Shifting Gears – Preparing for a Transport Revolution

Transport Industry Technology Readiness

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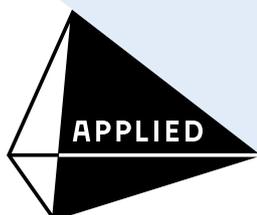
Australian Academy of Technology & Engineering

Shifting Gears – Preparing for a Transport Revolution

Transport Industry Technology Readiness

The Australian Academy of Technology and Engineering is undertaking a major three-year (2018–2020) Australian Research Council Learned Academies Special Projects funded research project to examine the readiness of different Australian industry sectors to develop, adapt and adopt new and emerging technologies, with a horizon out to 2030. The transport sector is the first industry sector to be examined by the project.

Executive summary

The rapid advancement of digital technologies across all sectors of the global economy has resulted in an extraordinary period of change.

With Australia's geographic isolation and long distances between large urban centres, the transport sector will be one area that is both significantly disrupted and revolutionised by this technological transformation.

Failure to be prepared will risk a decline in many aspects of our Australian way of life and society. For example, inadequate planning for population growth and the spread of urban centres could significantly impede the mobility of passengers and freight in both urban and regional areas. This could increase congestion and vehicle-related emissions, lead to a deterioration in health, safety and security, and negatively impact productivity and the cost of living.

In this early phase of the transition, it is critical that Australia identifies what we want for our society, what action government and industry need to take, and how this will translate to a transport sector for the future.

The Academy has identified **sustainability and climate change**, **productivity**, and **health** as the three key challenges that will need to be addressed within the transport sector over the next decade. Specifically, the transport sector will need to lower emissions, improve the efficient movement of people and freight, and reduce transport-related deaths and serious injuries. The deployment of connected and autonomous vehicles (CAVs), low and zero emission vehicles (LEVs), high frequency mass transport, and intelligent transport systems (ITS) are potential solutions to these challenges. These are outlined in **Figure 1**.

Figure 1: Transport technologies and systems to address key 2030 challenges
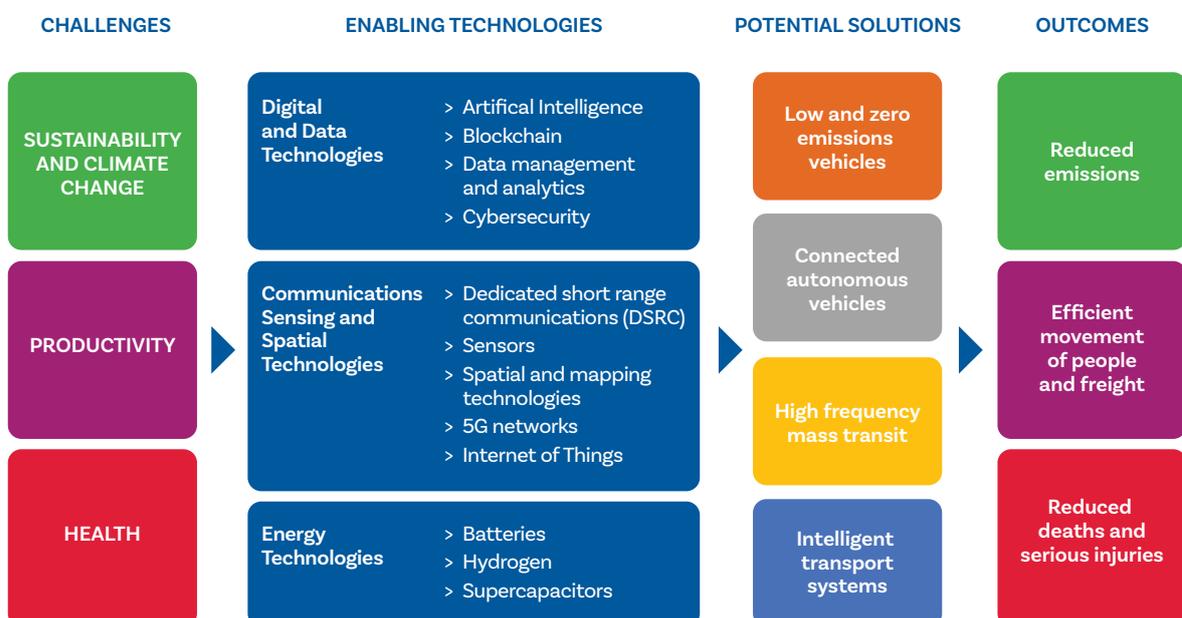
To gauge Australia's readiness to address these challenges, and to provide context for Australia's readiness to develop, adopt or adapt to the pending changes by 2030, the Academy has analysed each of these potential transport solutions against five readiness indicators:

> Infrastructure readiness

> Skills availability

> Social readiness

> Economic and commercial feasibility

> Policy and regulatory readiness

This analysis was informed by research and targeted consultations with transport stakeholders from industry, government and research from across Australia, and its development was overseen by a Steering Committee comprising Fellows of the Academy and transport experts.

