Connected and Automated Vehicles: Literature Review

Final Report (Part 1)

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About PATREC

The Planning and Transport Research Centre (PATREC) is a collaboration between the Government of Western Australia and local universities, constituted to conduct collaborative, applied research and teaching in support of policy in the connected spaces of transport and land use planning. The collaborating parties are: The University of Western Australia, Curtin University, Edith Cowan University, Department of Transport, Main Roads Western Australia, Western Australian Planning Commission and the Western Australian Local Government Association.

Executive Summary

Long term transport infrastructure planning and policy decisions are increasingly made in an environment that is volatile, uncertain, complex and ambiguous as technology development, consumer demand and transport service business models change. It is expected that there will be further changes on the horizon due to electric connected and automated vehicles (CAV). CAV refers to a range of vehicles including electric vehicles with some level of automation, to a high level of automation (self-driving) and equipped with interoperable cooperative ITS systems and cloud connectivity (that may be used for services such as live traffic information, automated crash notification, concierge and booking services).

Considerable work has been undertaken overseas and in Australia so far in regard to monitoring CAV technological developments and trials, and identifying and developing legislation and regulatory requirements, governance frameworks, harmonisation of certain parameters such as standard regulations across various states,in order to facilitate and be ready for the uptake of CAV.

However, little or no work has been done in regard to how the uptake of CAV may impact the practice of asset management. This project explores how CAV may influence the business of asset management, and what opportunities, if any, CAV can facilitate. More specifically, the impact of CAV on asset management is assessed in regard to:

- Two CAV uptake scenarios: less than 100% uptake and 100% uptake.
- Six key asset management areas: policy, strategy, planning, legislation and statutory requirements, customer and stakeholders expectations and risk management.

Asset management as applied to the roads sector represents “a systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organised and flexible approach to making the decisions necessary to achieve the public’s expectations”[151].

The Final Report of the study includes three parts as follows:

- Part 1 is a comprehensive literature review of the relevant CAV developments overseas and in Australia and a summary of learnings for asset management.
- Part 2 builds upon the learnings from Part 1 and provides an assessment model for the impact of CAV uptake on the six key asset management areas, for the two uptake scenarios, partial and 100% uptake, and the findings from the assessment.
- Part 3 summarises asset management considerations for the six areas of focus identified through the literature review and the impact assessment and provides recommendations for asset managers.

This is Part 1 of the Final Report.

Some of the main opportunities for asset management resulting from the literature review include:

- CAV enhanced mobility in the realm of public transportation, intermodal integration, freight supply chain first and last-mile can improve efficiency and is a feature of more mature systems.

- CAV can facilitate optimisation of parking planning, including the sharing of limited parking space for delivery vehicles in an urban environment.

- A new era in travel demand management utilising smart infrastructure interface/connectivity with CAV and potential access to a real-time data at very large scales is possible.

- Big data gets bigger with the uptake of CAV and potentially can create not only opportunities but also issues in regard to protection of data privacy, as well as cyber attacks on vehicle-to vehicle and vehicle to infrastructure communication.

- Modifying maintenance activities by utilising CAV for some maintenance tasks, such as litter and street sweeping during the night, can be undertaken potentially with reduced night staff and without contributing to day time traffic congestion. For public transport agencies, there is the potential to replace the vehicle fleet with CAV which in turn will result in new type of vehicles and inventory to manage and perhaps the need to develop new skills particularly in regard to the electric and electronic components of the cars.

- Enhanced safety features will feature more prominently on the vehicle portion of the Road Safety System, reducing road trauma.

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1. Introduction

Long term transport infrastructure planning and policy decisions are increasingly made in an environment that is volatile, uncertain, complex and ambiguous as technology development, consumer demand and transport service business models change, and it is expected that there will be further changes on the horizon due to electric connected and automated vehicles (CAV). Electric automated and connected vehicles refer to a range of vehicles including electric vehicles with some level of automation, to a high level of automation (self-driving) and equipped with interoperable cooperative ITS systems and cloud connectivity that may be used for services such as live traffic information, automated crash notification, concierge and booking services.

This project explores how the uptake of CAV may influence the business of asset management, and what opportunities, if any, CAV can facilitate regarding asset management practice. Asset management as applied to the roads sector represents "a systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organised and flexible approach to making the decisions necessary to achieve the public's expectations"[151].

The impact of CAV on asset management is assessed in regard to six key asset management areas.

- Policy
- Strategy
- Planning
- Legislation and Statutory Requirements
- Customer and Stakeholder Expectations
- Risk Management.

Two CAV uptake scenarios are considered: 1. less than 100% uptake and 2. 100% uptake.

The Final Report of the study includes three parts as follows:

- Part 1 is a comprehensive literature review of the relevant CAV developments overseas and in Australia and a summary of learnings.

- Part 2 builds upon the learnings from Part 1 and provides an assessment model and a methodology/Delphi technique to assess the specific impact on the six key asset management areas, for the two uptake scenarios.

- Part 3 summarises asset management considerations for the six areas of focus identified through the literature review and the impact assessment and provides recommendations for asset managers.

This is Part 1 of the Final Report of the project. Its purpose is to identify the status of CAV technology in Australia and highlights best practice from international perspectives. The report includes:

- Brief history of CAV
- CAV impact framework
- Level of automation and uptake timeline
- Australian developments
- State of play overseas, current and future
- Learnings and recommendations for asset managers in regard to policy, strategy, planning, customer/stakeholder expectations, risk management and legislation and statutory requirements.

2. History of CAV – a timeline

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 1, below, shows that history of the evolution of CAVs[150].

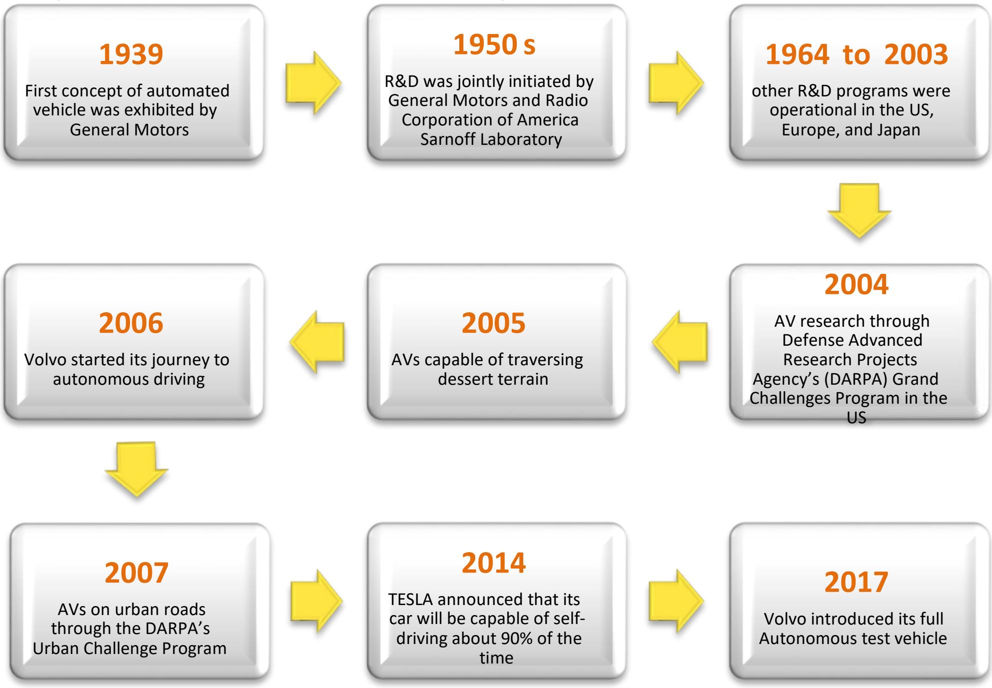

Figure 1: History of CAVs[150]

2.1. Historical context of CAVs in Australia

Many of the early rail systems in Australia were built to link colonies prior to the Federation of States in 1901, so planners had given little consideration to connecting up the rail systems. This simple oversight led to Australia having around 22 different gauges across the country. In 1895, the American writer Mark Twain had to leave his carriage at 5.00am and change trains to cross the border from the state of Victoria to New South Wales. Twain wrote of the situation: 'Think of the paralysis of intellect that gave that idea birth'. Two decades later in 1917 the situation wasn't much improved in passenger terms, for example, an east–west trip from Brisbane to Perth would involve changing trains six times. This inconsistency stymied both travel and transport efficiency, negatively impacting the economies of the individual state and territories as well as Australia as a whole. Further, the issue has never been entirely resolved. While Australian capital cities are now linked by a uniform gauge, three different gauges are still in existence today. The significance of this historical anomaly looms large in the context of CAV – inconsistency across borders impedes a coherent approach and should be avoided.

