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AUTOMATED VEHICLES

DO WE KNOW WHICH ROAD TO TAKE?

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Acknowledgements

The Authors would like to acknowledge the work of Dane Logan, Andrew Lau and Alex Li-Kim-Mui of Advisian and Dr. Hanna Grzybowska and Dr. Kasun P Wijayaratna of UNSW RCITI in producing this report.

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Executive Summary

Automated and Driverless Vehicles (AV/DVs) offer the prospect of positive and fundamental changes to the way Australia's cities work and how people utilise transport. At the highest level, AVs offer massive increases in road safety and capacity – and could see car ownership become the exception, with many choosing the lower costs and increased convenience of Mobility-as-a-Service (MaaS).

But this shift will not of itself be autonomous – fully automated vehicles do not yet exist for general sale, they are illegal under current Australian laws, and the community has equal levels of excitement and fear about ceding control to AVs at all.

DRIVING A MIDDLE ROAD

Our paper identifies three generalised approaches for policymakers to the prospect of AVs, which we describe as:

1. **A low road:** where regulation and investment severely lags AV adoption;
2. **A middle road:** where regulation is responsive, but follows observed community choices; and
3. **A high road:** where the government sector 'picks winners' in advance of community adoption.

Noting that AVs are yet to exist on public roads beyond modest trials, we recommend that Australia's governments drive the middle road – by ensuring that transport policy and investment decisions neither significantly lead, nor significantly lag, community choices.

THE AV FAMILY

AVs are something of a catch all term – describing vehicles that may have quite different levels of autonomy, built around one of two dominant families of AV:

» **Autonomous Only Vehicles (AOVs) –** which find their way using on-board sensors; and

» **Connected & Autonomous Vehicles (CAVs) –** which communicate with other vehicles, road users and road infrastructure.

STREET LEGAL?

If a fully autonomous or Driverless Vehicle (DV) – i.e. one without a steering wheel – became available for sale tomorrow, it could not operate on Australian roads.

A range of works have been done by the National Transport Commission and others, examining the changes to law and regulation needed to contemplate AVs, beyond limited trials already underway. Our paper touches on the central issues, which are gathered around definitions of control and the changes AVs require in regard to laws of liability.

Despite the work done to identify these impediments, much more work is needed to resolve these areas through concurrent Federal and state legislation. This should be tasked to the National Transport Commission, noting its existing and planned work in this area.

Once AVs become 'street legal', they will likely either require, or substantially benefit from, enabling investments in existing infrastructure. Examples range from modest changes to make signage or lane markings recognisable by the vehicle – through to much more expensive investments where 'Connected &

Autonomous Vehicles' are in constant contact with the infrastructure network.

GETTING THE MEASURE OF AVS

Ultimately, the decision as to whether and when to undertake modest, or major, enabling investments for AVs must be connected to the number, type and speed of penetration AVs achieve.

However ensuring that these decisions neither substantially lead, nor significantly lag community choices will require a system where governments collect and publish details on AVs, including:

- The number of AVs on the network;
- Their de-identified location;
- The level and type of autonomy; and
- The level of connection they are capable of.

PERSONAL AUTONOMY MEANS IT'S ULTIMATELY ABOUT INDIVIDUAL CHOICE

The ultimate success of AVs can only be enabled, not determined, by transport policymakers and AV technology developers. The best AV in the world cannot succeed in providing the transport network benefits promised if people do not make the decision to use them in sufficient numbers. A recent survey showed that 83 per cent of people would still prefer to drive manually from time to time even if they owned an AV, and less than a quarter would allow their children to use one.

This points to a substantial role for transport policymakers to engage with the public on AV technologies, including by understanding the hesitations that people may have about giving up driver control, whether they be safety, privacy or an attachment to direct vehicle ownership.

Recommendations

We recommend a four phase national process on AVs:

- **Phase 1:** Infrastructure Australia or Austroads to engage with transport industry partners and road users to benchmark community needs, hesitations and choices regarding AVs – and coordinate national policy on AVs;
- **Phase 2:** The National Transport Commission to develop concurrent Federal and state legislation and regulations to allow AVs and DVs to enter Australian roads;
- **Phase 3:** Government road agencies (coordinated through Austroads) to begin reporting on the number, type and de-identified location of AVs entering the vehicle fleet; and
- **Phase 4:** Transport planning to routinely assess AV uptake in long-term infrastructure, land use and wider strategic planning.

Phase 1 – Understanding the opportunity

Infrastructure Australia or Austroads to engage with transport industry partners and road users to benchmark community needs, hesitations and choices regarding AVs – and coordinate national policy on AVs

Infrastructure Australia or Austroads should be given a coordinating role across Federal and state governments. It should be specifically charged with coordinating a volume of work across the tiers of government, to measure and understand the motivations and hesitations of transport market stakeholders and users over time. This should include:

- Regular benchmarking of community and key user group views of the benefits and the risks or costs of enabling AVs;
- Consult with industry partners to produce detailed analysis of emerging preferences in the broader transport network; and
- Significantly increase community involvement and demonstrations during trials to raise awareness and help discuss and resolve issues.

Phase 2 – Street legal

The National Transport Commission to develop concurrent Federal and state legislation and regulations to allow AVs and DVs to enter Australian roads

The NTC's commendable work on AVs has already seen the publication of national Guidelines for trials of automated vehicles in Australia; but moving beyond trials will require concurrent legislation and regulations which:

- Define key issues like vehicle 'control' and resolve complex issues of legal liability, in the context of AVs;
- Harmonise design rules and technical specifications to provide connectivity between road and other infrastructure and AVs; and
- Implement consistent national regulatory frameworks for AV safety standards and certification to assist in achieving compliance across Australian jurisdictions.

Phase 3 – Data collection

Government road agencies to begin reporting on the number, type and de-identified location of AVs entering the vehicle fleet

AVs present a new type of vehicle, one that could change the way road agencies manage and operate their infrastructure. Multiple types of data from AVs can be captured and utilised in real time – managing individual user preferences and planning for future infrastructure requirements. To understand the penetration of AVs and maximise the potential of their data to inform decision making, it is recommended that governments, coordinated through Austroads:

- Begin recording and annually reporting the number, type, usage and safety performance of AVs over time across each state, collating this information into a national database; and
- Implement standardised data recording and communication methods to reinforce cyber resilience.

Phase 4 – Reflecting choices

Transport planning to routinely assess AV uptake in long-term infrastructure, land use and wider strategic planning

Road and supporting communications infrastructure may, over time, require investment by governments in response to AV uptake. Utilising the results of the data capture recommendations in Phase 3, it is recommended that to address infrastructure challenges, governments, potentially in the form of an annual report prepared by Austroads:

- Identify a programme of potential investments to upgrade infrastructure, including communications and access to data; and
- Identify possible adjustments to existing regulations or legislation to facilitate infrastructure improvements.

1 Introduction

While the prospect of automated and driverless vehicles has recently fuelled public interest, the evolution of the underlying technologies began decades ago, through safety and driver aids, such as cruise control, anti-lock braking systems and electronic stability control. Figure 1 shows this evolution and the prospect that more advanced forms could eventually replace the role of human drivers altogether.

Figure 1: Progression of automated technology

Pre 1990	1990 to 2010	2010 to 2020	2020 onwards
Anti-lock brakes Cruise control	Electronic stability control Adaptive cruise control Lane departure warning system Intelligent parking assist systems Autonomous emergency braking Lane keeping assist	Traffic jam assist Automated valet parking Automated highway driving	Fully automated vehicles

Companies like Tesla already have 'fully automated' functions within their vehicles; Google's self-driving car has clocked up more than 2.4 million kilometres in travel; DVs are widespread in areas including defence, mining and agriculture; 'driverless' passenger trains have been operating for many decades; and passenger aircraft routinely use autopilot – which can autonomously take off and land.

While these technologies already exist, and are now appearing in some (largely high-end) vehicles, their certification for routine use on public roads remains some way off – and their contribution and impact on the shape of transport needs and transport infrastructure is yet to be determined.

While the prospect of a driverless (fully autonomous) vehicle fleet – complete with animations of cars seamlessly criss-crossing each other at non-light controlled intersections – has caught the public imagination, it remains unclear as to how many, or how quickly, AVs will enter the road network, or even what type of technologies they will use – meaning a gap exists to better understand this aspect of transport policy.

1.1 Policy challenges for an uncertain future

As AVs and DVs increase as a proportion of the overall vehicle fleet, changes to regulation will obviously be needed. Depending on the technologies adopted by vehicle owners, DVs may also necessitate changes to road infrastructure networks themselves.

The prospect of DVs has seen many scenarios discussed. These range from the bullish – where DVs are ubiquitous across the entire road network and replace both private vehicle ownership and the role of human drivers altogether – through to more modest (and likely) scenarios, where a combination of AVs and DVs are part of a mixed fleet and where some people still drive some of the time.

Detailed analysis, modelling and strategic planning will be needed by governments to understand the range of technological possibilities – but also, the community's choices, over time.

For example,

» How will AVs and DVs affect mobility, urban planning, traditional traffic modelling and transport operations?

» What new laws and regulations will be required? Will road rules, infrastructure standards, and insurance and liability frameworks need to be harmonised across Australian states?

» How should the introduction of AVs be staged?

» Will it begin with a right-of-way for AVs on assigned, controlled corridors? If so, will these corridors eventually take over the road network and become the norm?

These questions and many others will need to be addressed to allow AVs and subsequently DVs to enter the road network and to play their proper role in Australia's mobility.

1.2 You take the high road and I'll take the middle road

As AVs enter the vehicle fleet, Australia's governments face choices around how quickly transport regulation and practice change – and how and what investment is needed in road infrastructure to cater for this shift.

In Figure 2, we describe three broad approaches that governments could take, being:

1. **A low road:** where regulation and investment severely lags AV adoption;
2. **A middle road:** where regulation is responsive, but follows observed community choices; and
3. **A high road:** where the government sector 'picks winners' in advance of community adoption.

Each brings a degree of challenge.

For example, taking the 'low road' could constrain important benefits; such as improved safety and reduced road network congestion; whereas taking the 'high road' could well see investments in the wrong enabling technologies or infrastructure. It would not make much sense to sink taxpayer funding into 'smart' intersections, for example, if adoption of AVs is lower or slower than policymakers assume.

To a large degree, governments will need to understand the choices made by the community about technology and vehicle types and driver behaviours – because these will dictate the pace, shape and cost of investments in technology – and the legal changes that will also be needed.

