong interest from private toll road operators to see AV operation on toll roads to improve the safety and vehicle throughput. Private toll operators may be interested in the potential use of systems which are required to identify connected vehicles or AV and their location as part of a tolling or charging process. One of the key reasons is that it could assist in the reduction of payment transaction infrastructure and costs. There may be interest to apply same identification information to other forms of payment, parking being the most obvious.

The above list is non-exhaustive and all are dependent on the arrangements brokered to share and exchange information between AV manufacturers, operators, or other parties involved with the management and exchange of data for these systems. Following the development of concepts of operation, initial deployment is likely to be through trials and test bed development, which will allow government and industry partners as well as the public experience and improve the operation of these systems.

One recent international example of AV test bed deployment was the "Smart City Challenge"[17]. This was promoted by the U.S. Department of Transportation in 2016, offering grants of up to $40 million to help a city integrate new technologies. These new technologies included infrastructure which supported AV operation, and traffic signals are highly likely to figure as part of that response. The winning proposal from Columbus, Ohio[18], proposed the deployment of several self-driving shuttles linked with a retail district and a bus rapid transit centre. The Smart Cities Challenge resulted in many cities competing for funds to consider the interaction between automated vehicles and their road environment in innovative ways with the potential to challenge our current views on road operation.

6.9 Summary

This section has outlined a range of road operation considerations for AVs. Key points are noted as follows:

- There is a need to take a whole of network approach to planning and managing traffic. Network Operating Plans and land use interaction considerations like “movement and place” are important to consider in the context of potential AV use cases.
- A range of standards and guidelines, and other supporting Government legislation and regulations, may need to be updated to support AV operation.
- There are a wide range of potential operational needs for AVs outlined, which are required to ensure positive guidance for the vehicle throughout its journey. This includes consideration of AV use cases such as heavy vehicle platooning as well as interactions that AVs may find challenging on our road networks. The need for consistency in operation is paramount.
- Some new AV use cases and scenarios (e.g. automated/shared taxi drop-off/pick-up) may require new localised traffic management solutions. In the long term this could be an influence on structural urban form.
- Road works are a key operational use case from an AV manufacturer’s perspective. Providing greater consistency is very important. Provision of real time information and information about planned works will help AV fleets re-route vehicles around roads affected by road works as well as seeking to provide better real time information during the journey.
- There is a need to consider what changes will be required to road operations to allow AVs to stop in a “minimal risk condition” on our roads and practical aspects such as how to manage AV breakdown.
- Road certification may also include some consideration of access management in the future for specific use cases in certain scenarios.
- Many road operators and systems providers flagged the significant opportunities that AV may provide to support efficient network operation. These include better real time information about traffic flow, improved communications systems, and automated monitoring of road pavements, line marking, and sign conditions which impact on AV operation. If vehicles are to be connected and automated many road operators see potential for significant improvements in vehicle throughput. We note however that these are not issues of primary interest to vehicle manufacturers and it could take significant time to see these opportunities developed.

17 Smart City Challenge, US Department of Transportation https://www.transportation.gov/smartcity
18 Smart Columbus – https://www.columbus.gov/smartcity/

Road operations will likely be the most complex area of AV implementation to consider due to the wide range of stakeholders, the wide range of use cases, scenarios to support, and potential for vastly different outcomes depending on an agreed approach. Development and use of Concept of Operations (including maintenance) is suggested as an important step to allow relevant parties involved in developing and deploying AVs to have a common benchmark to begin discussions and importantly, ultimately allow more information about modes of operation and their impacts to be discussed and shared with the community. Deployment is likely to happen initially through the development of trials and test beds. We are seeing many of these initiatives form in Australia, New Zealand, and other international jurisdictions at the time of writing this report.

7. Guidance for Road Operators

The following list is not an exhaustive list, but summarises guidance regarding Automated Vehicle introduction and operation for road operators. These issues were identified in literature reviews, stakeholder guidance, and subsequent analysis. We note that a short term response would be considered as 1-3 years, medium term 3-5 years, and long term being 5 years and beyond.