3. CAV Impact Framework: Big Picture

Kane and Whitehead (2017) developed a future mobility disruption framework that considers the uptake of three major disruptors: autonomous vehicles, vehicle electrification and a shift towards the sharing economy, in the context of increasing urban density. The basis for the framework is to understand the interplay of the three urban transport disruptions that planners and policymakers will need to address with the increasing market (and policy) demand for increasing urban density.

The model identifies five scenarios resulting from the interaction of the four elements and concludes the optimal scenario is when all elements are at play in synergy. Under the optimal scenario, planners would aim to achieve several transport outcomes, including meeting the demand for increased accessibility and number of transport trips within the urban context of increased density. This situation would require a “reduced need for unnecessary single person road trips and improved efficiency, and use of public transport systems. The benefit of CAVs would be a safer and more efficient use of road space, while largely negating the need for public and private parking. CAVs and the sharing economy are likely to significantly reduce private vehicle ownership. A shift towards a sharing economy, in a denser urban form, would also increase the mobility efficiency and options for individuals, providing greater levels of walkability improving health and the economy. Finally, the overall result of a CAV fleet would be significantly reduced transports costs for individuals. This approach would free up household and business income to be spent elsewhere in the economy. While these vehicles would become a competitor to traditional public transport, under a denser urban form, policymakers could redesign public transport systems to focus on mass, rapid trunk services. CAVs could instead provide feeder services to the trunk lines, as opposed to driving the full route from origin to destination. In part this strategy would likely be dependent on the introduction of road and/or public transport pricing schemes that encouraged such behaviour (i.e., schemes would need to be set to overcome the ultimate convenience of an CAV over public transport) (International Transport Forum 2015)”(Kane and Whitehead 2017).

A shift away from private vehicle ownership, combined with the advent of electric drivetrains and autonomous vehicles, would ultimately lead to a reduction in fuel taxes, registration fees, stamp duty, licencing fees,and potentially also public transport fares. As such, policy-makers and planners need to not only actively manage and support these four transformations, but must also start to prepare for a shift in thinking towards new revenue raising mobility pricing models.

Without careful consideration of the impacts of each of these mobility-related transformations, and if all four are not adequately managed, the likely outcome can be a sub-optimal urban mobility system; possibly with negative characteristics worse than those present in existing transport systems.

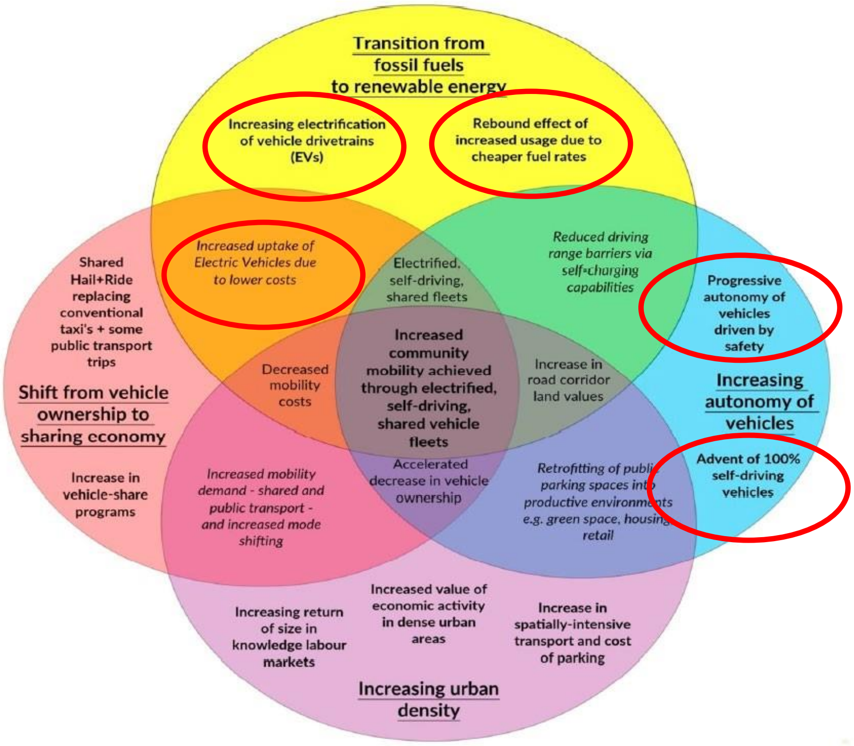

Figure 2: Future Mobility Disruption Framework [149]

4. Determining levels of automation

CAV is a term used for vehicles that involve various degrees of automation of the primary driving controls (i.e., steering, acceleration, braking[39]). There is a significant trend towards higher levels of automation in new vehicles as well as connectivity achieved through interoperable cooperative ITS systems and cloud connectivity. 'Partially' CAV that can drive themselves in limited scenarios are already on the roads. However, 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)[39]. Some automakers, including GM and Ford, proposed automation would occur in a progression of steps featuring increasing autonomy. Other automakers, and the technology companies such as Google, viewed automation at first would proceed in steps and then take a massive leap[29].

CAVs are required to adapt to the driving environment to complete a range of tasks from simple through to very complex, relying on internal sensors and systems such as LIDAR, and cameras; and 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.

Table 1 describes the different levels of automation and the human and car roles. The most advanced partially autonomous vehicles on the road in 2018 from Mercedes

Benz, Tesla and Toyota are level 2 and level 3 AVs. Japan and South Korea automakers are set to sell level AVs in 2020, while Kia, Honda, BMW and Mercedes Benz are expected to sell level 3 AVs by 2021[41]. Waymo is aiming at level 4 and level 5 AVs in near future[25].

4.1. The timescale of CAV introduction

CAVs may take some years to emerge and become widely adopted for a range of uses. Australian and global estimates of the adoption of fully CAV range from 30 per cent to 100 per cent of total vehicles by 2036. How the community uses the technology is difficult to predict and will be influenced by many factors, such as personal attitudes, costs and security concerns.

The National Transport Commission estimates that there could be up to 1.7 million conditionally and highly automated vehicles (levels 3 and 4) in the Australian fleet by 2020 (i.e., 9 per cent of total fleet), and almost 9.5 million by 2030 (i.e., 42 per cent of total fleet) [71]. Table 2 highlights the uptake of CAVs by the vehicle manufacturer in the future. Specifically, Figure 3 discusses the predication of uptake of fully automated vehicles by Telstra, Fehr and Peers, Morgan Stanley and IEEE. There is a forecast that by 2056, vehicles will be largely connected and autonomous vehicles (CAVs). Level 5 CAVs in which no human is needed, and cars do not even have a steering wheel or accelerator could be here as early as 2025[70].

In response to the coronavirus pandemic, autonomous vehicles are more likely to prove their potential amidst a human-free environment[53]. Chinese self-driving delivery company called Neolix has been deploying fleets of its self-driving vans to transport medical supplies, and food to areas of the country hit hardest by COVID-19, including the epidemic's epicentre in Wuhan[87]. Nuro, a Californian company, develops delivery vehicles similar to the ones that Neolix offers. The company has secured the first federal safety approval to operate self-driving vehicles that do not meet federal safety standards which apply to other cars and trucks that are driven by humans[53]. CAV makers have been trying to make a case for the acceptance and implementation of level 4 and level 5 CAVs, and this global pandemic provides a more compelling reason to support CAVs.