Figure 2: Three scenarios

	Public investment in enabling AV infrastructure/ICT	Law & regulation	AV fleet penetration	Motorist safety	Public acceptance of AV technologies	Transport network capacity
HIGH ROAD	Government 'picks winners', risking waste, cost overruns or stranded investment	Prefers particular technologies or vehicles, limiting choices	Facilitated, but limited to the 'chosen' technology/ies	Increased	Increased	Increased, but limited to the 'chosen' technology/ies
MIDDLE ROAD	In line with demand	Facilitates and enables community choices	Facilitated in line with community choices	Increased	Increased	Increased
LOW ROAD	Low	Law and regulations slow adoption of AVs	Slows	Status quo	Constrained	Status quo – deteriorates

In considering the many questions surrounding safety, regulation, legislation, industry involvement, community engagement, economic costs and benefits and infrastructure investments, this paper aims to assist governments in providing a framework to help smoothly achieve an automated and driverless future. Proactive and considered leadership by governments will help shape a path of relative certainty. This will help ensure that AVs are introduced in a way that enhances Australia's prosperity and people's satisfaction with the way they live.

2 Understanding the automated vehicle ecosystem

Automated and driverless vehicles have only recently captured the public imagination, as they move from science fiction and into the real world – but the concept is not new. Figure 3, below, shows that the move to automate part or all of a driver's tasks has existed almost as long as the motor car itself.

Figure 3: The evolution of task automation in motor vehicles

1920s

Houdina Radio Control demonstrated the first radio-controlled driverless car.[1]

1930s

Radio-controlled electric cars unveiled at the 1939 New York World's Fair. The vehicles moved using electromagnetic fields created by electric circuits embedded in the roadside pavement.

1948

Cruise Control invented by Ralph R. Teetor.[2]

1950s – 1970s

Wire controlled vehicles are developed in the USA and UK, moving vehicles through circuits embedded in roadways.

1980s

Modern-day AVs came closer with development of the "drive-by-wire" system in for engine-control module, automating the engine's operations.

Electronic stability control is developed and uses engine control system to reduce torque in "stability critical" situations.[3]

1990s

Mitsubishi introduced the autonomous cruise control system, relieving drivers of the need to control the throttle, the breaks and gear shifting while activated.[4] Microwave radiation was used to detect objects within the car's line of sight, allowing their distance and speed to be monitored.

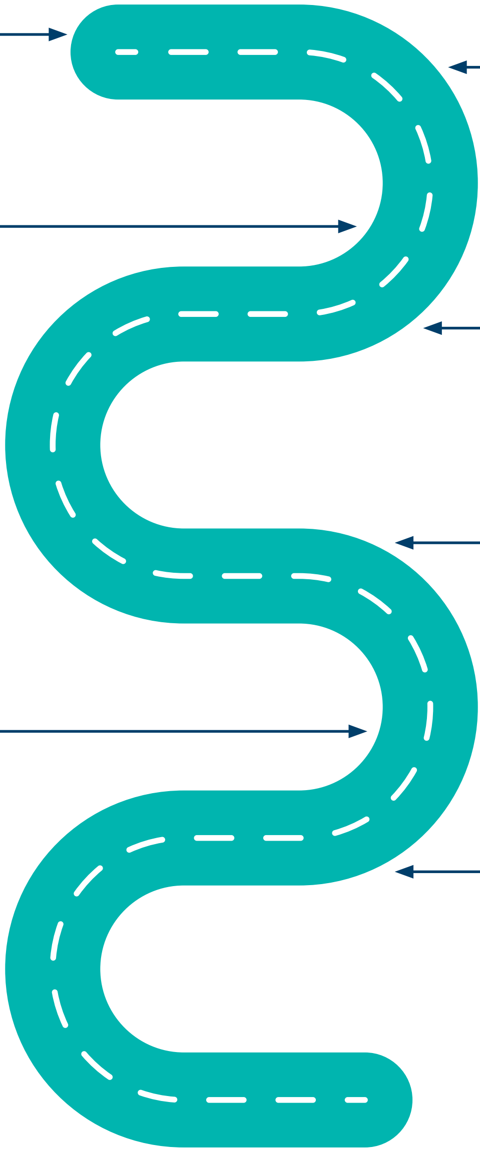
2004

A team from Stanford University created "Junior". Showcased at the Urban Challenge competitions,[5] its original features are now considered to represent the basic capabilities of an AV. It was equipped with five different laser measurement systems, a multi-radar assembly, and a multi-signal inertial navigation system.

2004 to present

Assistive and autonomous parking systems able to park a vehicle. Sensors mounted on the vehicle's sides determined the vehicle's most appropriate acceleration and turning radius.

Companies such as Google, Tesla, BMW, Volvo and Land Rover continue to work on developing fully automated and driverless vehicles.



While the concept of automation has existed for a long time, until now the automation of motor vehicles has been designed to assist, not replace, a human driver.

The rapid advance in technologies sees transport planners, policymakers and the community considering a very real prospect of AVs becoming a reality on our roads in the near term.

In this section, we discuss differing levels of automation, the interconnectivity that can be created between AVs and road infrastructure and the consequent benefits and challenges.

2.1 Defining automation levels

Automated vehicles mean different things to different people. There are different levels of vehicle automation—the highest levels of automation will be reached gradually, as technology develops.

Five key stages in the evolution of AVs, listed below and summarised in Appendix 1, will be used throughout this paper.[6]

» **Level 1:** Driver assistance
» **Level 2:** Partial automation
» **Level 3:** Conditional automation
» **Level 4:** High automation
» **Level 5:** Full automation (driverless)

2.2 Defining AVs – Autonomous Only or Connected and Autonomous Vehicles

Currently, there are two schools of thought on how AVs might work:

» **Autonomous Only Vehicles (AOVs)** – which find their way using on-board sensors (such as the Google and Tesla trials); and
» **Connected and Autonomous Vehicle (CAVs)** – which communicate with other vehicles and with road infrastructure.

Aside from the obvious technological and physical differences between the two approaches, the main distinction between the two types of AVs is in their interaction with the broader network.

AOVs will choose a 'best for individual' approach, where the AOV operates in isolation from other vehicles – and from the road network as a whole.

Alternatively, CAVs will choose a 'best for network' approach where travel choices like route, speed and location are optimised for the road network as a whole – as well as the individual driver.

CAVs may well offer superior benefits in the longer-term, but this scenario would require upfront technology investment via sensors or more sophisticated vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications systems. To some degree, the accelerating contemporary focus on digitising road network assets and the deployment of intelligent transport systems (ITS) technologies across key assets such as motorways, arterials and key bridges, and potentially car parks, may also play a role in lessening the cost of future CAVs. Once this digital capability is in place, enormous data volumes could be generated on road conditions, traffic patterns and vehicle movements.

It is likely that even enabling AOVs would also require some degree of upgrade or investment in transport infrastructure – though likely, more modest than for CAVs. For example, consistent signage may be required across regions or jurisdictions to enable AOVs to "read" their meaning; or a particular type of lane marking could be needed to enable AOV operation on particular sections of the network.

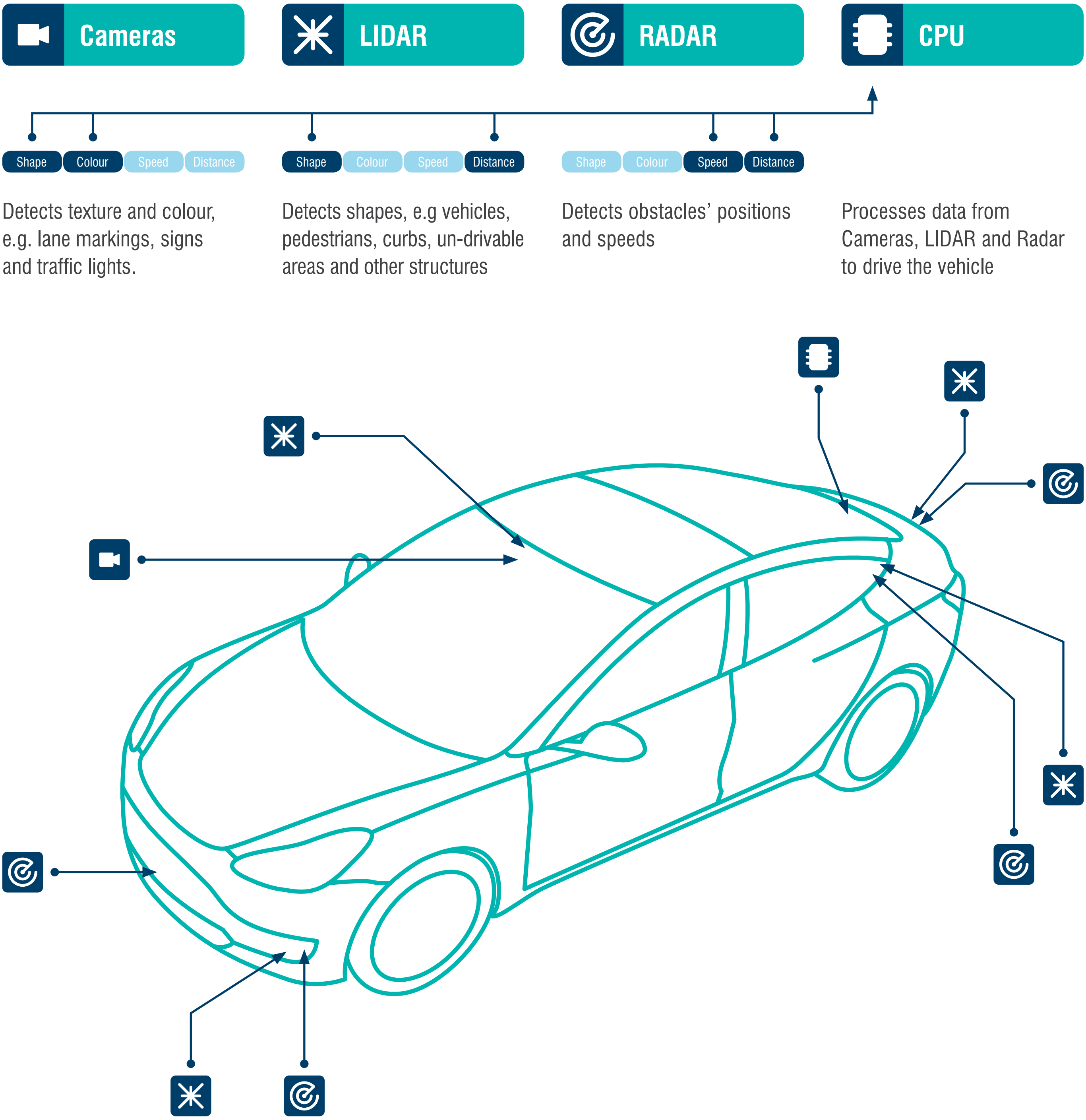
Given the likely differential in cost, it is logical to contemplate AOVs entering the network first – with a later shift to more complex CAVs reliant on enabling technologies and user demand.