Table 7.1 Guidance for road agencies: physical infrastructure

<table>
<tr><th colspan="2">Physical infrastructure</th></tr>
<tr><th>Issue</th><th>Timing of response</th></tr>
<tr><td colspan="2">Line marking and delineation</td></tr>
<tr><td>• Design
- Need for national and preferably international consistency
- Consistency for road works zones noted as particularly important</td><td>Short term: Consider separate project to document consistency in design approaches across jurisdictions.
Medium term: Consider additions to Australian Standards and Austroads Guides to improve consistency. Standards may consider new use case specific e.g. standards for roads which have heavy vehicle platoon operation.
Long term: Work with industry to develop design processes considering AV as core users and potentially consider design of dedicated infrastructure.</td></tr>
<tr><td>• Asset management
- Maintenance hierarchy and intervention levels between jurisdictions and within jurisdictions varies which results in varied outcomes
- Removal of old line markings at road works zones is particularly problematic for AV</td><td>Short term: Document consistency in maintenance intervention levels and maintenance priority across jurisdictions.
Medium term: Consider AV in design of roadwork zones including line removal and replacement. Consider case for revising intervention levels/trigger points for line maintenance.
Long term: See proactive maintenance processes considering AV as another key road user type. Seek to gain information from multiple sources including OEMs and System providers to improve operation.</td></tr>
<tr><td colspan="2">Road signs (static)
This is primarily focused on the most important regulatory signs (speed signs, stop signs, etc.) but does also apply to the consideration of all road signs</td></tr>
<tr><td>• Design
- Need for national and preferably international consistency
- Consistency for road works zones noted as particularly important as temporary signs will often differ from the underlying map or digital representation
- Need for minimum standards be applied. Issues with adherence to standards, placement of signs and lack of signs are known issues
- Speed limits used for a specific time of day and day of week may be difficult to interpret
- Advisory speed signs inconsistent and difficult for some AVs to interpret</td><td>Short term: Consider undertaking a separate project to review consistency of speed sign locations, and non-compliance/exception to standards.
Consider change to business processes to ensure the implementation or update of speed zones happens in a more timely and transparent manner. See Digital Infrastructure below.
Additional care needed to ensure consistency of sign application in road work zones
Medium term: Consider additions needed to Australian Standards and Austroads Guides to improve consistency. Consider use cases e.g. roads which have heavy vehicle platoon operation
Consider AV in design of road work zones
Long term: Consider need for more or less signs to support future vehicle use cases (e.g. platooning) and use of dedicated infrastructure
Seek greater international harmonisation of standards and guidelines and vehicle use cases</td></tr>
</table>

Physical infrastructure	
Issue	**Timing of response**
Electronic signs, incl. Variable Message Signs (VMS)	
• **Design and asset management** - Some cameras cannot clearly read some Variable Speed Limit Signs (VSLS) - Noted that direct transmission of information from sign to the vehicle (I2V) is possible. *See Digital Infrastructure below.*	**Short term:** Encourage discussion between VMS manufacturers and vehicle OEMs and System Suppliers to better understand and document issues **Medium term:** Consider additions to Australian Standards and Austroads Guides to improve consistency and readability. **Long term:** Road Operators work with industry to develop design processes considering AV as core users and potentially consider design of dedicated infrastructure.
• **Asset management** - Timeliness to install and confirm sign placement (in particular speed signs) of concern - Need for consistent readability of signs - Positioning of signs – particularly on service roads immediately adjacent to a road with another speed limit is very difficult for AVs	**Short term:** Seek consistency in maintenance intervention levels and maintenance priority across jurisdictions Ongoing review of speed signs may be required on a regular basis. Consider seeking data exchange with the private sector **Medium term:** Consider additions needed to Australian Standards and Austroads Guides to improve consistency. Standards may consider new use cases e.g. roads which have heavy vehicle platoon operation **Long term:** Road Operators work with industry to develop proactive maintenance processes considering AV as core users. Seek to gain information from multiple sources including OEMs and System providers to improve operation
Traffic systems Road vehicle and User Interaction and Geometric Design (lane width, gradient, curvature, intersection design)	
• **Design and asset management** - National and where possible international consistency needed - Consider for specific use cases (e.g. platooning – *see Road Operations below*)	**Short term:** Consider immediate implications for design by undertaking detailed ConOps with road operators. Most significant are Platooning and Passenger Pick up and Drop off in urban environments **Long term**: Consider access restriction and use of dedicated road space for AV only facilities
Structures pavements, bridges, tunnels and barriers to protect critical infrastructure	
• **Design and asset management** - Requirement to change infrastructure as a result of AV introduction. Heavy vehicle platooning is most prominent use case to be considered	**Short term:** Consider potential increased loadings due to heavy vehicle platooning – impact on design and asset management Pavement Design and Maintenance intervention levels for specific roads and structures may need to be revised **Medium term:** Consider changes to Australian Standards and Austroads Guidelines once new loadings etc. are understood. Consider implications for emergency lanes and safe stopping places to bring vehicles to a safe resting state **Long term:** Consider differing design and asset managing needs with the use of dedicated AV infrastructure