CAV Level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhance by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	The driving mode-specific execution by one or more driver assistance system of both steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Full Automation	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

Table 1: SAE automated driving taxonomy[15]

Timeline	2010>	2015>	2020>	2025>	2030>
Level 1-Driver Assistance	< Park Steering Assist-low Speed				
	< Adaptive Cruise Control (ACC)-high-mid speed				
	Lan Keep Assist (LKA)-active lane centring, high mid speed				
Level 2-Partial Automation	Low speed-Auto Parking Assist				
	High-to-mid speed-Highway Driving Assist (eg ACC+ LKA+ AEB)				
	Mid-to-low speed-Traffic Jam Assist (eg ACC + LKA +AEB + Stop&Go)				
Level 3-Conditional Automation		Low speed-Auto Valet Parking			
		High-mid speed, low-mid complex roads-Auto Hwy Chauffeur			
			Truck Platooning-only on specific roads		
			Hi-mid-low speed, highly complex urban and rural roads		
Level 4-High Automation			Low speed-Auto Parking Pilot		
				L4 on specific roads	
			Driverless (always in auto pilot), but road access limited		
Level 5-Full Automation					Driverless, all roads

Table 2: Developed by Austroads following discussions with vehicle manufacturers and wider industry[39]

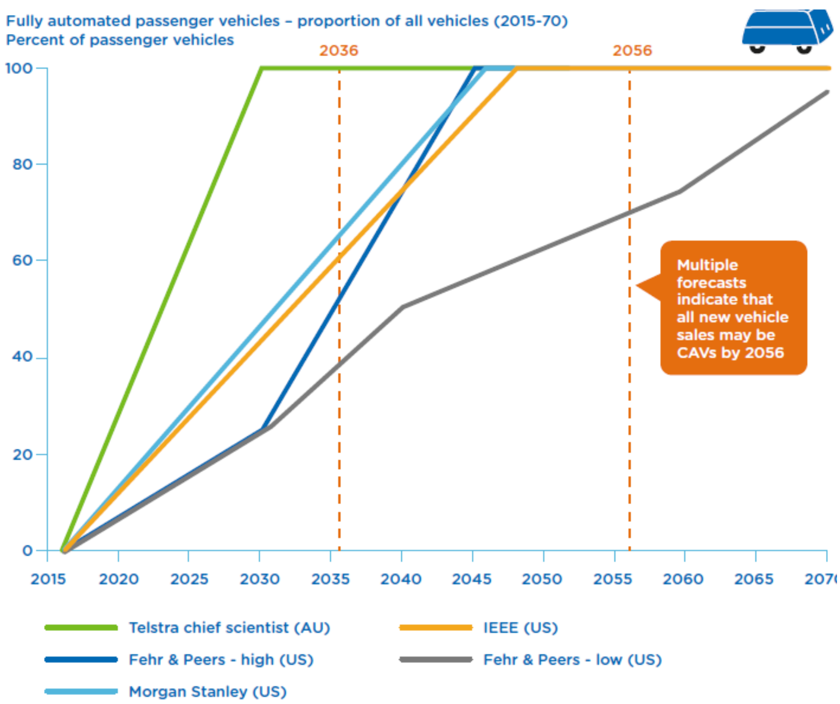

Figure 3: Predictions for the uptake of fully automated vehicles by major companies[71]

The timeline in Table 3 sets out a likely deployment timeline for increased automation. This timeline is a forecast and does not indicate the intent of the Government of Western Australia[86]. In the US, Jacobs has developed a potential 30-year CAV implementation, assuming that CAV technology continues to develop at the same pace and without barriers such as legislation issues[43]. The Institution of Electrical and Electronics Engineers (IEEE) suggests that by 2025, 60 per cent of cars on the road will be internet-connected. The increased dependence on CAVs will increase consumers' trust and reliance on automated systems. IEEE predicts that 75 per cent of cars on the road will be AVs by 2040[40].

5-10 years (2020-2025) Early days for self-driving	10-20 years (2025-2035) Transition	20+ years (2035+) Mobility transformed
• Continued growth in Level 1-2 automation • Self-driving limited to low complexity environment • Moderate level of self-driving (Level 2-3) • First Level 4 vehicles may become commercially available, but are expensive	• Less restriction on self-driving environments • High level of self-driving (Levels 2-3) • Level 4 vehicles become more common and more affordable	• Large, connected AV networks allow multiple mobility scenarios • On demand mobility and fleet services

Table 3: Forecast timeline for increased automation

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 CAVs.

5. Context of CAVs in Australia

Some new vehicles with limited automated features such as lane-keep assist and park-assist are already operating on the roads, and it is expected that automated features will continue to be rolled out incrementally. There are differing views about when developments in automotive technology will enable more sophisticated CAV to be ready for use on Australian roads. There is further uncertainty about when these vehicles will be commercially available in Australia, and when they may represent a significant part of the vehicle fleet.

Australia has mandated some Level-1 automated functions, with Australian Design Rule (ADR) 31/02 requiring Electronic Stability Control (ESC) on all light vehicles from 2011. Similarly, government road safety groups have commenced an advocacy campaign to encourage the use of Auto Emergency Braking (AEB). Level-2 combined function automation is starting to become more common in new vehicles. As an example, the Honda CR-V includes the combination of Adaptive Cruise Control (ACC), Collision Mitigation & Breaking System (CMBS) and Lane Keep Assist System (LKAS) in a model available 'on-road' for less than $50,000. Many other new vehicles lack the lane-keeping assistance required to complement ACC for Level-2 operation. It is unclear whether this is due to the quality of line marking on Australian roads or manufacturer responses to (perceived) buyer preferences. Some partial automation is available in Australian-built cars, including parking assistance on even the base models of new Holden Commodores.

5.1. State-based scenarios of CAV technologies

Australia is currently at the cusp of a transport revolution. Table 4 highlights the current practices in different states in Australia. The table discusses some examples of CAV development in Western Australia, Queensland, New South Wales, Victoria, South Australia, Tasmania, Australian Capital Territory and Northern Territory based on what is happening currently (NOW), in the immediate future (NEAR) and in long term future (NEXT).

	NOW	NEAR	NEXT
Western Australia	Curtin University is trialling a Level 4 Navya Arma Bus called Kip. Royal Automobile Club WA has been trailing an autonomous bus in South Perth and Busselton[58] Rio Tinto added a new facet to its automated operation in 2019 with the deployment of its AutoHaul system, which brought autonomous trains to the Pilbara project[38]	CAV to include machine learning to predict outcomes on the road network, based on data from previous days. Another example is a project with the UWA extracting data from video footage[54] Western Australia's RAC announced a significant expansion of its automated vehicle program with the purchase of a $490,000 NAVYA Intellicar prototype, with designs for this to become a fleet to be trialled on public roads in the first half of this year, an expansion of its testing of the Intellibus[100]	Autonomous transport research and development centre to be developed in Karratha, in the resource-rich Pilbara region of Western Australia, aimed at accelerating the rollout of driverless vehicles in urban environments[101]
Queensland	Renault ZOE2 completed the trip at level four on the automation scale, where the car can travel fully autonomously, but a human driver can still	Queensland Government's CAVI (Cooperative and Automated Vehicle Initiative) is comprised of three pilot projects—the connected vehicle pilot, connected and automated vehicle	Modelling commissioned by the Queensland Department of Transport and Main Roads suggests that saturation of highly CAV in the Australian fleet could occur roughly between 2050 and 2060[21]

	take control if needed[45]	pilot, and the vulnerable road user pilot. The connected vehicle pilot will be conducted in Ipswich; however, the location of the other two pilots has not been finalised at this time—these are likely to reach across a number of jurisdictions[24]	
New South Wales	Newcastle debuts driverless CBD to beach shuttle for tourists[47]. Easy Mile EZ10 as CAV are launched by Transport NSW[90]	Sydney is also planning on using autonomous vehicle technology on the new metro line between Sydney's north-west and Chatswood[81.] Trial of wireless communications between heavy vehicles and roadside infrastructure for safety and vehicle priority applications[21] . NSW legislation takes a more stringent approach to in-vehicle supervision of trials[55]	Sydney's driverless shuttle bus service at Olympic Park is set to become the first in the country to autonomously interact with live traffic conditions[46]
Victoria	Bosch Australia began trials of its Tesla-built autonomous vehicle on the Mornington Peninsula in November 2019[34]	Tesla is set to sell vehicles with the necessary hardware to enable Level 4/5 autonomy in 2021[9] . On-road testing will get underway in the Australian-first trial of connected vehicle technology[90]	Projected that Victoria has 100 per cent electronic vehicles in the state in 2046 and found that could require an additional 50 per cent more energy than is already planned for in that timeframe[78]
South Australia	Developed by SAGE Automation, the mobile Matilda transport hub aims to work with any driverless vehicles while providing users with an interactive experience to aid in their commute[28]	Airspeeder weighs about 550 pounds, uses a battery pack that can be swapped out during the race. The packs are expected to last for about 15 minutes. Four 32-horsepower electric motors propel the cars to a top speed of about 125 miles per hour	The South Australian Government has taken a strong leadership approach to position the state at the forefront of innovative transport technologies. The Future Mobility Lab has focused on projects that demonstrate, develop, or contribute to the applied research of Future Mobility technologies and provide real benefits