This paper considers AOVs and CAVs collectively as AVs, and considers pathways relevant to either, or both, technological schools of thought – or others.

AV TECHNOLOGY UNDER DEVELOPMENT

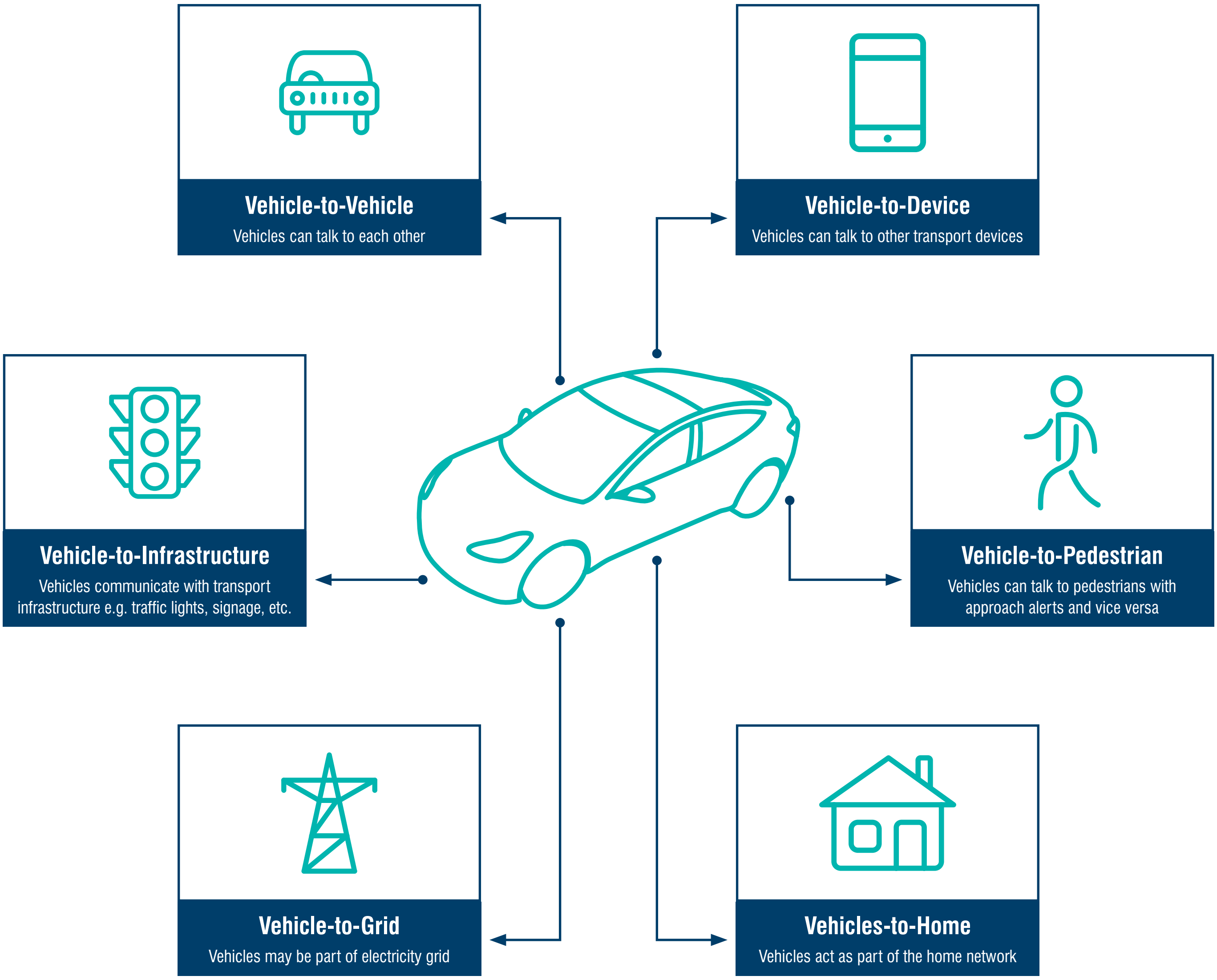
In the more immediate future, the ability of AVs to gather intelligence and navigate quickly, securely and reliably with the surrounding environment is fundamental to their safe and efficient operation, as shown in Figure 4.

Figure 4: Integration of LIDAR, radar, camera and sonar with a computer



Sophisticated vehicle-to-everything communications (referred to as V2X, as illustrated in Figure 5) enable CAVs to share data about their positions, as well as their future intentions. For example, CAVs can know in advance which direction the vehicle in front is planning to turn. The benefit of being equipped with all this information is that vehicles can safely move in more efficient platoon-like formations—that is, closer together. This could reduce congestion and increase overall network efficiency and capacity, even if there are more cars on the road. On an automated highway system, entire platoons of cars or trucks would be able to accelerate or brake simultaneously.

Figure 5: Vehicle to everything (V2X) communication technology



This prominence and importance of communication between the vehicle and its environment is key – the role of the driver's eyes and ears' will be performed by digital communications and supporting infrastructure. Currently, however, the level of communication required for CAVs to become a reality is a distant vision. AVs offer the prospect of a revolutionary change to the way we live, work and travel. In this section, we examine the potential benefits – and challenges – posed by the prospect of AVs on the road network.

2.3 Benefits

AVs could offer major benefits, such as improved safety and increased throughput on the road network. Fully automated or driverless vehicles have the potential to make fundamental changes to how we consider mobility and the design of our urban conurbations themselves.

SAFETY

Research indicates that human factors contribute to 95 per cent of road accidents. A reduction in the number of accidents could save Australia alone more than $30 billion a year.[7]

That means that one major benefit from AVs could be significant improvements in road safety. Eliminating human error as a factor in road accidents would see far fewer deaths and injuries, resulting in lower human and economic costs such as reduced insurance charges.

MORE EFFICIENT ROAD USE

Traffic congestion in Australian cities could cost $53.3 billion per annum by 2031[8] in economic and social effects, according to Infrastructure Australia.

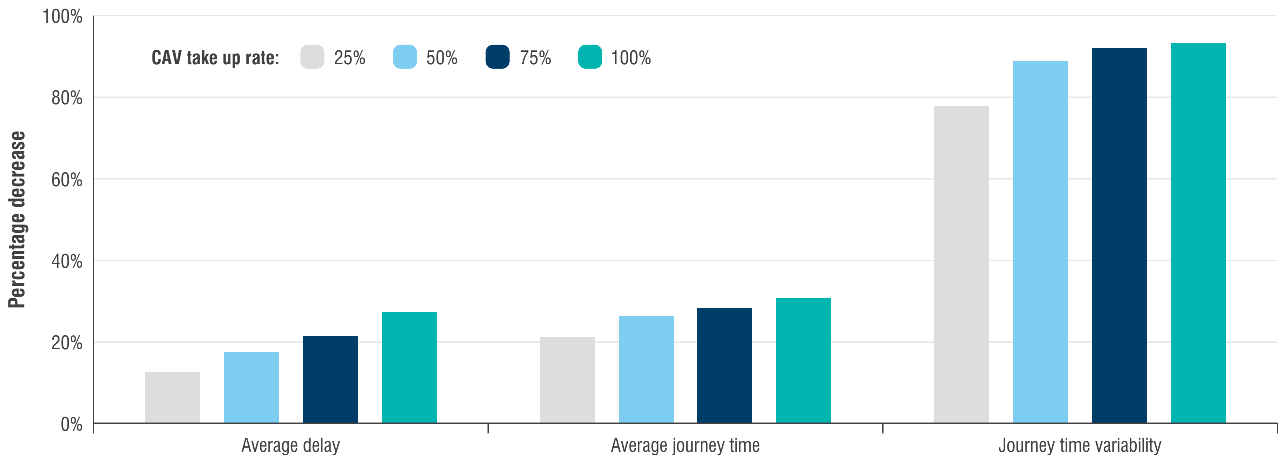
Without human drivers, AVs could operate with much smaller headways between vehicles – which could radically increase the capacity of the transport network, without the cost of new lanes or motorways.

Connected technologies would offer additional benefits, allowing traffic to be actively optimised across the system – for example, around congested areas or away from accidents. Some studies have estimated that these scenarios could triple the capacity of existing highways.[9]

In this way, AVs could defer expansions of the road network; and simultaneously improve travel conditions on the existing network, particularly for congested urban areas.

Modelling undertaken in the UK,[10] shown in Figure 6, reveals the following results for delay and journey times in an urban road environment based on different levels of CAV take up.

Figure 6: Modelling results for high demand in an urban road environment



Source: Department for Transport, UK, 2016, Research on the Impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow.

These results demonstrate the potential improvements in congestion and journey times, even with a relatively low level of uptake of CAV vehicles. This is particularly true for journey time variability, with a reduction of almost 80 per cent, even for a take up rate for CAVs of 25 per cent.

ENHANCED MOBILITY AND CHANGING TRAVEL PATTERNS

AVs will provide a new range of secure travel options to those who were previously constrained, such as the young, the disabled or the elderly. In doing so, there are new markets and businesses that could develop from the provision of a secure and affordable transport option achieved through DVs. This could radically change many aspects of the community's wants and mobility needs.

Productivity could be dramatically improved. With humans relieved of the need to navigate and drive, there is some prospect that even longer commute times could become productive. DVs could also erode private vehicle ownership – perhaps in favour of car sharing or subscription services. It makes little economic sense to have individual motor vehicles stationary, or in car parking stations, given that they could be meeting the mobility demands of others. In this scenario, vehicles may become public transport – so called Mobility-as-a-Service (MaaS).

ENHANCED DATA AND INFORMATION

AVs could provide vast quantities of data about aspects like road network utilisation, infrastructure condition and maintenance needs or traffic interruptions. In this way, the prospect of AVs offers other benefits, in terms of live traffic patterns and a much deeper understanding of where travel demand occurs – and the condition, capacity and quality of the infrastructure which underpins mobility.