Table 7.2 Guidance for road agencies: digital infrastructure

Issue	Timing of response
Asset data Make key data available (in addition to roadside dissemination): • Time based and dynamic speed limit data is needed in real time • Accurate speed zone data (permanent signs) is needed in a timely, well controlled manner • Road closure and lane availability data (road works data) to be provided in real time. Seen as critical to AV operation for planning as well as guidance on route • Information about clearways, loading zones and parking restrictions to be provided in a timely and well controlled manner • Information about new and changed roads to be shared with industry in advance of road opening	**Short term:** Speed limits: Consider and adjust business processes (to provide this data in timely manner) Road Works: Seek to provide information on lane closure and alternative routes – data provided directly to the vehicle by cellular or non-cellular means Parking Signs: Work with local and state authorities to determine what meaningful information can be provided and the timeliness of this information Access for Mapping: Allow access to drive through new infrastructure as early as possible prior to opening
Road asset condition data More asset condition information needed to assist in maintaining best possible environment for all road users (incl. AVs)	**Short term:** Seek discussions with OEMs and Systems Providers to get access to these data sets **Long term*:*** Design of systems to support asset management and road operations informed by availability of AV and other historic and real time data sources
Privacy Ensure appropriate consideration of relevant privacy and data surveillance legislation and guidelines from the perspective of any data exchange	**Short term:** State/Territory and national regulations and guidelines need careful consideration by all operators in particular to consider the implications of the expanded information exchange likely to be in place Ensure compliance with relevant privacy regulations and privacy principles **Medium term:** Consideration of a national code of practice or guidelines for road operator capture and use of data from vehicles
Data ownership Road operators will be an authoritative source of some information, other information will be available from 3rd party sources but potentially still owned by operators.	**Short term:** Consider need for ownership of data. The private sector will promote alternative models for consideration. This will ensure that operators are best positioned to use these datasets in processes which assist them to improve the operation of their networks
Business models Digital infrastructure is also a focus for road agencies for other reasons beyond AV mapping such as BIM/asset information management. As yet unclear how road agencies, industry and vendors can best work together to realise efficiencies and unlock benefits	**Medium term:** Consider the opportunities and challenges for the emerging digital models as well as the business processes that support and/or are transformed by these models. This will ensure operators have the flexibility to use these datasets in processes which assist them to improve the operation of their networks
Cellular communication coverage Likely minimum pre-requisite for AV operation (for most use cases) Support coverage for all carriers	**Short term:** Future expansion plans for cellular networks should consider needs of the road network and AV use cases. **Medium term:** Consider approach which ensures coverage is available from multiple suppliers
Other wireless communication Potential need for non-cellular V2I and I2V Communication	**Short term:** Consider availability of device in or on vehicle to deal with data will be the key element determining likely take-up. Consider need for C-ITS infrastructure (DSRC) or Bluetooth and other direct forms of communication. Consider likely adoption given potential penetration and benefits

Issue	Timing of response
Positioning services Need for positioning services with high accuracy and integrity to support AV operation • Across whole of road network • Consider particular positioning needs in tunnels and built up areas (urban canyons)	**Short term:** Continue to work with key government agencies (e.g. Geosciences Australia) to outline need for future positioning services (which may include SBAS) Monitor international efforts to provide solutions to positioning needs for tunnels and built up areas (urban canyons)

Table 7.3 Guidance for road agencies: road operations

Issue	Timing of response
Strategic framework for AV operation Need for a common framework to consider AV operation in the road network at a strategic (network wide) level	**Short term:** Consider potential framework to incorporate movement and place in Network Operating Plans and use this to inform consideration of AV use cases across a range of urban and rural contexts developed through the Concept of Operations / Systems Engineering
Detailed guidance for AV operation Guidance needed to outline specifically where certain vehicles should or should not operate	**Short term:** Consider the potential impacts including legal and liability. Determine AV use cases that may need to be supported. A Concept of Operations process is recommended. Develop guidelines for road operators to support AV testing and operations (links with other NTC/Austroads work). Consider need to certify where certain AV use cases may or may not operate or alternatively i.e. could advise where a particular AV use case is not recommended. **Medium term:** Consider certifying or developing risk assessments for AV use cases on individual roads (see 'Suitability of roads for individual AV use cases')
Detailed information about road works and closures Critical need of all road users (including AV) for road works / closures / special events information	**Short term:** Road operators to take responsibility for the validation and sharing of key information **Medium term:** Consider the implication of this data for the concept of "road certification" noted above
Monitoring of AV Need to monitor key infrastructure characteristics required by AV as AV usage increases.	**Short term:** Consider need to monitor key characteristics such as line marking and speed sign information. **Medium term:** Develop programs to monitor characteristics which are proven to be vital to AV operation. This would ideally mean obtaining information from OEMs about the condition of road infrastructure e.g. road markings or road signs.
Suitability of roads for individual AV use cases Need common methodology/mechanism to assess suitability of roads for AV use cases	**Short term:** Development of an assessment guide/program for assessing whether/how well road segments support key AV use cases **Medium term:** support and improve ongoing assessment program
Maintenance intervention levels Asset management and maintenance intervention levels needed for AVs should be considered for improved AV operation and optimal asset management	**Short term**: Investigate what intervention levels are important to AV performance. Consider how to meet these minimum conditions in the context of AV penetration and potential use case for any given road
Consistency in road operations Seek greater consistency in road operations across jurisdictions to encourage more wide spread use of AV	**Short term:** 1. NTC review and maintenance of Australian Road Rules to ensure and influence an appropriate level of national consistency for driving rules 2. Austroads Guides (e.g. Guides to traffic management) reviewed and amended where deemed appropriate