		Testing will now shift to South Australia in 2020[5]	to our communities. Building on the government's introduction of legislation to allow on-road trials of driverless cars, the Lab aims to stimulate developments in connected and autonomous vehicles (CAVs). The Lab is eager to unlock and attract industry investment to South Australia and further promote our reputation as one of the most welcoming environments for testing connected and autonomous vehicle technologies[23]
Tasmania	The state's first driverless electric bus trial conducted in December 2019 in Hobart. The driverless electric bus has cameras to detect lane markings, signs and traffic lights[44]	The Explorer model Autonomous Underwater Vehicle (AUV), was developed under Theme 4, Marine Technology and Polar Environments, of the Australian Research Council (ARC) Antarctic Gateway Partnership. The AUV is a vital research tool that will be deployed in the Antarctic by Australian and international researchers, including from the ARC Antarctic Gateway partners the University of Tasmania, CSIRO and the Australian Antarctic Division (AAD)[94]	Towards Zero – Tasmanian Road Safety Strategy 2017-2026 (Towards Zero Strategy), which is based on the best-practice Safe System approach to road safety. Governments to enact legislative change and introduce regulatory regimes to enable these increasingly autonomous (and driverless) vehicles on our roads[91]
Australian Capital Territory	A new intelligent transport systems vehicle trial has begun in the Australian Capital Territory, with a particular focus on the reaction of the driver as they re-	Government is supporting a two-year trial that will include testing driver monitoring systems on 40 residents driving semi-CAV for up to two weeks at a time[2]	ACT transport minister Chris Steel projected that zero-emissions vehicles are a viable alternative for Canberra's public transport network going forward in future[57]

	assume control of the vehicle from an automated driving mode. And it is looking for ACT drivers as to help carry out the testing[30]		
Northern Territory	The Northern Territory Government has announced a six-month trial of an automated shuttle bus at the Darwin Waterfront during 2017[21]	The electric bus on the Darwin Waterfront Precinct in 2018 in its second stage, the vehicle is moving people to and from restaurants and shops in the area[2]	Depending on the 12-month trial is a success, the council says it will put out expressions of interest for companies to apply for a licence to operate e-scooters in Darwin[96]

Table 4: Latest state of play in CAV technology in different States in Australia

5.2. Australia CAV Trial Guidelines

On-road trials are necessary to ensure CAV can operate safely and efficiently in Australian conditions. They are also important for building public understanding and confidence in the technology. Vehicles cannot operate in automated driving mode on public roads due to existing legal barriers. Organisations seeking to run automated vehicle trials require state and territory road transport agencies to provide permits or exemptions from legislative obligations in the Australian Road Rules and other road transport legislation[104]. Several state governments are planning or have undertaken trials and demonstrations of CAV. As road owners and managers, state and territory governments may be best placed to undertake trials.

In November 2016, the Transport and Infrastructure Council agreed to the National Transport Commission (NTC) and Austroads developing national guidelines for 'on-road field testing and trials of CAV in Australia' [104]. The NTC led consultation on the scope of the guidelines. The council also directed state and territory road transport agencies and the National Heavy Vehicle Regulator to undertake a review of current exemption powers to ensure they had sufficient powers to undertake and manage on-road trials of CAV, including in relation to vehicle standards, road rules and driver licensing requirements, and to review how cross-border trials could be managed. This review was completed in 2018. Some states found that exemption powers were not sufficient and enacted legislation to enable trials[105]. The guidelines were developed to ensure a level of national consistency in trials across the country by forming the basis for conditions a trialling organisation would need to meet to receive an exemption or permit to trial an automated vehicle on a public road. To apply for a permit or exemption, trialling organisations must address the criteria in the guidelines (including explaining why particular criteria are not relevant in their circumstances).

A summary of general trial guidelines is provided in Table 5, which illustrates the end-to-end post-trial regulatory system[51].

Key management criteria	Trial location • Description of the technology being trialled • Traffic management plan • Infrastructure or network requirement • Stakeholders and public engagement • Managing change
Insurance	Appropriate insurance could include: • compulsory third-party insurance • comprehensive vehicle insurance • public liability insurance • product liability insurance • self-insurance • work or occupational health and safety insurance
Safety management plan	Security of the automated system • Risks to other road users • Risks to road infrastructure • System failure • Appropriate transition processes between automated and manual mode • Presence of human driver • Pre-trial testing • Driver training • Driver fitness-for-duty • Appropriate vehicle identifiers if necessary
Data and information	Data for serious incidents, which may include time, date, location, automation status, traffic conditions, road and weather conditions, vehicle information, sensor information, and identity of the vehicle operator • Data for other incidents, including near misses, when a human takes back control of the vehicle, a public complaint regarding the performance of the vehicle • End-of-trial report • Commercially sensitive information needs to be respected by road agencies
Implementation	Cross-border trials need to be arranged with all relevant state road agencies • Existing trials will operate under the existing arrangements • Transition into deployment needs ongoing dialogue • The guidelines are not for large-scale commercial deployment • Trials that are commercial in nature may be permitted, but not for large-scale deployment • Vehicle limits for trials • Time limit for trials

Table 5: Trial guidelines in Australia[51]

Trials have occurred in every state and territory. Governments have actively encouraged and in some cases, part-funded these trials. The majority have been trials of automated shuttle buses in limited operating domains. No trials have taken place across state boundaries[105]. South Australia, New South Wales and Victoria have enacted legislation to enable trials, and other jurisdictions allow trials through permit or exemption schemes. Victoria has also developed its own trial guidelines[105].

5.3. Australian Governance and Regulatory Arrangements

Governance impacts include the requirement to establish new frameworks or policies to ensure the impacts of CAVs are aligned with the needs of the community. The increased mobility provided by highly CAV 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[39].

Vehicles with automated features such as lane-keep assist and the autonomous emergency braking are already commercially available in Australia. These features assist with driving, but a licensed human driver is still in control of the vehicle at all times[19]. Vehicles with higher levels of automation are not yet commercially available in Australia, although trials of these vehicles are currently underway both in Australia and overseas. These more sophisticated vehicles – in which an automated driving system is responsible for all aspects of driving – are not currently consistent with the requirement under current driving laws that a licenced human driver is in control of the vehicle. These driving laws are administered by state and territory governments. The Australian Government is working to ensure reforms to the driving laws take place in advance of manufacturers bringing these vehicles to the Australian market[19].

The Austroads board is responsible for advising on technical, operational and regulatory issues. Austroads' connected automated and electric vehicle program includes developing recommendations to address issues such as road and road-side infrastructure suitability and national consistency, road operator data access, driver education and licensing. Austroads' Network program develops guidance that ensures the safe, efficient and shared use of the road space for the end-to-end movement of people and goods[107].

The NTC (National Transport Commission) has assessed existing road rules and identified the following areas for review[51]:

- Current driving laws and offences assume a human driver.
- An automated driving system (ADS) is not a person and cannot be legally responsible for its action.
- Current law does not provide for a legal entity (the Automated Driving System Entity, ADSE) to be held responsible for the actions of the ADS.
- Some legislative duties and obligations given to drivers could not be controlled by the ADSE if ADS is the driver.
- Safety duties may need to be carried out by someone else if the driver is an ADS and legislation would need to clarify who has the safety duty.
- Control and proper control of a vehicle, if an ADS is driving, are not defined.
- Legal obligations to ensure readiness to drive.
- Compliance and enforcement.

Following this investigation, it has been proposed that[65]:

- The ADS is in control when it is engaged in Level 3 or above.

- The ADSE is responsible for complying with DDT obligations when the ADS is engaged.
- The ADSE is only responsible for tasks within its control.
- Readiness-to-drive obligations of the users of a CAV are needed.

CAV has the potential to impact State/Territory and Local Governments in several of ways that can be broadly grouped into two categories:

1. Impacts on existing operations.
2. Impacts on governance frameworks and policies.

Operational impacts include changes that may cause adjustments to 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 the provision of public transport and parking services in response to changing needs.

The National Transport Commission (NTC), in collaboration with Austroads, has released several publications addressing regulatory requirements for CAV operations in Australia, including establishing guidelines for CAV trials in Australia[62], establishing safety assurance systems of CAVs[63,64,65], developing legal reform options to clarify how the current driver and driving laws may apply to commercially deploy CAV[59,65], and clarifying safety-related definitions for policy making[60,61]. This work program is aimed to cover the whole-of-life cycle of CAVs commercially operating in Australia and New Zealand[51].

The Australian Federal Government and all State and Territory Governments are members of the Council of Australian Governments (COAG) and Transport Infrastructure Council. The Council sets priorities and makes decisions on nationally consistent preparation for CAV, informed by work from bodies such as the National Transport Commission and Austroads. In general terms, the Australian Government is responsible for ensuring the safety of cars coming into the country (first supply), and State and Territory Governments are responsible for the on-road operation of cars, including road rules, registration and approval of automated vehicle trials. The Australian Government is also working on several policies which will impact the safety and success of CAV, including cybersecurity, communications technology and innovation. This work is being coordinated by the Office of Future Transport Technology[19].This will bring CAV as important technology for future mobility.