DIRECT TRANSPORT COSTS

AVs could prove revolutionary, in terms of the overall monetary cost of transport, a key input cost to individual households as well as the broader economy. According to the Australian Bureau of Statistics, Australian households spent an average of $165.06 per week (in 2011 prices) on owning and operating private vehicles.[11] More broadly, DVs could also reduce or remove labour costs in freight and public transport – the cost of travelling "the last mile" – for example, from the train station or bus stop to work or home – is estimated to account for about 28 per cent of overall transportation costs.[12]

Running costs for electric AVs are some 70 per cent less per kilometre than a traditional vehicle – and autonomous long haul freight vehicles could save 10 per cent in fuel costs by 'platooning' – travelling in a close convoy, to reduce air drag and resistance.[13]

If road use were optimised across the network, avoiding stop-start congestion, AVs would also conceivably reduce wear and tear costs on vehicles.

2.4 Challenges

The benefits associated with AVs are wide-ranging but not without various challenges, particularly in the implementation and initial buy-in from the community.

WINNING TRUST: OPERATIONAL SAFETY AND DATA CONFIDENTIALITY

One (sometimes neglected) reality in contemplating AVs is that community choices, not simply technological possibility, will determine how quickly AVs enter the vehicle fleet – and how ubiquitous AVs become. That means that the community will need to trust both the operational safety offered by AVs – and trust how, when and why journey data might be used.

While the community is aware of and interested in AV and DV technologies, developing trust in AVs generally, and their ability to operate in diverse situations will likely be important. Establishing trust in 'full' AV operations – autonomously navigating in changing or adverse weather conditions, all while adapting and responding to unfamiliar environments and emergency situations – will probably require substantial community assurance first.

CASE STUDY: SECURITY AND SAFETY OF AVS

While AVs have clear appeal, it is likely that there will be some degree of natural human caution about giving up control of a vehicle. This is reflected by the very high degree of public commentary over the relatively few incidents that have involved AVs. For instance, there was global publicity in May 2016 when a Tesla, operating semi-autonomously, failed to recognise a truck across its path due to glare from the sun, resulting in the death of its driver.

Elsewhere, a group of researchers from Keen Security Lab managed to access the operating system of a Tesla through Wi-Fi and remotely control its functions such as braking and acceleration, opening up concerns about malicious intent.[14]

That both of these stories went viral reflects both the community's interest in, and concern about, moving from driver to computerised control of motor vehicles.

INFRASTRUCTURE

Regardless of the type of AV vehicle that enters the road networks, some level of investment in infrastructure would likely be required, as all AVs will need to engage with the surrounding environment.

For example, if AOVs need to 'read' roadside signage, signs may well need to be standardised and designed to be 'readable', as AVs enter the road system. If CAVs become widely adopted, they may need more complex enabling investments like 'smart' intersections and other connected technologies.

The pace at which AV technology is developed and the level of penetration they achieve will in turn dictate the types and level of enabling investments that will be needed.

This will itself be complex, given that the road network is owned, funded or managed in a confused mix, across all three tiers of government; and depending on technological availability and consumer choice, hard discussions will eventually be needed about what is required – and who and how these infrastructure investments will be paid for.

Some form of collaboration between governments and vehicle manufacturers and technology providers is going to be required. Recent announcements by Caltrans (USA)[15] to upgrade lane marking is a move in this direction.

CASE STUDY: DIGITAL MOTORWAY TEST BED

In Germany, the government has partnered with industry by setting up the Digital Motorway Test Bed – a 589 kilometre stretch of federal motorway in Bavaria that allows all stakeholders from the automotive industry to trial, assess and evolve AV related technologies. The Test Bed is a technology neutral offering that complements the wider work being done by the German Government around Mobility 4.0 innovations.

Through the test bed, the Government is focusing on connected driving using car-to-car and car-to-infrastructure communications. Developments at the Test Bed will be accompanied by scientific research, with all advancements being evaluated and documented in an innovation report to be published at regular intervals.[16] This open data approach ensures the industry, government and community are aware of the available technologies, DV performance and potential infrastructure investment requirements.

While there is significant progress being made in Australia across industry, academia and government, the coordination that the Digital Motorway Test Bed provides Germany to progress their understanding of AV technology and infrastructure requirements, is something that Australia can learn from.

Providing a coordinated approach to AV technology development across Australia would avoid duplication and provide awareness around Australia's AV technology progression.

LEGAL AND ETHICAL CONSIDERATIONS

With road rules currently focused on the actions of the driver – the prospect of AVs will require relatively obvious, but complex and fundamental, changes of law.

For example, changes would be needed regarding liability when an accident occurs, and the law will also need to clarify what data can be collected regarding user journeys – and how it can be used.

The move from a human driver to a vehicle operating system also poses a range of complex ethical considerations, such as what 'choices' a vehicle operating system makes in an unavoidable collision scenario. For example, does it solely protect the occupants of that vehicle – or have regard for other vehicles or pedestrians – or both?

The US Department of Transportation's 2016 draft Automated Vehicle Policy, for example, recommends a conscious and transparent process on how ethical issues can be resolved and programmed.

This is uncharted territory, with no precedent to draw on – and ethical or moral considerations are difficult to be practically reflected in laws. To some extent, it is likely that vehicle manufacturers will largely self-regulate in this area although international developments and further real world testing will inform the global and Australian approach over time.[17]

PRIVACY CONSIDERATIONS

Safety, cybersecurity and data privacy remain key concerns, with the broader impact of a transition to AVs yet to be discussed and understood by communities and the public – there is some way to go before the technology is truly accepted. If the broader benefits of AVs are to be captured governments cannot leave public education and acceptance to the "market". There are major roles governments need to play in the regulation and certification of AVs (from a safety perspective both initially and on-going as software updates are introduced) and more generally in how AVs will impact our roads and communities.

As with many new technologies, the effective use of AVs and DVs will rely on the generation, collection and processing of large volumes of data. This data, by its nature, will include information on the travel patterns and whereabouts of individuals, making it an extremely powerful and useful tool across many applications. Privacy concerns in relation to the access and ownership of this data will need to be comprehensively addressed by Australian governments to ensure public confidence in the technology. This issue, along with cybersecurity, will be of key public concern given Australian's attitudes towards privacy of information.

SHORT-TERM ECONOMIC CONSIDERATIONS

In the long term there is a significant opportunity for AVs to generate a positive economic impact, driving new jobs that may have not even been defined yet. Whilst the economics of implementing AVs and eventually DVs onto roads around the world is quite positive – particularly with the decreased economic cost of having fewer road accidents with safer vehicles on the road, or the improved utilisation of existing road space – the short-term economics surrounding the potential for job losses, mostly in the transportation sector, should be accounted for.

Phase 1 – Understanding the opportunity

Infrastructure Australia or Austroads to engage with transport industry partners and road users to benchmark community needs, hesitations and choices regarding AVs – and coordinate national policy on AVs

Infrastructure Australia or Austroads should be given a coordinating role across Federal and state governments. It should be specifically charged with coordinating a volume of work across the tiers of government, to measure and understand the motivations and hesitations of transport market stakeholders and users over time. This should include:

- Regular benchmarking of community and key user group views of the benefits and the risks or costs of enabling AVs;
- Consult with industry partners to produce detailed analysis of emerging preferences in the broader transport network; and
- Significantly increase community involvement and demonstrations during trials to raise awareness and help discuss and resolve issues.

3 Current state of play

This section briefly considers the contemplation of AVs in other countries – and our approaches across Australia's jurisdictions.

3.1 International experience

ASIA

China, Japan and Singapore are globally well advanced in preparing for AVs and DVs entering the road system. For example, Japanese Prime Minister Shinzo Abe committed US$16.3 million per year from 2016, to develop maps and enabling technologies that will permit AVs to enter public roads by 2020.

2016 also saw Singapore launch an on-road trial of its nuTonomy autonomous technology and taxi service[18] – the first private company approved to test AVs on public roads in Singapore.

Meanwhile the Chinese government has committed to legalise AVs by 2021[19] – with sequential five year plans to develop AVs between 2016 and 2030 – and an expectation that fully automated vehicles will enter the market between 2021 and 2025. Recently, Baidu announced Project Apollo, which open sources code and technology capabilities to its partners, to further AV technologies.[20]

However, DVs have not been welcomed by all Asian governments. The Indian Government has stated that they would not allow driverless vehicles onto Indian roads in order to protect jobs in the driving industry.[21] Whilst this decision may be changed in the future, the priorities of the Indian Government are not aligned with incubating driverless technologies in the short term.

EUROPE

Several European countries have allowed for the testing and use of AVs on public roads.

The city of Gothenburg in Sweden has formed a joint venture with Volvo – and is expected to introduce 100 fully autonomous vehicles on the public road network shortly. Sweden's trial will see DVs on the city's highways and main ring road and will see the vehicles 'self park', by navigating alone to find a parking spot after all human passengers have alighted.

In 2016 the town of Milton Keynes in the UK hosted a trial of an AV with further trials planned to take place in Milton Keynes and Coventry in 2017.[22] Helsinki, the capital of Finland, has also played host to driverless buses with a view to have these buses become a viable alternative to personal car ownership in the city.[23]

At a European level, there has already been some contemplation of a coordinated model to allow AVs to enter the road system. The Vienna Convention on Road Traffic has been amended to reflect the transition to AVs – although it still requires a human driver to be present and available to override the AV system at all times. The so-called Declaration of Amsterdam was signed by European transport ministers in April 2016, outlining the European Union's (EU) process of change for AVs.

CASE STUDY: DRIVE SWEDEN

Drive Sweden is a Strategic Innovation Program that combines several government agencies, industry leaders and academia.[24] Drive Sweden's mission is to draw on the combined expertise from the various participants to develop a holistic perspective on automated vehicles; assure world-class projects and competence; and coordinate various national activities and engagements with stakeholders to help meet the challenges faced in the implementation and operation of an AV future.

The collaborative approach behind Drive Sweden carries particular advantages in communicating the benefits of AVs and other automated modes of transport to stakeholders including the community. Projects such as Drive Me aim to build community and consumer confidence around automated and driverless vehicles. These programmes also provide opportunities for Drive Sweden's collaborators to understand human behaviour around automated transport and how that may affect the perception of the benefits and ultimate utilisation of this kind of mobility.