Issue	Timing of response
Consider unique AV operational requirements How to manage broken down AV or AV that reverts to minimum safe operation (fall back) including access to safe stopping areas. This may be a shared consideration between road operators and motoring clubs. Interaction with traffic management personnel (traffic control) and emergency services personnel.	**Short term:** Consider AV needs in Traffic Management and in particular Road Works Specific Guidance and standards. Ensure any elements which impact on road design are also considered (e.g. any changes in positioning of emergency stopping lanes)
Impact of AV use on roads Determine impacts of AV use have on transport and land use	**Short term:** Consider undertaking strategic transport modelling and detailed operational (meso or microscopic) traffic simulation modelling of different AV use cases and the associated impacts (positive or negative) on road operation and need for improvement/augmentation works **Medium term:** Further modelling as possible impact become clear
Impacts on community Determine impacts AV use will have on community and in particular ensure public perception on AV usage.	**Short term:** Undertake consultation with community groups in particular vulnerable road users. Strategic and operations models provide a good opportunity to discuss underlying assumptions and the impact of outcomes.

This report and the guidance outlined above are for consideration and action by road operators relating to physical infrastructure, digital infrastructure and road operations. The scope does not include identifying actions for road agencies such as vehicle registration, driver licensing or similar issues. These are subject of another Austroads project (BR1982: Investigation of potential registration and licensing issues due to the introduction of automated vehicles).

References

ABS 2005, Year Book Australia, 2005, Australian Bureau of Statistics, Canberra, ACT [http://www.abs.gov.au/ausstats/abs@.nsf/0/FA7086AC621CD2DFCA256F7200832FC2?opendocument]

AdaptIVe 2015, *Deliverable D2.1: System Classification and Glossary,* AdaptIVe Consortium, Germany, EU [https://www.adaptive-ip.eu/files/adaptive/content/downloads/Deliverables%20&%20papers/AdaptIVe-SP2-v12-DL-D2.1%20System%20Classification.pdf]

Arem, B.V, Driel, C.J.G, & Visser, R, n.d, *The impact of Co-operative Adaptive Cruise Control on traffic flow characteristics*, Netherlands.

AASHTO 2001, *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington DC, USA. [http://nacto.org/docs/usdg/geometric_design_highways_and_streets_aashto.pdf]

AASHTO 2014, *AASHTO LRFD Bridge Design Specifications,* Seventh Edition, American Association of State Highway and Transportation Officials, Washington DC, USA. [https://bookstore.transportation.org/item_details.aspx?id=2211]

Austroads 2009, *Network Operations Planning Framework*, Austroads, Sydney, NSW, Australia [https://www.onlinepublications.austroads.com.au/items/AP-R338-09]

Austroads 2012, *Guide to Pavement Technology Part 2: Pavement Structural Design*, Austroads, Sydney, NSW, Australia [https://www.onlinepublications.austroads.com.au/items/AGPT02-12]

Austroads 2013a, *Standardised Bridge Barrier Designs,* Austroads, Sydney, NSW, Australia [https://www.onlinepublications.austroads.com.au/items/AP-R445-13]

Austroads 2013b, *Vehicle Positioning for C-ITS in Australia (Background Document),* Austroads, Sydney, NSW, Australia [https://www.onlinepublications.austroads.com.au/items/AP-R431-13]

Austroads 2014, *Guide to Traffic Management Part 4: Network Management* (2nd Edition) (superseded), Austroads, Sydney Australia

Austroads 2015, *Glossary of Terms*, Austroads, Sydney, NSW, Australia [https://www.onlinepublications.austroads.com.au/items/AP-C87-15]

Austroads 2016a, *Guide to Traffic Management Part 4: Network Management* (4th Edition), Austroads, Sydney, NSW, Australia [https://www.onlinepublications.austroads.com.au/items/AGTM04-16]

Austroads 2016b, *Guide to Traffic Management Part 10: Traffic Control and Communication Devices,* Austroads, Sydney, NSW, Australia [https://www.onlinepublications.austroads.com.au/items/AGTM10-16]

Ballingall, S 2015, *Preparing for connected and automated vehicles,* IRF & Roads Australia Regional Conference, Sydney, Australia.