5.3.1. Australia’s current regulatory framework on CAVs

In August 2016, the Transport and Infrastructure Council agreed to the National Policy Framework for Land Transport Technology. The Policy Framework outlines a principles-based approach to facilitate the efficient, effective and consistent implementation and uptake of transport technology across Australia[20]. The Policy Framework outlines the following four roles for government:

1. **Policy leadership**—providing a clear, nationally coordinated approach across different levels of government, being responsive to changes in the technological environment;
2. **Enabling**—ensuring that the private sector is able to bring beneficial new technologies to market;
3. **Supportive regulatory environment**—ensuring that community expectations of safety, security and privacy are appropriately considered in new technology deployments; and
4. **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 (including collaboration with the private sector).

The 2016-19 Action Plan delivered important foundational work in a range of key areas, including regulatory reform, trials and research on Intelligent Transport Systems (ITS), geo-positioning and security for connected vehicles. This policy response has positioned Australia strongly in a global environment, as governments around the world prepare for the opportunities and challenges of new transport technology. Australia has been internationally recognised for its proactive approach to regulatory settings.

The 2020-23 Action Plan builds on the work established and underway from the 2016-19 Action Plan. New priorities in this update explore technology in the freight sector, low and zero-emissions vehicles, Mobility as a Service (MaaS), and how connected and automated vehicles (CAVs) will influence future infrastructure and land use planning. The updated Action Plan also includes areas of future focus. These areas represent upcoming priorities for national coordination, depending on the outcomes of key actions in this document and the context of a rapidly changing technological environment[107].

The Australian Government is responsible for developing and implementing national vehicle standards (the Australian Design Rules) and regulating the first supply of vehicles to market. It is a significant funder of infrastructure and represents Australia's interests in international policy-making bodies, such as the United Nations World Forum for the Harmonisation of Vehicle Regulations[19]. The federal government is currently implementing the agreed first supply recommendations from the Safety assurance system for the CAV project[74].

The Australian Government also plays a role in advocating for a nationally consistent approach to the regulation of motor vehicles. In the current regulatory environment, when CAV become ready for deployment[36]:

- Government may introduce new in-service safety risks that the market will not eliminate or mitigate.
- Nationally inconsistent approaches to in-service safety and multiple regulators without clearly defined roles could be a regulatory barrier to market entry. These risks need to be addressed to support the uptake and safe operation of CAV on Australian roads and unlock their broader benefits.

Australian Design Rules

The Motor Vehicle Standards Act 1989 (the Act) and associated regulations provide the legislative basis for the Australia Government to control the safety, environmental performance and security of new and used vehicles supplied to the Australian market. Under the Act and the Motor Vehicle Standards Regulations 1989, the Australian Government maintains a system that generally requires road vehicles to meet national design and performance standards – the Australian Design Rules (ADRs) – that are established and maintained in line with community expectations and international standards. The ADRs apply equally to vehicles manufactured in Australia and vehicles imported into Australia.

The ADRs are becoming increasingly harmonised with the United Nations (UN) vehicle regulations. Harmonisation ensures that vehicles built to the most recent safety, environmental and anti-theft standards are supplied to the Australian market at the least cost. It also ensures that Australians can access the latest vehicle technologies (including automated vehicle technologies).

Current government policy is that each new or amended ADR must be subject to a stringent regulatory impact process before introduction. The regulatory impact process involves establishing market failure; that there are no other non-regulatory options available that could achieve the same outcome, and that regulation is the option that would lead to the greatest net benefit to the community. Real-world crash data provides the basis for this analysis. Finally, there must be a full offset of the compliance costs of each ADR by the amendment or removal of existing regulatory cost burdens.

On 10 February 2016, the Federal Government announced a package of reforms to the Act and its associated regulations, delivering modernised legislation to increase community safety, providing greater choice and competition in the Australian vehicle market and to remove unnecessary red tape on businesses. The reforms follow a review of the regulatory framework (including an extensive consultation process) that began in 2014.

The Government also announced its intention to accelerate the harmonisation of Australian vehicle standards and requirements with the United Nations Regulations, maintaining the Australian Design Rules (ADRs) as the mechanism for implementing these standards in Australia. The ADRs are designed to be flexible in response to changes in technology and do not specifically prohibit the deployment of CAV. However, the ADRs do require traditional design features such as steering wheels and windscreens and could be a barrier to deployment of these features if they are not present in future vehicles (e.g., highly CAV designed to operate without human oversight).

Safety Assurance for commercial deployment of automated vehicles

Automated vehicles are widely expected to improve road safety in the future by reducing human error. However, there are also new risks associated with introducing automated vehicles[36]. Beyond the framework of the trials, government ministers at state have agreed on a safety assurance approach to the first supply of CAV for commercial deployment. Entities seeking to bring automated driving systems (ADSs) to market in Australia will need to self-certify that they have met a set of safety criteria and obligations to be granted a type approval under the Road Vehicle Standards Act 2018 (Cth). The entity, called the Automated Driving System Entity (ADSE), will be responsible for assuring the safety of the vehicle type for the life of the vehicle. Once the ADSE receives approval for AVs, its vehicles can be deployed anywhere on the road network (subject to any type of approval or registration conditions)[105].

Through the National Road Safety Strategy (NRSS) 2011-2020[130], the Transport and Infrastructure Council has adopted the long term vision that no person should be killed or seriously injured on Australia's roads. This strategy is applicable to emerging technologies such as automated systems, including adaptive cruise control, lane keep assist and autonomous emergency braking. Autonomous emergency braking, for example, is estimated to prevent 20–40 per cent of particular crashes. In the future, higher levels of automation, including vehicles that require no human control, may significantly reduce the number of road deaths, potentially by as much as 80 or 90 per cent [131].

Key cost considerations for the future regulation of CAV

The key costs to all levels of government associated with the regulation of CAV when they are in service include establishing and maintaining the regulatory framework (e.g., the laws and regulations), and establishing an entity to undertake the regulatory task and ensure ongoing regulatory compliance[67]. The rate of automated vehicle adoption will also be influenced by businesses' willingness to supply technology to the Australian market. This aspect can be influenced by substantive regulatory requirements and hindered by national inconsistencies in regulation.

Substantive regulatory requirements indicate the regulatory requirements for CAV when they are in-service may be a disincentive for ADSEs supplying CAV to the Australia market. Based on the types of companies that are currently developing CAV technologies, CAV will most likely be developed overseas for global markets. As Australia comprises just 1-2 per cent of the international vehicle market, 13 international suppliers may not be willing to make substantial changes to their processes to comply with regulatory requirements that are not in-line with major world markets, which would in-turn delay uptake. There would be a strong disincentive for ADSEs to supply CAV to Australia.

6. Overseas State of Play

Based on Autonomous Vehicles Readiness Index[48, 50] compiled by KPMG in 2019, countries are ranked according to their preparedness to adopt self-driving cars. According to the Index, Australia is ranked 12th in its readiness for policy and legislation in CAVs. The following section will discuss the current state of play in CAVs for countries which are ranked above Australia in terms of policy and legislation to support AV uptake. The countries that are ranked first to 11th respectively in terms of policy and legislation include Singapore, United Kingdom, New Zealand, Finland, The Netherlands, Germany, Norway, Canada, United States, Sweden, and United Arab Emirates.

6.1. Singapore

Singapore is using driverless technology to improve the punctuality of mass transport and overcome manpoer constraints[102]. In August 2014, Singapore's Ministry of Transport announced a 17-member Committee on Autonomous Road Transport for Singapore (CARTS) to provide leadership and guidance on the research, development and deployment of AV technology for the city-state and study the associated opportunities and challenges[11]. From January 2015, a network of roads in the north of the country was used as test routes for CAVs operating amongst non-CAVs[86]. Singapore's

Land and Transport Authority (LTA) pilots will be conducted on the deployment of autonomous buses and autonomous on-demand shuttles in Punggol, Tengah and the Jurong Innovation District in the early 2020s [103].

Regulatory Framework and lessons learned for Australia

- LTA introduced a regulatory framework that minimises the occurrence of accidents. This regulatory framework suggests that operators are required to have a qualified safety driver who will be able to take control of the vehicle in an emergency, hold third-party liability insurance and share data from the trials with the LTA[50].
- LTA takes a safety-first approach with CAV trials starting on lightly used roads and graduating to more congested environments only after they have demonstrated readiness. All test CAVs are required to log travel data to enable accident investigations and liability claims[48].
- Singapore's 2017 amendment to its Road Traffic Act has allowed self-driving vehicles to be tested on public roads[48]
- Singapore has released a set of national standards called Technical Reference 68 (TR 68) to guide the local industry in the "safe" development and rollout of autonomous vehicles, outlining guidelines related to vehicle behaviour, functional safety, cybersecurity, and data formats. TR 68 provides a strong foundation that will ensure the interoperability of data and cybersecurity that are necessary for the deployment of autonomous vehicles in an urban environment. The TR 68 also helps to build up the autonomous vehicle ecosystem, including startups and SMEs (small and midsize enterprises) as well as testing, inspection, and certification service providers[99].
- CAV-enabled mobility could be a central feature in Australia's future town-planning, enabling commuters to get around effortlessly by offering first- and last-mile connectivity within neighbourhoods. The sharing of autonomous vehicles will reduce the number of vehicles on the roads, thereby increasing convenience to commuters[102].