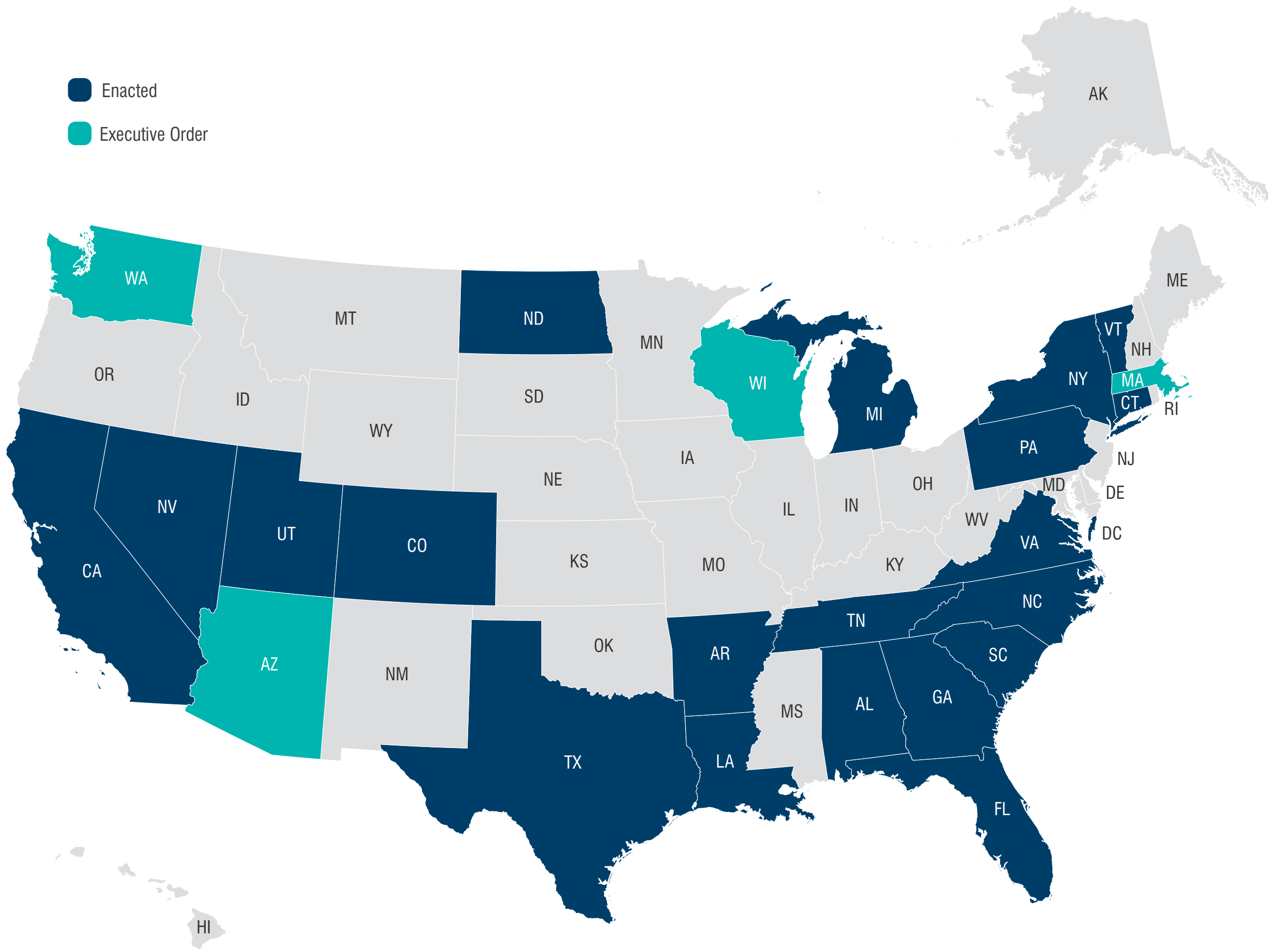
UNITED STATES

As a large Federation, the USA is seeing a 'state by state' approach to AVs and DVs. Since 2012, at least 41 states and the District of Columbia have considered draft legislation related to DVs, and some have enacted enabling laws, shown in Figure 7.[25]

Michigan is particularly advanced, allowing companies to test self-driving cars, on public roads, without a driver or even a steering wheel. These laws permit vehicle manufacturers and technology companies to run autonomous taxi services – and also permits 'test platoons' of self-driving tractor-trailers, as long as human drivers are in each vehicle.

Progressive changes to existing road infrastructure have also begun in California in preparation for DVs.[26] The California Department of Transportation (Caltrans) has started removing the existing Botts' Dots, or circular non-reflective raised road markers, and delineating thicker line lanes in their place. This process is performed as part of routine road maintenance.

Figure 7: States with enacted autonomous vehicle legislation (Source: National Conference of State Legislature 2017)



The US Government's National Highway Traffic Safety Administration issued updated national guidance for the safe development of AVs in September 2016 – which presents 15 best practice principles to guide manufacturers on regulatory and design matters.

3.2 Australia

Australia has seen encouraging signals that political and public service leaders are willing to take a leadership role – with a range of trials, tests or demonstrations of AVs already underway in many states.

These trials usually include technology and vehicle providers, infrastructure owners and state government road agencies and regulators.

Noting that vehicles including AVs ideally operate across state boundaries – but under different state legislative and regulatory frameworks – there is a case for Australian Government involvement and leadership, which offers opportunities to:

- Develop nationally consistent laws and regulations for AVs;
- Refine consistent safety certification and operational requirements; and
- Allow governments to share their efforts and learnings.

IMPLEMENTING REGULATORY CHANGE

The Australian Government has already taken a degree of interest in AVs, including through advisory papers published by the National Transport Commission (NTC). Together, the NTC recommendations argue for a national government process to identifying regulatory or legal barriers and to recommend changes when and as appropriate.

The NTC argues that a flexible regulatory framework is needed, to allow consumer choices regarding AV technologies. The NTC's work cautions against prematurely selecting a 'winning' AV technology; i.e. direct interventions should be avoided save for well-established market failure – but that regulation should provide maximum opportunities for AVs and similar technologies to emerge.

In addition to the work of the NTC, the Council of Australian Government's (COAG) Transport and Infrastructure Council (TIC) have agreed on the following roles for Australian governments in facilitating deployment of emerging technologies:

- **Policy leadership** – providing a clear, nationally coordinated approach across different levels of government, effectively managing the transition between old and new technologies, and raising public awareness and acceptance of new technologies.
- **Enabling** – ensuring that the private sector is able to bring beneficial new technologies to market, including by supporting investment in digital infrastructure and/or data streams.
- **Supportive regulatory environment** – ensuring that community expectations of safety, security and privacy are appropriately considered in new technology deployments, that regulatory barriers are removed in a proactive fashion and that there is certainty about future regulatory requirements.
- **Investment** – investing in research, development and real-world trials that benefit the entire transport network customer base or provide a sound basis for government decision-making.[27]

LEGAL AND REGULATORY BARRIERS

As with many areas, road related legislative and regulatory responsibilities are split between Federal and state governments. The Commonwealth oversees national rules governing vehicle design and certification; while the states and territories set and enforce road rules, as well as vehicle registration and driver licensing.

Logically, the road rules currently only contemplate driver-operated vehicles – meaning that some degree of change will be needed, to allow AVs to become 'street legal'.

According to the NTC, the legal and regulatory issues include:

- The definition of "control" of a vehicle within state road rules;
- Rules governing vehicle trials;
- Delivering safety oversight through vehicle safety and standards; and
- The use of, and access to, data.

Road rules governing vehicle control

Australia's road rules require that a driver must have "proper control" of a vehicle.[28] In a conventional vehicle, this can be clearly understood as a driver seated in the driver's seat controlling the vehicle. The issue of proper control becomes less clear, if vehicle automation sees the role of a human driver reduced or replaced. The NTC identifies more than 700 potential regulatory barriers to AVs[29] with many stemming from established definitions of control.

The NTC recommends that for Level 3 automation, a driver would continue to assume responsibility for vehicle control.[30] That would likely see the human driver retain liability for any adverse incidents, including when the vehicle was operating in Level 3 mode and a failure by the automated system is a contributing factor.

In the US and some other countries, the vehicle manufacturer is set to assume responsibility, in such cases. In a submission made in May 2016 to the NSW Parliament's Joint Standing Committee on Road Safety, the NSW Government noted the willingness of Google, Mercedes-Benz and Volvo to assume full responsibility for incidents caused by their driverless and autonomous vehicles.[31]

Discovering optimal regulatory approaches will require road rules, vehicle standards and other road related regulations to be responsive over time; evolving as AV technologies or other smart technologies continue to disrupt established mobility patterns.

Rules governing vehicle trials

There are a range of trials underway on Australian roads – including those on major public roads such as the Adelaide Southern Expressway and Melbourne's CityLink and EastLink – as well as controlled environment tests, like those along the Swan River in Perth, the Darwin Waterfront Precinct and around Sydney Olympic Park (refer to Table 3 for a detailed list of tests underway). However these trials have been conducted under varying State government legislation in each respective jurisdiction. For example South Australia and NSW have legislated amendments to their Motor Vehicles and Road Transport Acts respectively, while Victoria has adopted the UK code of practice for trialling AVs.

In November 2016, Australia's transport ministers agreed to develop national guidelines for future AV trials on the road network. These guidelines were then released in May 2017 with the implementation of the NTC's *Guidelines for trials of automated vehicles in Australia*.[32]

The guidelines are intended to provide certainty to the AV industry, by providing:

- Nationally consistent conditions for AV trials in Australia;
- Assist state road agencies to provide for trials in their own jurisdiction – as well as allowing AVs to cross jurisdictions;
- Establish minimum standards of safety whilst providing flexibility for industry innovation; and
- Promote community understanding of AV technologies as they develop.

While not legally binding, the Guidelines provide a base to develop the nationally uniform regulations and reforms required for the implementation of AVs.

CASE STUDY: THE AUSTRALIAN DRIVERLESS VEHICLE INITIATIVE

The Australian Driverless Vehicle Initiative (ADVI) is a partnership between government, industry and academic researchers to inform the development of robust national policy, regulation and operational processes with respect to DVs.[33] According to a study of 5,000 Australians commissioned by the ADVI in October 2016 nearly 83 per cent of the respondents would still prefer to drive manually from time to time even if they owned a DV. While 69 per cent would allow a self-driving car to take over when driving becomes "boring or monotonous", 60 per cent of respondents would give up using the steering wheel during heavy traffic. Trust in the technology remains an issue—79 per cent of respondents are worried about cybersecurity threats and 72 per cent are worried about the privacy of their data. Less than a quarter of the respondents say they would use a DV to travel with their children and less than 10 per cent would allow their children to travel on their own.

In addition, the ADVI will advocate for its members the safe introduction of DVs to Australian roads by working with government, industry and academia to best inform the development of a robust national policy, legislation, regulation, facilities and operational processes. There is an understanding of the importance of public education and raising public awareness through live demonstrations, research, collaborating with partners and the media.