Bergenhem, C, Huang, Q, Benmimoun, A, & Robinson, T 2010 "Challenges of Platooning on Public Motorways", in Proceedings of the 17th ITS World Congress, Busan, Korea, October 25-29, 2010 {http://www.sartre-project.eu/en/publications/Documents/ITS%20WC%20challenges%20of%20platooning%20concept%20and%20modelling%2010%20b.pdf]

Bertoncello, M & Wee, D 2015, *Ten ways autonomous driving could redefine the automotive world*, McKinsey & Company, viewed 7 October 2015, http://www.mckinsey.com/insights/automotive_and_assembly/ten_ways_autonomous_driving_could_redefine_the_automotive_world

Bertozzi, M, Broggi, A, Cellario, M, Fascioli, A, Lombardi, P & Porta, M 2002, *Artificial Vision in Road Vehicles,* Proceedings of the IEE, Vol 90 No 7.

Birdal, T & Ercil, A n.d, *Real-Time Automated Road, Lane and Car Detection for Autonomous Driving*, research paper, Sabanci University, Turkey.

BITRE 2015a, *Yearbook 2015: Australian Infrastructure Statistical Report*, Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2015, BITRE, Canberra ACT [https://bitre.gov.au/publications/2015/files/BITRE_yearbook_2015_full_report.pdf]

BITRE 2015b, *Road Trauma Australia 2014 Statistical Summary*, Bureau of Infrastructure, Transport and Regional Economics (BITRE), July 2015, BITRE, Canberra ACT [https://bitre.gov.au/publications/ongoing/road_deaths_australia_annual_summaries.aspx]

Bosch 2016, *Driver assistance systems,* web page accessed 24.02.2017 [http://products.bosch-mobility-solutions.com/en/de/driving_comfort/driving_comfort_systems_for_passenger_cars_1/driver_assistance_systems_4/driver_assistance_systems_5.html]

Bottazzi, V.S, Borges, P.V.K & Jo, J n.d, *A Vision-Based Lane Detection System Combining Appearance Segmentation and Tracking of Salient Points*, research paper, Griffith University & CSIRO, Australia.

Bain, R, 2009, *Toll Road Traffic & Revenue Forecasts,* Robert Bain (13 April 2009)

Brkic, K, Pinz, A & Segvic, S n.d, *Traffic sign detection as a component of an automated traffic infrastructure inventory system,* research paper, The National Foundation for Science, Higher Education and Technological Development of the Republic of Croatia and the Institute of Traffic and Communications, Croatia, under programme Partnership in Basic research project number #04/20, Croatia.

Brindle, RE 1987, *The "difficult distributor": the problem of the traffic route in residential areas*, AIR 853-3, Australian Road Research Board, Vermont South, Vic.

Brown, S.L 2015, 774, *Legal issues keep autonomous vehicles off the road but Australia needs to consider the new technology, University of Michigan's Diana Bowan says*, ABC Melbourne, 19 November 2015, http://www.abc.net.au/news/2015-03-05/legal-issues-keep-autonomous-vehicles-off-the-road-says-academic/6282606

Burmeister, G, Engels, S, Hamm, S and Kraus, A 2014, *Automated Vehicles for a Sustainable City,* white paper, Dow Interdisciplinary Sustainability Fellowship University of Michigan Ann Arbour, USA.

Cao, X, Young, W, Sarvi, M & Aghabayk, K 2014, *Automatic Discrimination of Traffic Conflicts during Lane Changing Manoeuvres,* 26th ARRB Conference - Research driving efficiency paper, Sydney, Australia.

Carnaby, B 2003, "Line marking – cosmetic or critical?" Australasian Road Safety Research, Policing and Education Conference 2003, Australasian College of Road Safety, Canberra, ACT [http://acrs.org.au/files/arsrpe/RS030026.pdf]

Claudel, M & Ratti, C 2015, *Full speed ahead: How the driverless car could transform cities,* McKinsey & Company, viewed 7 October 2015, http://www.mckinsey.com/insights/sustainability/full_speed_ahead_how_the_driverless_car_could_transform_cities

Commonwealth Government 2016, *Smart Cities Plan*, Australian Government, Department of the Prime Minister and Cabinet, April 2016 [https://cities.dpmc.gov.au/smart-cities-plan] de la Escalera, A, Armingol, J.M & Mata, M 2002, *Traffic sign recognition and analysis for intelligent vehicles,* paper, Division of Systems Engineering and Automation, Universidad Carlos III de Madrid, Elsevier Science B.V, Spain.