6.2. United Kingdom

Although Europe has seen a lesser focus on driverless cars than in the USA, there have been some areas where European developments have been notable: Truck platoons; Automated public transport, including personal rapid transit; and Lower level automation[21].

The UK government is actively encouraging the increasing automation of vehicles, starting with an announcement by the Department for Transport (DfT) in July 2013 that it would "work to encourage the development and introduction of autonomous vehicles" [93]. This initiative was followed by an announcement in July 2014 that autonomous vehicle testing to happen from January 2015 and would be supported by a £10m competition[92].

The government announced support for three public trials in 2021, including CAV buses across the Forth Bridge in Scotland and self-driving taxis in London[50].

Regulatory Framework and lessons learned for Australia

- In August 2018, the UK Parliament passed the Automated and Electric Vehicles Act, which adapts the existing motor insurance framework by extending compulsory insurance to CAVs as well as the driver[50].

6.3. New Zealand

The first trial of a highly automated vehicle occurred at the Christchurch International Airport in 2017[21]. In the second stage, there was an introduction of New Zealand's first Smart Shuttle in 2019. The New Zealand Intelligent Transport Systems Technology Action Plan 2014-18 includes an action for the government to assist the introduction of increased vehicle automation[76]:

The country has no specific legal requirements for cars to contain drivers, the NZ Transport Agency can provide support to those undertaking testing, and it is collaborating with Australia to minimise duplication and share knowledge[50].

Regulatory Framework and lessons learned for Australia

- The Ministry of Transport, in conjunction with transport agencies, scans all transport legislation to identify barriers to the continued deployment of ITS technologies in New Zealand. It also considers the need to review legislation in light of the increasing introduction of advanced driver assistance systems (ADAS) and semiautonomous vehicles.

6.4. Finland

Finland is exploiting its cold climate through research on how CAVs can handle icy roads and tracks[50]. Finland has supportive regulations, its proactive judicial system, a large number of CAV companies and the availability of the latest technologies. The traffic safety authority is quite permissive, granting permits for trials to anyone who is interested in experimenting with CAVs.

Regulatory Framework and lessons learned for Australia

- The government has recently passed two new laws that enable CAVs. The Transport Service Law opens taxis to competition, allowing ride-hailing services to gain access from 2020, and permits someone to control a vehicle remotely.

- The Road Traffic Act will mandate the integration of detailed location data on roads, signs, traffic lights and other control mechanisms for CAV operators to use, and is set to repaint the continuous yellow lines on Finnish roads in white, partly as these are easier for machines to detect. [50]

6.5. The Netherlands

The Netherlands has an excellent road infrastructure, highly supportive government and enthusiasm for adopting CAVs[48].

Regulatory Framework and lessons learned for Australia

- The Ministry of Infrastructure and the Environment (I&M) has opened the public roads to large-scale tests with self-driving passenger cars and trucks without a driver being physically present in the vehicle, however, remote monitoring of the vehicle is mandatory. With effect from 1 July 2019, public road tests involving self-driving vehicles are allowed under strict conditions [133].

- The Netherlands is also preparing a Driving License for a Vehicle. This is being developed in cooperation between the Dutch Vehicle Authority (RDW), the main road authority (Rijkswaterstaat) and the central office for driving exams (CBR). The approach focuses on the extent to which a vehicle can produce safe and predictable automated driving behaviour that aligns as closely as possible to human performance in an open traffic system.

- Finally, the Netherlands is working on a “Vehicle Safety & Security Framework (VSSF)” to be able to assess the robustness of in-vehicle software[50].

6.6. Germany

Since 2015, the German government has followed a national CAV strategy and has recently started working to ensure that CAVs are used ethically, including protecting people rather than property or animals. Several of Germany’s powerful states are also working on CAVs.

Regulatory Framework and lessons learned for Australia

- The legal requirements for the use of the first highly automated and fully automated driving functions for regular operation in road transport have been in place since 2017. North Rhine-Westphalia, which includes Cologne and Düsseldorf, has established a Zukunftsnetz Mobilität (future of mobility) network to support municipalities[50]. This network includes six Working Groups which discuss a range of topics relating to sustainable transport, such as climate change, digitization, alternative fuels and industry standardization.

- Germany is working on ethical regulation autonomously for CAVs, without the European Union coordination[135]. The ethics commission adopted a final report comprising a total of 20 ethical rules, which include clauses to emphasis that protecting humans always take priority. The ethics commission has also specified strict requirements in terms of data protection which are already taken into account today as part of the development of Daimler's automated and autonomous systems. In this process, three clear principles apply transparency, self-determination, and data security[138].

6.7. Norway

On 1 January 2018, Norway legalised AV testing on public roads, and operators have started small-scale autonomous bus services as a result[50]. Norway has by far the highest market penetration of AVs, contributing to its second place in the technology and innovation pillar.

Norway has ratified the Vienna Convention on Road Traffic from 1968, and the principle on a natural person being the liable driver has been an important principle in Norwegian road traffic legislation. The CAV testing law requires a liable applicant for CAV testing pursuant to the test law. During the period from the effective date of the CAV testing law of 1 January 2018 until the end of 2019, the Norwegian authorities issued 25 licenses to conduct CAV testing on a larger scale.

6.8. Canada

The CAV Pilot Program started in 2016 involving Uber — which is testing self-driving vehicles in Ontario and in Toronto together with Canadian technology company Black-Berry and the University of Waterloo[5,] The country's large size and remote locations may stretch CAV infrastructure[48].

6.9. The United States

The North American efforts appear to focus almost exclusively on cars, which is in contrast to the European developments that also include Personal Rapid Transit (PRT) and truck platooning[21]. Firms have obtained approval to test CAV on public roads. Some testing activities are open to the public with oversight by a professional driver[1].

Federal Automated Vehicles Policy (September 2016) — provides guidance on best practices for the safe design, development and testing of vehicles. It includes a model state policy to facilitate nationally consistent deployment of vehicles.
President Trump signed into law the Consolidated Appropriations Act, 2018. This legislation, among other things, directs the U.S. Department of Transportation (DOT) to conduct research on the development of CAV and provides necessary funding[106]. US authorities are undertaking research into policy issues, similar to work occurring in Australia, such as the applicability of vehicle standards, insurance and liability issues[21].

6.10. Sweden

In April 2018, Sweden opened the world's first electric-charging road, a 2km stretch near Arlanda airport. An electric truck belonging to PostNord, the SwedishDanish postal company, uses it to recharge automatically while moving between the airport and a logistics centre 12km away. Sweden is second only to Norway in adopting EVs, which means developing infrastructure that will be used by CAVs [50]. The government has already permitted small-scale CAV pilots. These include a driverless bus service that started running on 1.5km section of public road in northern Stockholm[50].

Regulatory Framework and lessons learned for Australia

- The government is also undertaking direct measures, with legislative changes in 2019 that will allow CAVs on public roads and tests without human drivers[50].

- New electric routes, infrastructure and operating in accordance with the country's traffic regulations, Einride's T-pod (electric truck) has the potential to reduce CO_2 emissions from road freight transport by up to 90%[32].

6.11. United Arab Emirates

The UAE is a global leader in preparing for the advent of autonomous cars on its roads, and it is expected to be among the first to introduce driverless vehicles, according to a 2019 report by global consultancy KPMG[143]. Dubai, the UAE's largest city, aims to make 25 per cent of all transportation autonomous by 2030, based on a strategy launched in 2016 that focuses on environmental and efficiency improvements. This strategy is expected to generate AED22 billion ($US6 billion) annually. In September 2016, Dubai's Road and Transport Authority trialled a CAV shuttle on a 700m route, offering free rides to commuters.

Regulatory Framework and lessons learned for Australia

- Newly built Masdar City, in Abu Dhabi in the UAE, has transported more than two million people on its Personal Rapid Transit driverless pods since 2010, running on special guideways. In October 2018, the city launched a regular CAV minibus service[50]. It operates on the roads, using vehicle infrastructure technology that communicates directly with traffic lights and integration with pedestrian pathways[49].