These are important efforts, in which the government must also be involved, to bring the community along the journey for the introduction of AVs and DVs into Australia whether for private vehicle use, new public transport services, or road and safety awareness.

The National Transport Commission is well underway with a regulatory roadmap for the introduction of AVs, and contains a series of projects and timeframes including:

- Automated vehicle trial guidelines by May 2017 – released as *Guidelines for automated vehicle trials in Australia*;
- Clarifying control of automated vehicles by November 2017;
- Safety assurance system for automated vehicles by November 2017;
- Driver reforms to support automated vehicles by May 2018;
- Automated vehicle exemption powers and compulsory third party insurance review by 2018; and
- Regulatory access to Cooperative Intelligent Transport Systems (C-ITS) and automated vehicle data by 2018.

Guidance to road agencies

In May 2017 Austroads released the Assessment of Key Road Operator Actions to Support Automated Vehicles report. The purpose of the 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, and the possible infrastructure requirements needed to support the nationally consistent introduction of AVs.

Key issues were captured in three broad categories:

- Physical infrastructure;
- Digital infrastructure; and
- Road operations.

The report notes 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.[34]

Developments by State

Federal

- NTC has released a series of papers discussing legal and regulatory implications and issues for the safe development of AVs.[35]
- iMOVE Cooperative Research Centre (CRC) is being set up in South Australia to open in mid-2017. Focus areas include Intelligent Transport Systems & infrastructure, along with enhanced personal mobility and end-to-end freight solutions.[36]

SA

- In June 2016, SA became the first state to pass legislation for on-road AV trials Under the Motor Vehicles (Trials of Automotive Technologies) Amendment Bill 2016, allowing companies to apply for exemptions to trial vehicles.[37]
- Volvo XC90 and ADVI Adelaide Southern Expressway road demonstration in November 2015.
- Setup the Future Mobility Lab Fund in November 2016 to stimulate developments in AVs. From this, AV shuttle buses are being trialled at Adelaide Airport and Tonsley Innovation Precinct, the latter of which will also see driverless cargo pods trialled. On road trials by Cohda Wireless, a C-ITS company, have also been funded.[38]

WA

- Trial of RAC Intellibus, a fully electric level 4 autonomous shuttle bus.
- Trialling of truck platooning in collaboration with Peleton Technology, ADVI, Telstra and the WA Road Transport Association.[39]

NSW

- Transport for NSW (TfNSW) is investing in an Intelligent Congestion Management Program to deliver a multi-modal network management platform, leveraging emerging technology and predictive analytics to deliver more reliable journeys.[40]
- NSW Centre for Road Safety's Cooperative Intelligent Transport Initiative (CITI) is testing C-ITS in the Illawarra region on 60 trucks, 11 buses and 55 cars. C-ITS allows the vehicles to communicate with other vehicles and infrastructure through V2V and V2I technology, which allows drivers to receive alerts about upcoming hazards.[41]
- Established the Smart Innovation Centre in 2016 to be NSW's hub for collaborative research and development of emerging transport technology, including AVs C-ITS.[42]
- In March 2017 a Parliamentary Joint Standing Committee investigating driverless vehicles and road safety in NSW recommended government commit to adopt the national regulatory framework being developed by NTC.[43]
- TfNSW is developing a CAVs Strategy to maximise the transport and social benefits from the introduction of CAVs.[44]
- A two year trial of an automated Smart Shuttle in Sydney Olympic Park will start in August 2017.[45]
- NSW Government passed the Transport Legislation Amendment (Automated Vehicle Trials and Innovation) Bill 2017 in August 2017, allowing for the trialling of AVs and AV fleets on NSW roads, along with appointing TfNSW to develop policy and facilitate research for the purposes of promoting innovative transport solutions.[46]

ACT

- The ACT Opposition introduced the Road Transport (Safety and Traffic Management) (Autonomous Vehicle Trials) Amendment Bill 2016 but the bill did not pass.[47]
- ACT Government in partnership with local company Seeing Machines is conducting a two year trial of Level 3 automated vehicles to assess how drivers behave when operating the vehicles manually and in partially automated modes.[48]

VIC

- VicRoads has sought input from the public on how trials and tests on public roads could be conducted.
- Victoria has adopted the UK code of practice with a schedule of amendments to tailor them to Victorian laws.
- The Victorian Government in partnership with Transurban is conducting an AV trial on the Monash-CityLink-Tullamarine corridor. The trial will test vehicles currently on the market to understand how autonomous vehicle technology interacts with road infrastructure including overhead lane signals, electronic speed signs and line marking.[49]
- The National Connected Multi-modal Transport (NCMT) Test Bed project was established by the Victorian Government in partnership with University of Melbourne in April 2017 to study connected data (V2X) over a five square-kilometre area of the Melbourne CBD.[50]
- The VicRoads ITS Grants Program is working with industry to undertake a range of trials and assessments to clarify the current and new infrastructure technology needed to optimise mobility and safety benefits from emerging technologies. Projects announced include:[51]
  - A trial of automated vehicles, including their integration with roadside infrastructure, undertaken by the Australian Road Research Board (ARRB), ConnectEast and LaTrobe University.
  - A trial of connected technologies that can give trams priority at signalised intersections, undertaken by YarraTrams, ARRB and LaTrobe University.
  - Development and trial of connected vehicle applications that interface with signalised intersections and managed motorway systems, undertaken by Intelematics
  - A consortium of partners including HMI Technologies, La Trobe University, RACV (Royal Automobile Club of Victoria), ARRB and Keolis Downer will conduct a trial of a driverless shuttle bus in the context of a university's student mobility requirements.
- In October 2016 Bosch developed and began to trial a vehicle with self-driving capabilities as part of the Bosch Highly Automated Driving Vehicle partnership with the Transport Accident Commission (TAC) and VicRoads.

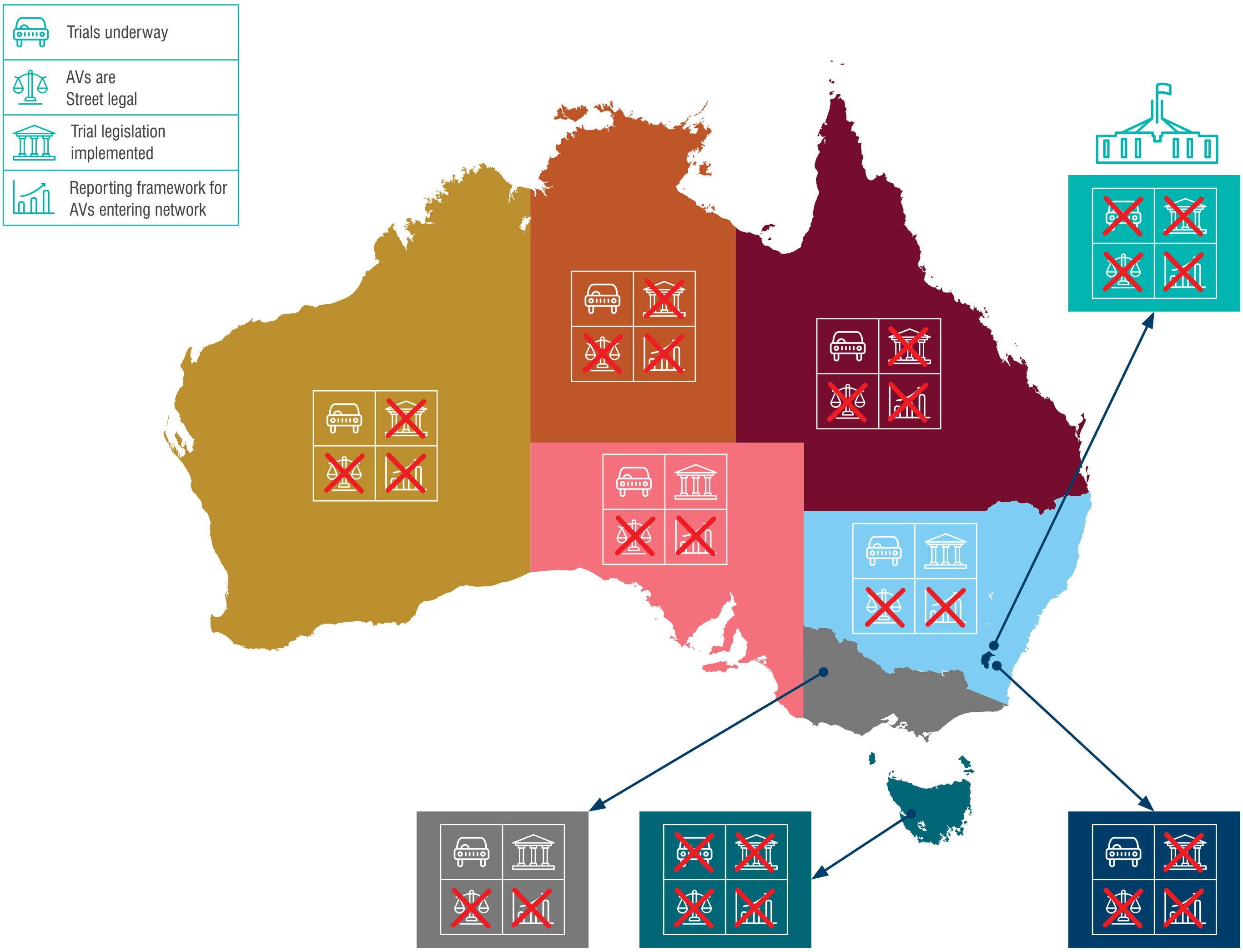
QLD

- The Cooperative and Automated Vehicle Initiative (CAVI) by the Department of Transport and Main Roads is currently under planning. Testing to be undertaken through CAVI will consist of:
  - A C-ITS technology pilot in Ipswich starting in 2019.
  - A Cooperative and Highly Automated Driving (CHAD) pilot, which will test a number of cooperative and automated vehicles.
  - Proof-of-concept tests for new technology applications that address vulnerable road user priorities.[52]

NT

- A discussion paper on regulatory barriers to AVs, identifying the need to define who is in 'control' of the vehicle has been published.[53]
- A successful trial deployment of driverless vehicles to transport people along the Darwin Waterfront Precinct occurred from February 2017 to June 2017 with a second phase of operation currently being explored.[54]

Figure 8: The state of AVs in Australia



Phase 2 – Street legal

The National Transport Commission to develop concurrent Federal and state legislation and regulations to allow AVs and DVs to enter Australian roads