Department for Transport 2007, *Manual for Streets*, Thomas Telford Publishing for the UK Department for Transport, London, England [https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/341513/pdfmanforstreets.pdf]

Desiraju, D 2013, *Minimizing the Disruption of Traffic Flow of Automated Vehicles during lane changes*, Master of Science thesis paper, Utah State University, USA.

Dutta, V, Bera, R, Dhar, S, Chakravorty, J & Bagehel, N 2008, *Automated Vehicle Location (AVL) Using Global Positioning System (GPS),* NCEEERE research paper, Sikkim Manipal Institute of Technology, India.

Escalera, S, Baró, X, Pujol, O, Vitriá, J & Radeva, P 2011, *Ch, 2 Background on Traffic Sign Detection and Recognition*, in Traffic Sign Recognition Systems, SpringerBriefs in Computer Science, Spain.

EuroRAP 2011, *Roads that Cars Can Read: A Consultation Paper*, European Road Assessment Programme and Euro NCAP, June 2011, Europe [http://www.eurorap.org/wp-content/uploads/2015/04/20110629-Roads-That-Cars-Can-Read-June-2011.pdf]

Fambro, D.B, Collings, J.C, Della Vedora, R, Liesch, J.P & Mason Jr, J.M 1999, *Geometric Design: Past, Present, and Future,* A2A02: Committee on Geometric Design, Transportation Research Board, USA. [http://onlinepubs.trb.org/onlinepubs/millennium/00048.pdf]

Fraedrich,E & Lenz, B. 2014, “Automated Driving – Individual and Societal Aspects”, Transportation Research Record: Journal of Transportation Research, Issue 2416, Transit 2014, Volume 2: Carsharing, Taxis, and Automated Transport

Gao, P, Hensley, R & Zielke, A 2014, *A road map to the future for the auto industry,* McKinsey & Company, viewed 7 October 2015, [http://www.mckinsey.com/insights/manufacturing/a_road_map_to_the_future_for_the_auto_industry]

Gartner 2015, Gartner Says By 2020, a Quarter Billion Connected Vehicles Will Enable New In-Vehicle Services and Automated Driving Capabilities, Gartner Research, Stamford, Connecticut, USA, January 2015 [http://www.gartner.com/newsroom/id/2970017]

Gill, V, Kirk, B, Godsmark, P & Flemming, B 2015. *Automated Vehicles: The Coming of the Next Disruptive Technology*, The Conference Board of Canada, Ottawa.

Gordon, R.L n.d, *Advanced Lane Management Assist (ALMA) for Partially and Fully Automated Vehicles*, PowerPoint slides, N.Y., USA.

Guttikonda, G & Potumeraka, C.S 2015, *Automated Traffic Sign Board Classification System,* International Journal on Computational Sciences & Applications, Vol. 5, No. 1.

Hatzidimos, J, 2004, *Automatic Traffic Sign Recognition in Digital Images*, Proceedings of the International Conference on Theory and Applications of Mathematics and Informatics, Thessaloniki, Greece.

Haung, A.S 2010, *Lane Estimation for Autonomous Vehicles using Vision and LIDAR,* Doctor of Philosophy thesis paper, Massachusetts Institute of Technology.

Intel Corporation 2014, *Technology and Computing Requirements for Self-Driving Cars,* brochure, USA.

Ioannou, P 2002, *Evaluation of the Effects of Intelligent Cruise Control Vehicles in Mixed Traffic*, University of Southern California, USA.

Isaac L 2016, *Driving Towards Driverless*: *A Guide for Government Agencies,* Parsons Brinckerhoff, New York, New York, USA [http://www.wsp-pb.com/wsp-usa/connected-and-automated-vehicles/our-projects/driving-towards-driverless-a-guide-for-government-agencies/]

Jones, P & Boujenko, N 2009, 'Link' and 'Place': A new approach to street planning and design, Australasian Transport Research Forum 2009 [http://atrf.info/papers/2009/2009_Jones_Boujenko.pdf]

KPMG & Centre for Automotive Research 2012, *Self-driving cars: The next revolution*, brochure, KPMG & CAR, USA.