- Dubai aims to run "all applicable government transactions" through blockchain, a decentralized system that uses encryption to make data entered permanent and unalterable, which can be used for 'smart contracts' that automate transactions between multiple parties.

6.12. Country scenarios of CAV technologies

The following table (Table 6) gives some examples of CAV technologies in different countries that are happening currently (NOW), imminent in the near future (NEAR) and in long term future within the next 5-10 years (NEXT). Table 6 takes into account the acceptance of fully autonomous vehicles, the scope of human drivers, and policy or future plans for adoption for CAV in these countries.

	NOW	**NEAR**	**NEXT**
Singapore	Singapore's Land Transport Authority (LTA) takes a safety-first approach with CAV trials starting on lightly used roads and graduating to more congested environments only after they have demonstrated readiness. All test CAVs will be required to log travel data to enable accident investigations and liability claims[50]	Hyundai Motor Company will establish a Hyundai Mobility Global Innovation Centre in Singapore (HMGICs) to accelerate its innovation efforts, with support from the Singapore Economic Development Board (EDB). As an open innovation lab, HMGICs will help ensure the company's transformation into a smart mobility solution provider and secure its sustainable growth[33]	With self-driving technology, deploy trucks for the delivery of goods, as well as public utility vehicles for rubbish collection and road sweeping, during the night. This means they would no longer have to compete with other traffic during the daylight hours[82]
UK	Testing guidelines in the UK has developed	Europe leaning towards IEEE 802.11p	An important part of the European strategy on

	a code of practice for testing CAV, with recommendations for safety and minimising potential risks[37]	through its recently published delegated act on C-ITS (Cooperative Intelligent Transport Systems)[80]	CAVs is the creation of a common European mobility data space, to be further developed in the Q4 'Smart and Sustainable Transport Strategy'. Several related EU legislative initiatives seek to regulate the handling of data critical to the CAV space[12]
New Zealand	The first trial of a highly automated vehicle occurred at the Christchurch International Airport 2017[21]	The Christchurch airport's interest in new technology has also led it to provide logistics support and air space to allow Zephyr Airworks to test the world's first self-piloted air taxi, Cora, in Canterbury, as well as developing Virtual Reality (VR) training for its firefighters[4]	Cora, entering the shared mobility era, electric flying car, which does not need a pilot, or rely on fossil fuels. The vehicle will not be delayed by traffic congestion[8]
Finland	Local CAV company Sensible 4 has developed automated minibuses that work in harsh Finnish winters. It recently partnered with Japanese designer Muji to develop Gacha, an all-weather CAV bus that also aims to look elegant [50]	Finland plans to introduce commercially viable driverless bus services in 2021 [50]	The FABULOS (Future Automated Bus Urban Level Operation System) project was initiated by Finland, in its third phase aims to verify and compare the first end-products in real-life conditions[137].
The Netherlands	In Rotterdam, the Netherlands, a test involving the Park Shuttle, an autonomous bus connection between a metro station and an industrial park are to be continued and extended this year[135]	The startup Amber is working consistently on the concept of driverless vehicles to overtake Uber, Tesla and Google.[147]	The Netherlands is also watching future opportunities closely, supporting projects including "truck platooning pilots and autonomous public transport in airports and harbours[146].
Germany	Finances were provided through the Electric Mobility	The National Platform Future of Mobility (NPM) is a body	To analyse ethics and the legal situation as part of autonomous driving, a

	and Automated Driving R&D program by the government to the industry [135]	set up by the Federal Government to monitor and analyse current and future trends in the field of mobility[138].	multidisciplinary steering committee is set up to brings together comprehensive specialist expertise and different perspectives at an early stage of product development [138]
Norway	Through Aurora Project, the government allows anyone to test autonomous vehicle technology on the challenging highway that stretches across the border into Norway [136]	In the near future, self-driving buses could run to and from a subway station or a local centre or in a hospital area, essentially connecting inner cities. This is the biggest self-driving project in Norway, which is a collaboration between Oslo Municipality, the Norwegian Public Roads Administration, Ruter and Holo[139]	Through AVENUE (Autonomous Vehicles to Evolve to a New Urban Experience) project led by the University of Geneva , the future public transport in urban and suburban environments, autonomous vehicles will be revolutionised the way citizens use public transportation, by making time-tables and fixed bus stop obsolete, and by offering a service that will allow passengers to call and hop a ride at any time, at their doorstep for example, and deposit them as close as possible to their destination140
Canada	Ontario has lifted some regulations on CAVs, and started from January 2019 driverless vehicles were tested on its roads[48].	Ontario's Automated Vehicle Pilot Program until 2026, involving Uber — which is testing self-driving vehicles in Toronto — Canadian technology company BlackBerry and the University of Waterloo[48]	A large group of Toronto city staffers and experts on autonomous vehicles have proposed to the city's Infrastructure and Environment Committee a plan for slowly integrating autonomous vehicles into Toronto society. The plan begins by stating that it wants to get Toronto ready for self-driving vehicles by 2022[145]
United States	Waymo is permitted to operate CAVs on the public roads without a human inside offering driverless deliveries during COVID[17]	Boston start-up, Optimus Ride, plans to begin operating driverless shuttles at the Brooklyn Navy	Automakers are eager to deploy commercial robotaxi fleets without human controls, but none

		Yard that also travel at 25 m.p.h. or less[6]	are expected to eventuate until 2021 at the earliest[83]
Sweden	A select group of families have started testing Swedish car giant Volvo's new self-driving XC90s in the west of the country, marking a key period in the company's push to unleash the technology by 2021[142]	AstaZero facility is developed by the Swedish government and industry as a test facility for autonomous vehicle technologies – with its eyes on the global prize of creating an international standard for testing driverless vehicles. It is a next-generation 5G and digital innovations to support the development of self-driving cars and other vehicles [141]	AstaZero will target Nordic and global car manufacturers as world's most advanced testing facility in CAV market that is projected to be worth about $US7tn by 2050[141]
UAE	While there are some semi-autonomous self-driving vehicles on the roads (such as those that can park themselves, or effectively work as smarter cruise control), fully self-driven cars are still not allowed on roads[144].	The first step towards driverless cars will begin with draft legislation. If it is approved, the UAE would be the first country in the world to have standards around autonomous vehicles. It's expected the final legislation would be signed off in 2020, with driverless vehicles arriving around a year after that[144].	The new laws under the Dubai Smart Mobility Strategy aim to ensure that a quarter of journeys in self-driving vehicles by 2030 [143]
Australia	Renault ZOE2 completed the trip at level four on the automation scale, where the car can travel fully autonomously, but a human driver can still take control if needed[45]	Tesla is set to sell vehicles with the necessary hardware to enable Level 4/5 autonomy in 2020[9].	CAV technology to work effectively, 5G network to be used to support it[30].

Table 6: State of play in CAV technology in different countries

7. Considerations for Asset Management

Based on the discussion presented so far, the following section provides recommendations for the CAV adoption in Australia covering the six areas of asset management: planning, policy, strategy, customer/stakeholder expectation, risk management, and legislation/statutory requirements.

7.1. Planning

- CAV-enabled mobility could be a central feature in Australia's future town-planning by enabling commuters to get around more efficiently and change modes effortlessly and by improving supply chains offering better first- and last-mile connectivity.

- CAV can revolutionise the future public transport in urban and suburban environments, by making time-tables and fixed bus stop obsolete, and by offering a service that will allow passengers to call and hop on and off a ride at any time. CAV technology can communicate directly with traffic lights and integrate with pedestrian pathways[49], hence potentially reducing the incidence of road crashes.

- CAV, either cars, buses, freight trucks, light rail etc present the opportunity for transport planners to achieve better intermodal integration[108].

- Planning processes, including project assessment and prioritisation need to be adapted to include uncertainties arising from the uptake of CAV[111]. Planners need to rethink conventional tools and develop new tools and practices to meet future challenges[109].

- Many of the benefits claimed for the new technologies in safety and more efficient use of contested urban space are expected to be realised only when the transition to full autonomy is reached[110].

- CAV uptake and CAV data has the potential to support governments in improving network efficiency and safety and may be used as an input to inform investment decision making. There is a need to develop learnings, potentially drawing from trials, to inform the approach to data that would help guide governments developing policies and plans for data usage while protecting data privacy. Any CAV data projects needed to align with other data projects and national data consistency guidelines[107].

- Many automotive and transport sector leaders have indicated that connectivity in vehicles will help solve complex problems in emerging technology. National and international initiatives are underway on connectivity solutions, including short-range communications and cellular technologies. A greater understanding of business and assurance models for deployment in Australia and their cost-benefit for industry and government will support effective regulatory and investment decision-making[107].