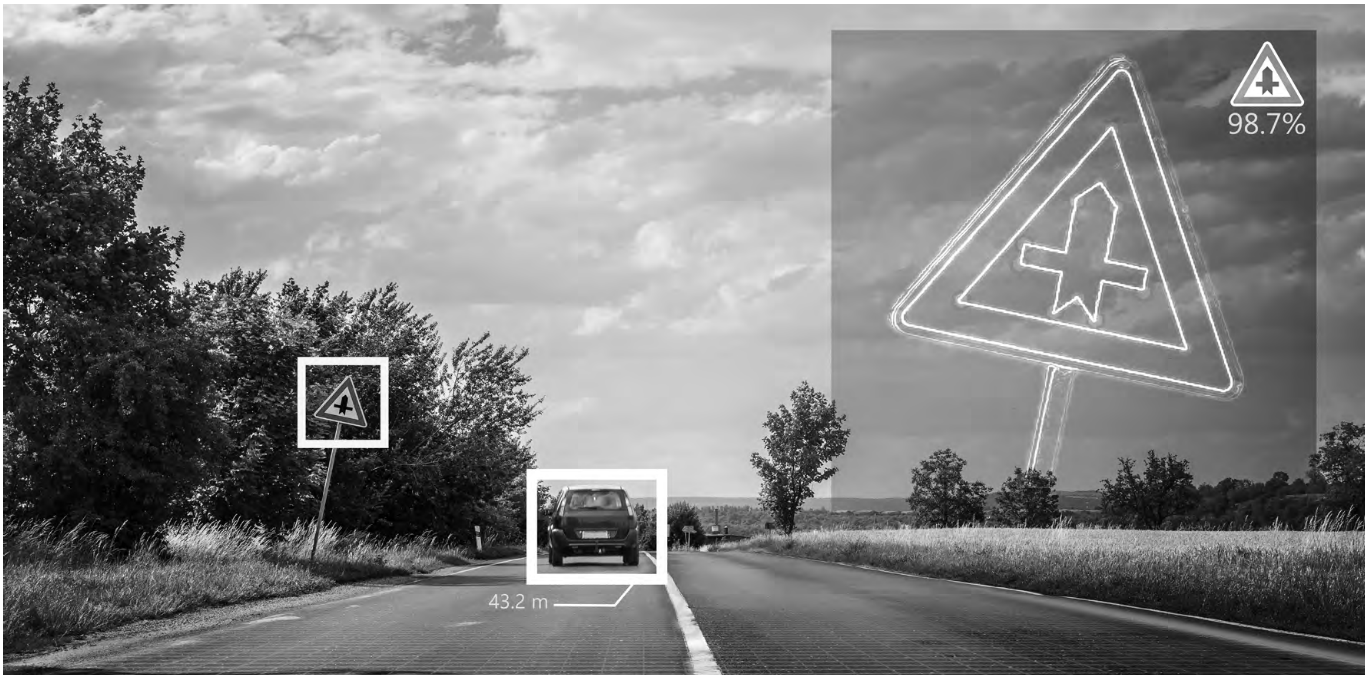
The NTC's commendable work on AVs has already seen the publication of national Guidelines for trials of automated vehicles in Australia; but moving beyond trials will require concurrent legislation and regulations which:

» Define key issues like vehicle 'control' and resolve complex issues of legal liability, in the context of AVs;

» Harmonise design rules and technical specifications to provide connectivity between road and other infrastructure and AVs; and

» Implement consistent national regulatory frameworks for AV safety standards and certification to assist in achieving compliance across Australian jurisdictions.

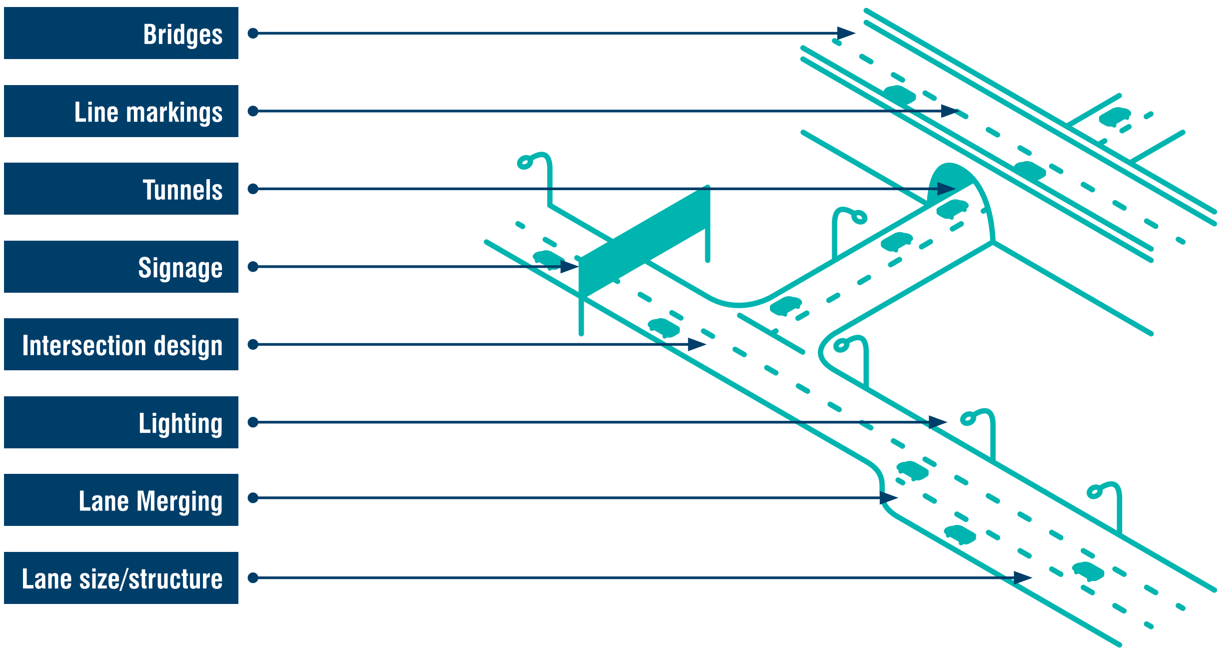
4 Infrastructure considerations



All AVs will interact with their surrounding environment – irrespective of whether they are AOV, CAVs or some other variant yet to emerge. Alongside the regulatory considerations, it is likely that enabling infrastructure of some form will be needed over time, as and when AVs enter the road network.

What that investment is, how much it will cost – and indeed, who will pay for it and how – will ultimately depend on what the community chooses, and how quickly AVs are adopted on the network.

Figure 9: Examples of infrastructure considerations for AVs



4.1 If roads could talk…

Irrespective of which AV technologies enter the road system, there will be a need for an ongoing consideration of the changes needed to allow road infrastructure and related systems to best manage mobility.

While effectively all AVs under development are AOVs, over time, maximising the potential benefit of AVs may well require some or potentially all road network infrastructure and related systems to be able to interact directly with vehicles.

A very likely issue will be how AVs and traditional vehicles interact on the road network. For example, will road lanes or parts of a city be designated solely for AV use – or will AVs and traditional vehicles operate on the same road segments?

If users adopt technologies that allow direct communications between road infrastructure and vehicles, when should that begin to be reflected in the roll out of 'smart' infrastructure?

If a mix of driver-operated vehicles and AVs co-exist, potentially indefinitely, will communication systems embedded in road infrastructure provide information about driver-operated vehicles to surrounding AVs – or will some other system be used?

Table 1 outlines some of the necessary changes to infrastructure, as the move to AVs accelerates, and, the ways in which these changes could be managed.

Table 1: Road-related infrastructure

Possible divergence from traditional requirements	Investment required
Design of structure, surface, size and line markings will change because: » AVs may travel closer together, by platooning and with less margin of error, so less physical road width is required » AVs will be positioned and guided by lane-markings. Unclear or poorly maintained line markings will inhibit vehicle performance » AVs separated from non-AVs will provide greater safety » AVs can travel at faster speeds with accurate in-vehicle processing of road condition, real-time traffic and the environment » AVs may find bridges difficult to navigate due to lack of surrounding structures and environmental cues » Variable lane merge configurations will need to be standardised	**Review of design standards to ensure compatibility with autonomous vehicle development including consideration of:** » Interaction between AVs and normal vehicles and the associated safety implications; » Reconfiguration for dedicated lanes for AVs on freeways and high-volume arterial roads; » "Staging" or "connection" areas to transition between autonomous and controlled operation, and vehicle access, egress and merging; » Development and implementation of standardised road designs; » Revised road maintenance and monitoring programmes to new standards » Intelligent scheduling and tracking of roadworks is needed to ensure vehicles can act on the latest information; » Review bridge design standards to ensure they are compatible with autonomous vehicle development; and » Regulation for road standard compliance for autonomous vehicles will be required, and/or ensure AVs can accommodate non-conforming roads.

As AVs and DVs become a reality on the roads, there will need to be a complementary process that considers whether AV enabling ICT infrastructure like cabling, sensors and transmitters are required in:

» Road design standards for new projects;

» Road maintenance/upgrade programmes for existing corridors; and

» Road maintenance scheduling and implementation practices.

Table 2 discusses some of these options.

Table 2: Communications infrastructure

Element of communications infrastructure	Possible divergence from traditional requirements	Investment required
Sensors	AVs currently cannot distinguish between a person and a rock; all they can see is the presence of an obstacle. Similarly, AVs might read a street sign incorrectly due to sun glare or rain. Increased use of AVs and C-ITS is likely to require substantial installation of sensors. Some will be embedded in road surfaces, while others will be mounted on roadsides or on gantries over lanes.	» Road authorities will need to adjust their ITS solutions (for example, those embedded within traffic lights and lane markings) so they can be easily detected by AVs. » Designation of corridors and precincts that enable vehicles to communicate with infrastructure, including the installation of sensors, transmitters and cabling to a network. » Connectivity to Internet of Things (IoT) devices.
Traffic light and intersection communication	In a fully autonomous world, there will be no need for physical traffic lights and stop signs. Instead, vehicles will wirelessly communicate directly with each other. However, traffic light controls will be required during the transition phase and must be maintained. AVs would have to obey the traffic controls. Technology at a test facility in Michigan uses a roadside unit (RSU), a small grey box attached to the traffic light. The RSU's 'sniffer' knows when a car is approaching the intersection, its speed and other related data. The unit has a minimum range of 300 metres within line of sight and uses signal phase and timing to monitor traffic and connected car signals.[55]	» Governments will need to build and maintain complex, smart intersections to the specifications expected by AV developers. For example, long-range Wi-Fi, cellular data service and mobile satellite communication. Intersection management or intersection control systems must allow a mix of autonomous and controlled vehicles. » Traffic signals will need to communicate directly with autonomous vehicles detection systems (V2I). » Audi is the first manufacturer to include V2I in the Audi A4, Q7 and all-road models. At connected infrastructure, it will provide the driver with the remaining time until the traffic signal changes green.[56]
Live traffic data	Interaction with the freeway control system will give vehicles information about what the road management systems plan to do, as well as real time road and traffic conditions to allow effective journey planning.	» Road Side Units (RSUs) will be needed for vehicle-to-infrastructure communication. » Road mapping and databases may need to be maintained to a higher standard.
Signage	Digital and static road signs will be needed, with the signs and markings conspicuous and legible to autonomous vehicle sensors and human eyes.	» Signage will need to be compatible with autonomous vehicle development and requirements.
Incident and roadwork communication	Common standards for traffic and incident data will be needed as vehicles will start to inform the road management systems of their intentions and make requests.	» Standardise and format all traffic and incident information for digital transmission.
Pedestrian and cyclist interaction	AVs will depend on effective communication with road infrastructure and other vehicles. However, this will not allow for interaction with other road users such as pedestrians and cyclists.	» Make provisions for vehicle to pedestrian/cyclist communication, possibly via mobile device. » Investigate how to facilitate interaction between vehicles and non-connected road users.