Letter, C & Elefteriadou, Dr L. n.d, *Efficient Control of Automated Vehicles on Freeway Merge Segments*, research paper, University of Florida, USA.

Liersch, C 2014, *Driverless Vehicles,* brochure, BOSCH, Australia.

Litman, T 2015, *Autonomous Vehicle Implementation Predictions – Implications for Transport Planning,* Victoria Transport Policy Institute, Melbourne, Australia.

Lorsakul, A & Suthakorn, J 2007, *Traffic Sign Recognition for Intelligent Vehicle/Driver Assistance System Using Neural Network on OpenCV,* The 4th International Conference on Ubiquitous Robots and Ambient Intelligence paper, Mahidol University, Thailand.

Martinez-Perez, F.J 2012, *Impacts of Road Trains on the Geometric Design of Highways*, Open Access Master's Theses Paper 717, University of Rhode Island, USA.

McCall, J.C & Trivedi, M.M 2005, *Video Based Lane Estimation and Tracking for Driver Assistance: Survey, System, and Evaluation*, research paper, University of California, USA.

McKinsey & Company 2015, *Competing for the connected customer – perspectives on the opportunities created by car connectivity and automation*, brochure.

Miao, X, Li, S & Shen, H 2012, *On-board Lane Detection System for Intelligent Vehicle Based on Monocular Vision,* International Journal on Smart Sensing and Intelligent Systems, Vol 5 No 4.

Mitchell 2010, "An analysis of road signage and advertising from a pragmatic visual communication perspective: Case study of the M1 Motorway between the Gold Coast and Brisbane", Journal of the Australasian College of Road Safety, May 2010, Vol 21 No 2 [http://acrs.org.au/wp-content/uploads/ACRS-21-2Web.pdf]

Motoring 2015, *Benz claims autonomous lead with E-Class*, 23 June 2015 [http://www.motoring.com.au/benz-claims-autonomous-lead-with-e-class-52005/]

PIARC 2003, *Road Network Operations Handboo*k, Technical Committee 16 Network Operations, World Road Association, Paris, France [https://www.piarc.org/en/order-library/4379-en-Road%20Network%20Operations%20Handbook.htm]

Qing, X, Hendrick, K, Sengupta, R & Vanderweft, J, n.d, *Effects of vehicle-vehicle/ roadside-vehicle communication on adaptive cruise controlled highway systems*, University of California, USA.

Rämä, P & Innamaa, S 2015, *The Impact of Automation on the Urban Environment – Findings of Finnish Study,* CityMobil2 Reference Group Meeting PowerPoint slides, La Rochelle, Finland.

Ramos, A, Ferreira, J & Barceló, J 2012, "Modelling & Simulation for Intelligent Transportation Systems" *International Journal of Modelling and Optimization*, June 2012 [http://www.ijmo.org/papers/126-C022.pdf]

Regan, M n.d, *Automated Vehicles: Human Factors Challenges and Solutions* brochure, ARRB Group, Australia.

Sage, A 2016, *Where's the lane? Self-driving cars confused by shabby U.S. roadways,* Reuters, Los Angeles, California, USA, 31 March 2016 [http://www.reuters.com/article/us-autos-autonomous-infrastructure-insig-idUSKCN0WX13]

Saha, A, Das Roy, D, Alam, T & Deb, K 2012, *Automated Road Lane Detection for Intelligent Vehicles,* Global Journal of Computer Science and Technology, Vol 12 Issue 6 Version 1.0.

SIBA 2014, *Spatial Industry innovation key to Intelligent Transportation futures*, Spatial Industries Business Association, 18 December 2014, Canberra, ACT [http://www.siba.com.au/News/News-Articles/Spatial-Industry-innovation-key-to-Intelligent-Tra.aspx]

Sivak, M & Schoettle, B 2015, *Should we require licencing tests and graduated licencing for Self-driving Vehicles? technical report,* University of Michigan Transportation Research Institute, USA.

Skinner R & Bidwell N, 2016, *Making Better Places: Autonomous Vehicles and Future Opportunities* WSP | Parsons Brinckerhoff and Farrells, United Kingdom [http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf]

Somers, A & Weeratunga, K 2015, *Automated Vehicles Are we ready?* Internal Report, Main Roads WA, Western Australia, Australia.

Srivastava, S, Lumb, M & Singal, R 2014, *Improved Lane Detection Using Hybrid Median Filter and Modified Hough Transform,* International Journal of Advanced Research in Computer Science and Software Engineering, Vol 4 Issue 1.