- Identification of any gaps in the standards of CAV needs to be in-line with national developments on connectivity solutions, including short-range communications and cellular technologies.

- It is essential to understand the developments in sharing economy to assess their potential impact on public transport demand and road use[113]. Without careful consideration of the impacts in interrelationships between CAV, electrification of vehicles, sharing economy and increased urban density , and if all four are not adequately managed, the likely outcome can be a sub-optimal urban mobility system; possibly with negative characteristics worse than those present in existing transport systems. There is scope for considering multi areas impact scenarios and analysis where relevant, when developing asset management strategies and planning processes.

- Need to develop guidance on how infrastructure can be future-ready for CAV technology within an integrated transport and land use planning framework. The guidance developed will support policy and investment decisions on technology in the road transport sector. The guidance will consider strategic priorities for governments to harness the safety, productivity, sustainability and accessibility benefits of transport technology[107].

7.2. Policy

- The concept of a driver licence for a vehicle is being explored internationally, may require consideration in Australia.These considerstions might include AVs as licensed as drivers.

- Driverless vehicles may require remote monitoring, and Vehicle Safety & Security Frameworks may need to be developed to assess the robustness of in-vehicle software.

- Policy debates on the adoption of CAVs are likely to involve more than their direct impact on mobility and will be caught up in the wider discussion on responses to climate change and a shift to a low-carbon economy [116]. For example, transforming to ensure they deliver on the goals of the Paris Agreement and create sustainable, prosperous and healthy communities for their citizens.

- The CAV technology will also dramatically lower the likelihood of accidents so that the insurance premiums contained in current car-sharing rates could be reduced [117].

- Policymakers could potentially consider offering incentives to people who use ride sharing to encourage vehicle sharing and limit the potential negative effects of the introduction of these vehicles[122].

- Privacy issues with personal data sharing may be another constraint with public acceptance of fully CAVs. It is important that future policies take into consideration the privacy issues involved in the use of sharing data and respect the privacy of CAV owners/operators[122].

- The Guidelines for Trials of Automated Vehicles in Australia in 2017 opened the way for larger-scale trials with a view to commercial deployments[107].

- Autonomous vehicles can affect infrastructure planning decisions and will impact the design and costs of infrastructure. National standards are particularly important when considering smart infrastructure and vehicle communications [116].

- Governments will need to establish regulations for the CAV systems operating on different levels of automation, and regular testing regimes to monitor their performance [112].

- The peculiarities of Australian urban politics and patterns of urban development mean that local CAV policies will be influenced but not determined by the European and North American practice as these policies cannot simply mimic international conditions depending on climate, space, and geography[115].

7.3. Strategy

- CAV uptake with its full range of safety features will enhance the benefits of the Safe System approach advocated by the road safety strategy, by minimising and later on possibly eliminating the impact of driver behaviour and by increased safety resilience from the vehicle perspective.

- It is expected CAV uptake will improve mobility and can have significant impact on travel demand management and sustainable transport, with flow on ramification into broader areas such as climate change and digitisation, if managed in conjuction with sharing economy and increasing urban density.

- Provided appropriate investments are made, CAV will further improve the performance of smart infrastructure, such as Smart Freeways/ramp metering, and will need to be captured in asset management strategies (e.g. Travel Demand Management; Sustainability)

- Maintenance strategies can consider the use of driver less cars as utility vehicles for rubbish collection and road sweeping on urban roads at night, therefore not impeding traffic during the day. (e.g. as in Singapore)

- CAV can drive the optimisation of parking planning and parking pricing strategy, following from the expansion of the sharing economy[123].

- There is a need to proactively develop strategies to optimise the use of active transport such as walking, cycling or public transport before, during, and after the wide-scale introduction of CAVs [124].

- There is a potential to establish a 'lessons learned' repository for Australian trials of automated vehicle technologies, connected vehicle technologies and zero and low-emission vehicle technologies[105]. If established, the repository would enable asset manager to periodically revise their strategies, policies, planning in order to take into cosidersation, where appropriate, any significant advances in technology and overall CAV functionality, particularly in regard to vehicle to vehicle and vehicle to infrastructure communication.

7.4. Customer/Stakeholder Expectations

- "Future of mobility" network(s) can be established to support urban communities; they can consist of working groups to cover a range of topics relating to sustainable transport, impact on and of climate change, digitization, alternative fuels and industry standardization.

- The issue of CAV data security needs to be addressed to ensure privacy is protected while data can be utilised to improve network efficiency.

- Potential deployment scenarios for CAV may influence commercial issues such as eCommerce platforms and access to data. Research into this aspect of the technology will guide future regulatory decisions making and identify future analysis needed[107].

- Customer expectations potentially could increase in terms of seeking reduced congestion, emissions reduction, improved mobility, delivered by a variety of choices, including CAV individual ownership, CAV public transport, and other micromobility options like electric bikes and scooters, and possibly air taxis, as well as walking[122].

- Implementation of mileage-based fees, carsharing and ridesharing are expected to have a profound impact on lifestyles and travel behaviours such as different commuting patterns or reduce active transport[125].

- Customer expectations may be influenced by their opinion regarding CAV, their trust in the technology and the willingness to give away control of the vehicle. Males, younger people, and those living in urban areas tend to be more positively oriented toward CAVs and more capable of accepting CAVs [112]. During the period of partial CAV uptake, asset managers will need to manage the various expectations arising from these differences.

7.5. Risk Management

- CAVs should be able to prevent an appreciable number of crashes. International and Australian trials and research have shown that new technologies in CAVs can increase network efficiency, decrease risk to transport users, reduce fuel usage and emissions, and enhance traceability of supply chains[107]. There is a need to develop evidence-based studies to validate such claims and inform the development of risk management framework.

- As fully driverless cars have not been implemented, their efficiency is hard to forecast [119]. An obvious potential impact of advanced CAVs will be that traffic congestion should improve due to the decrease in human-error road accidents and because of the improved efficiency of autonomous driving which has the ability to constantly monitor traffic [120]. For example, the smart technology of fully

CAVs trucks to detect objects in their path in the mining sector is valuable to implement fully CAVs on public roads[149].

7.6. Legislation/Statutory Requirements

- There is scope to create a common Australian mobility data space and to regulate the handling of data critical to the CAV space and develop legislation to address Cooperative Intelligent Transport Systems.

- End-to-end regulation for the commercial deployment of CAV: The National Transport Commission is working with the Commonwealth, states and territories to develop a regulatory system that supports the safe deployment and operation of CAV in Australia. Key actions related to this work include implementing regulatory arrangements so fully CAVs are safe at the point of first supply in Australia[107].

- There is a requirement for legislation that promotes global mitigation strategies to reduce GHG emissions[116]. CAVs are able to support such legislations by implementing low carbon vehicles.

- According to National Transport Commission (NTC), it is recommended that “whether human monitoring of an automated vehicle constitutes legal control of the vehicle requires clarification”, and hence for the purposes of road rules and insurance schemes, the legal definition of a ‘driver’ should be clarified on the same basis [129].

8. Conclusion

This report highlights selected nations’ progress on, and capacity for, adopting CAV technology and learning for the Australian context. The potential implementation of automation until 2025 is increasing, and from 2025 to 2035, the focus will be on improving fully driverless and managing disruption. In 2035-2045, the focus would be on developing new vehicle platforms and improving the road space. The future implementation issues would be the eradication of congestion and collisions.

The report reviews the policies around CAVs at both international and national levels and identifies specific considerations for asset management in relation to six key areas: policy, strategy, planning, customer/stakeholders expectation, risk management and legislative and regulatory requirements.

Some of the main opportunities for asset management include:

- CAV enhanced mobility in the realm of public transportation, intermodal integration, freight supply chain first and last-mile improved efficiency.

- CAV can facilitate the optimisation of parking planning, including the sharing of limited parking space for delivery vehicles in an urban environment.

- A new era in travel demand management utilizing smart infrastructure interface/connectivity with CAV and potential access to a real-time data at very large scale.

- Big data gets larger with uptake of CAV and potentially can create not only opportunities but also issues in regard to proptection of data privacy, as well as cyber attacks distorting the vehicle-to vehicle and vehicle to infrastructure communication.

- Modifying maintenance activities, by utilising CAV for some maintenance tasks such as litter and street sweeping during the night, potentially with reduced night staff and without contributing to day time traffic congestion. For public transport agencies, there is the potential to replace the vehicle fleet with CAV which in turn will result in new type of vehicles and inventory to manage and perhaps the need to develop new skills particularly in regard to the electric and electronic components of the cars.

- Enhanced safety features relating to the vehicles as part of the Road Safety System, hence CAVs offer an improved approach to reducing road trauma.

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