Element of communications infrastructure	Possible divergence from traditional requirements	Investment required
Internet connectivity	AVs rely on GPS and the internet (including cloud applications) for accurate positioning and navigation data, and up-to-date situational data. Google's self-driving car gathers almost 1 GB of data per second. This indicates a need for significant technological enhancements, including short-range systems for vehicle to vehicle communications and long range systems for accessing maps, software upgrades, road condition reports and emergency messages.	» Roll out of 5G network. » Enhanced connectivity. » Sharing of data between road management jurisdictions, vehicle manufacturers and technology providers. » Reliable backup systems.
Data storage	In a world of AVs, the car itself essentially becomes a computer, complete with the ability to send, receive, store and use a vast amount of telematics information. Google's driverless car uses pre-built navigation maps that indicate static infrastructure such as telephone poles, pedestrian crossings and traffic lights. This enables the software to quickly identify moving objects such as pedestrians and cyclists. This data will need to be stored and retrieved on demand through a wireless network.	» Significant enhancements to wireless networks will be needed to support short-range systems for V2V communications and long-range systems that are necessary to access maps, software upgrades, road condition reports and emergency messages. » Enhanced data storage capabilities. » Interaction between information 'owners' and information 'storers'. » Reliable backup systems.

Austroads has already begun discussing the harmonising of data collection across government.[57] Through their proposed implementation of a road asset data standard, Austroads aims to streamline the metrics by which road characteristics and features are measured by. By coupling this system with communication infrastructure improvements, there is an opportunity to both future-proof road infrastructure for AVs and provide a consistent basis for data to be used for asset management purposes.

Phase 3 – Data collection

Government road agencies to begin reporting on the number, type and de-identified location of AVs entering the vehicle fleet

AVs present a new type of vehicle, one that could change the way road agencies manage and operate their infrastructure. Multiple types of data from AVs can be captured and utilised in real time – managing individual user preferences and planning for future infrastructure requirements. To understand the penetration of AVs and maximise the potential of their data to inform decision making, it is recommended that governments, coordinated through Austroads:

- Begin recording and annually reporting the number, type, usage and safety performance of AVs over time across each state, collating this information into a national database; and
- Implement standardised data recording and communication methods to reinforce cyber resilience.

4.2 Other potential changes

AVs could also substantially change other aspects of city planning, mobility and existing infrastructure.

PARKING AREAS

It is quite conceivable that DVs could fundamentally change parking arrangements. This might see on-street parking removed or reduced; and could also see parking stations and public transport 'park and ride' reduce in importance – with DVs dropping off passengers and continuing to operate on the road network or moving away to less congested areas, not taking up parking spaces or parking in curb side lanes.

DROP-OFF ZONES

If transport patterns change along the above lines, then complementary changes to drop off zones could be required. Examples might include accessible, high-turnover passenger set down and pick up areas in areas of high demand.

TRANSPORT INTERCHANGE

Technology is already shifting transport demand, including through an emerging shift from direct vehicle ownership, to consuming transport through MaaS.

Ride sharing apps like Uber, Go Catch and Lyft serve to directly connect transport demand with suppliers, increasing the reliability and predictability over radio taxi networks while also reducing the cost.

Already, there is some evidence that ride sharing is growing rapidly as a commuter choice to connect between mass transit modes and the home, alleviating the need to park and ride.

Forward looking scenarios see the prospect of AVs allowing 'Public transport as a Service' – with public transport AVs providing much more customised public transport journeys 'as and when' required – rather than on a timetabled basis and offering a 'door to door' journey.

AN INFLECTION POINT

The introduction of AVs and DVs coupled with more fuel-efficient vehicles powered by electricity, provides an "inflection point" or disruption opportunity for governments to consider a move to more sustainable models to raise revenue to fund infrastructure. Whilst this paper does not offer alternative models, the alignment of technologies in automation and electrically powered vehicles represents a step change in transportation and mobility that governments can leverage to shift the infrastructure funding paradigm.

Phase 4 – Reflecting choices

Transport planning to routinely assess AV uptake in long-term infrastructure, land use and wider strategic planning

Road and supporting communications infrastructure may, over time, require investment by governments in response to AV uptake. Utilising the results of the data capture recommendations in Phase 3, it is recommended that to address infrastructure challenges, governments, potentially in the form of an annual report prepared by Austroads:

» Identify a programme of potential investments to upgrade infrastructure, including communications and access to data; and

» Identify possible adjustments to existing regulations or legislation to facilitate infrastructure improvements.

5 Conclusion

A world with safer roads, near zero fatalities and a more efficient road network – all achieved with fully optimised automated vehicles – could remain a distant vision if governments fail to act proactively in a coordinated and collaborative manner.

The uptake of vehicles required to act as a catalyst for real change to the design of Australian roads is potentially decades away and change from human-controlled to computer-controlled vehicles is unlikely to be a defined step change; rather, an extended period of transition can be expected.

In addressing the transition, this paper recommends that government take the middle road – coordinating community and industry engagement and monitoring AV penetration into the road network – to ensure that transport policy and investment decisions neither significantly lead, nor significantly lag, community choices. Specifically, government should take action on multiple fronts through a four phase national process:

- **Phase 1:** Infrastructure Australia or Austroads to engage with transport industry partners and road users to benchmark community needs, hesitations and choices regarding AVs – and coordinate national policy on AVs;
- **Phase 2:** The National Transport Commission to develop concurrent Federal and state legislation and regulations to allow AVs and DVs to enter Australian roads;
- **Phase 3:** Government road agencies (coordinated through Austroads) to begin reporting on the number, type and de-identified location of AVs entering the vehicle fleet; and
- **Phase 4:** Transport planning to routinely assess AV uptake in long-term infrastructure, land use and wider strategic planning.

The four phases highlight an approach that would assist governments in breaking down the otherwise complex topic of AVs and their synchronisation with the broader transport landscape. The challenges posed to governments range from the need to adjust existing legislation and regulation to allow AVs onto our roads to the significant technical and fiscal infrastructure challenge to the need for community buy-in and industry consultation.

The paper acknowledges that progress has already been made in a number of these areas. Guidance on trials from the National Transport Commission and the positive reception to various AV trials around the country illustrate the steps governments have taken to start and continue the conversation.

It is critical that governments and their respective agencies continue to provide leadership in areas of policy development, regulation, legislation and stakeholder engagement. There are opportunities for national agencies, such as Infrastructure Australia, the National Transport Commission and Austroads, to coordinate actions and provide overarching guidance. This may be especially useful in the provision and supervision of a national database to analyse the penetration of AVs in the broader vehicle market.

Lessons can also be drawn from the experience of various other countries. Collaboration across government, industry and universities can be a source of truth and build the community's trust in AV technology and its application. The outcomes of AV trials abroad can advise the requisite local regulations to encourage further innovation.

Automated and driverless vehicles offer the potential for a once in a century change to the way we travel in our urban environments and how we fund our infrastructure. They offer tangible travel benefits ranging from improved road safety, improved asset utilisation, improved journey times, and could change the way we view travel time.

By carefully considering the various scenarios of where an automated vehicle future could take us through proactive and considered leadership, governments can emerge with a new best practice strategy to turn potentially disruptive technologies into evolutionary ones.

Abbreviations

ADVI — Australian Driverless Vehicle Initiative

AOV — Autonomous Only Vehicle

ARRB — Australian Road Research Board

ATO — Automatic train operation

AV — Autonomous Vehicle

CAV — Connected Autonomous Vehicle

CPU — Central Processing Unit

DARPA — Defence Advanced Research Projects Agency

DV — Driverless Vehicle

GPS — Global Positioning System

IATA – International Air Transport Association

IoT — Internet of Things

OBU — On-board unit

LIDAR — Light detection and ranging sensor

MaaS — Mobility-as-a-Service

NTC — National Transport Commission

RSU — Roadside unit

SCH — Service Channel

V2D — Vehicle-to-device

V2G — Vehicle-to-grid

V2H — Vehicle-to-home

V2I — Vehicle-to-infrastructure

V2P — Vehicle-to-pedestrian

V2V — Vehicle-to-vehicle

V2X — Vehicle to another component

WAVE — Wireless Access in Vehicular Environment

VMS — Variable message sign

RFID — Radio-frequency identification

Appendix 1 – Levels of automation

Five key stages in the evolution of automated vehicles:[58]

Level 1 Driver Assistance	Vehicles perform specific operations such as lane guidance, cruise control and parallel parking while the driver keeps full control. The automated functions are purely supportive and the driver is the final decision maker. Full driving skills are required.
Level 2 Partial Automation	Vehicles perform specific operations such as adaptive cruise control and lane centring. While this gives the driver an opportunity to cede some control, they are still expected to remain alert and ready to take control at any moment if needed. As such, the driver is still the final decision maker although they are required to act in fewer situations. Full driving skills are still required.
Level 3 Conditional Automation	Vehicles perform all critical safety functions, allowing drivers to redirect attention completely as they will be notified in advance if intervention is required. The driver only needs to act in a limited number of "critical" situations. However, in these situations, driving skills are still required.
Level 4 High Automation	Vehicles perform all the driving-related operations without any input from the driver, who essentially becomes a passenger.
Level 5 Full Automation	The steering wheel and driver's seat are no longer required – A Driverless Vehicle (DV)

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