Texas Instruments 2015, *Advanced Driver Assistance (ADAS) Solutions Guide* [http://www.ti.com/lsds/ti/applications/automotive/adas/overview.page]

Thompson, RJ 2011, *Mine Road Design and Management in Autonomous Hauling Operations: A Research Roadmap*, Second International Future Mining Conference 2011 Paper Number 21, Western Australia, Australia.

Trafi 2015, *Automated vehicle trials in Finland*, brochure, Finnish Transport Safety Agency, Finland.

Transoptim Consulting 2015, *How might driverless transport transform demand?* ITEANZ Seminar brochure, Transoptim Consulting, Australia.

TRB 2010, *Highway Capacity Manual (5th Edition),* Transportation Research Board, Washington DC, USA [http://hcm.trb.org/?qr=1]

TRB 2013, *Transit Capacity and Quality of Service Manual (3rd Edition),* Transportation Research Board, Washington DC, USA [http://www.trb.org/Main/Blurbs/169437.aspx]

Turnbull, K 2015, *Towards Road Transport Automation – Opportunities in Public-Private Collaboration*, Transportation Research Board Conference Proceedings 52 Summary of the Third EU-U.S Transportation Research Symposium, U.S. Department of Transportation European Commission Transportation Research Board, Washington, USA.

Van Schijndel-de Nooij, M, Krosse, B, Van Den Broek, T, Maas, S, Van Nunen, E, Zwijnenberg, H, Schieben, A, Mosebach, H, Ford, N, McDonald, M, Jeffery, D, Piao, J & Sanchez, J 2011, *Definition of necessary vehicle and infrastructure systems for Automated Driving,* SMART – 2010/0064 Study Report V. 1.2, European Union.

Walker, K.S, Shogan, S, Huntsinger, L, Wallace, R & Hong, Q 2015, *Use of data from Connected and Automated Vehicles for Travel Demand Modelling*, Michigan Department of Transportation and the Centre for Automotive Research, USA.

Washburn, S.S & Washburn L.D 2014, *Future Highways Automated Vehicles*, online education course material, SunCam, USA.

Wachenfeld, W & Winner, H 2014, *Use Cases for Autonomous Driving,* Daimler and Benz Foundation, Germany, June 2014 [https://www.daimler-benz-stiftung.de/cms/images/dbs-bilder/foerderprojekte/villa-ladenburg/Villa_Ladenburg_Use_Cases_English_Release_2.pdf]

Wiggins J 2016*, Transurban CEO Scott Charlton in driver's seat for driverless future*, Australian Financial Review, 16 May 2016 [http://www.afr.com/business/infrastructure/roads/transurban-ceo-scott-charlton-in-drivers-seat-for-driverless-future-20160510-gos4y4]

Yan, X, Zhang, R, Ma, J & Ma, Y 2013, *Considering Variable Road Geometry in Adaptive Vehicle Speed Control,* Hindawi Publishing Corporation, China.

Australian Standards

AS1742 *Manual of Uniform Traffic Control Devices*

AS1742.3 – 2009 *Manual of Uniform Traffic Control Devices, Part 3: Traffic Control for Works and Roads*

AS3600 *Concrete Design*

AS5100 *Bridge Design*

International Standards

SAE J3016, *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*, Society of Automotive Engineers, September 2016

Appendix A Stakeholder Input

Formal Meetings and interviews held with a range of interested stakeholders. In addition to these more formal meetings many other informal contact and communication was held with other industry stakeholders. A list of stakeholders is outlined in the table below. Some of the stakeholders were also co-authors as indicated with an asterisk (*) below.

Table A.4 Stakeholders consulted

Stakeholder	Stakeholder type
American Association of State Highway and Transportation Officials (AASHTO)	Technical association – sets standards and guidelines
Connect East	Road operator
European Intelligent Transportation System (ITS) organisation (ERTICO)	Partnership of 100 companies and institutions involved in the production ITS for the EU.
General Motors Holden	Vehicle Manufacturer
Here	Intelligent Transport Systems Supplier - Mapping
National Transport Commission	Government Agency
Roads and Maritime Services (RMS)	Government Agency
Robert Bosch*	Automotive equipment supplier
Dr Steven Shladover (PATH)	Consultant and academic
Swedish Road Agency	Government / Drive Sweden
Telstra*	Telecommunications provider
TomTom	Intelligent Transport Systems Supplier - Mapping
Toyota	Vehicle Manufacturer
Transmax	Intelligent Transport Systems Supplier – Traffic Management Systems
Transurban	Road operator
Victorian Taxi Directorate	Government Agency
Viktoria ICT	Research Organisation
Volvo	Vehicle Manufacturer
VicRoads	Government Agency

Austroads

Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia

Phone: +61 2 8265 3300

austroads@austroads.com.au
www.austroads.com.au