The readiness scale is outlined in **Table 1**, and the results of the analysis are provided in **Table 2**.

Table 1: Readiness Indicator scale

	Not ready	More work still required			Ready
Readiness scale	○	◔	◑	◕	●

Table 2: Readiness Indicators

	Infrastructure readiness	Skills availability	Social readiness	Economic and commercial feasibility	Policy and regulatory readiness
Low and zero emissions vehicles	◔	◔	◕	◑	◕
Connected autonomous vehicles	◑	◔	◑	◑	◑
High frequency mass transit	◔	◔	◕	◑	◑
Intelligent transport systems	◔	◑	◕	◑	◑

The Academy's findings indicate that the Australian transport sector is least prepared in terms of:

> **Infrastructure readiness:** with respect to low and zero emission vehicles, high frequency mass transit and intelligent transport systems

> **Skills availability:** with respect to low and zero emission vehicles, connected autonomous vehicles and high frequency mass transit

Our analysis also shows that Australia is performing well on a number of other readiness indicators and is well placed to capitalise on the coming technology revolution. However, with technology developing at a rapid pace and competitor countries investing and acting strategically, Australia needs to ensure we also make smart, strategic decisions to keep pace with the technological frontier.

This report provides an opportunity for government, industry and research organisations to develop and plan for future urban environments based on the transport needs and mobility patterns of Australian communities. The report is intended to inform governments to enable smart, adaptable regulation and provide funding and incentives where appropriate, and to inform industry and research organisations to build practical research agendas to address the questions that remain about our likely transport future.

To achieve the desired outcomes within the transport sector by 2030, the Academy makes the following key policy recommendations to support emerging transport technologies. The Academy has also highlighted future research opportunities to address the challenges that the sector will face in the decade to come.

Recommendation 1: Implement mechanisms to drive a widespread shift towards low emission transport options

The Academy recommends that the Commonwealth Government implement policies to reduce vehicle emissions and to encourage the rapid and widespread uptake of LEVs. This should be driven by the following mechanisms:

> A national target and associated regulatory mechanism to drive the uptake of LEVs in Australia

> Public and private corporations should be incentivised to use LEVs as fleet vehicles

> Industry should lead ambitious uptake of LEVs by ensuring that vehicles imported into Australia meet stringent standards for emissions, supported by government vehicle emission standards

These mechanisms will need to be accompanied by efforts in the energy sector to ensure that LEVs are powered by low emission energy sources, in the context of our national emissions reduction target.

Research priorities

> What impact will the uptake of LEVs have on Australian emissions, under various plausible scenarios?

> How can we ensure that EVs have a neutral to positive impact on the electricity grid?

> How will the costs and benefits differ between privately owned LEVs and shared fleet ownership models?

Recommendation 2: Provide a framework to regulate new transport technologies

The Academy recommends that an adaptive regulatory framework be established to provide guidance to the transport sector to help shape future transport systems.

> Australian governments should introduce flexible and adaptable legislative and regulatory frameworks that can keep pace with the global technology frontier to ensure that Australia becomes, and remains, a key competitive player in the global market of advanced transport technologies

> COAG should set nationally consistent standards and regulations to facilitate the uptake of productivity-enhancing technology. For example:

  – The development of a consistent regulatory approach for transport technologies and infrastructure, such as the development of standards for charging infrastructure and connections for LEVs, the development of standards for data sharing and data privacy, and the selection of standards for V2X communications based on global standards

  – Data aggregation and availability, where this would offer an avenue to insight for the market and consumers. Which data should be collected, the situations in which it needs to be shared in real-time and post real-time, and what can be shared for forensic purposes needs to be specified for key platforms (for example, from CAVs and ITS)

Research priorities

> Where are international best practices found within the transport sector, and what lessons can be transferred to Australia?

> What is the best approach to a whole-of-government, integrated transport systems view involving industry, technology providers, infrastructure planning and education and training?

Recommendation 3: Develop and adapt transport technologies to an Australian setting

It is essential that Australia does not miss out on the benefits of technology because it does not yet meet the needs of our unique geography and climatic conditions. Transport technologies that are developed or adapted to an Australian setting have the potential to create the greatest impact.

> The Commonwealth and state governments should establish competitive grants programs that encourage the trial of transport technologies that can be adapted to the geographical or climatic conditions that are unique to Australia

> State, territory and local governments should plan for and adapt to future changes to Australia's vehicle fleet by undertaking integrated land use and transportation planning through coherent and consistent policies that take into account likely network use changes from new technologies

Research priorities

> In terms of prioritising the early adoption of transport technologies to improve Australia's readiness within the transport sector, where should the greatest emphasis be placed? What transport technologies should Australia adopt early, and why?

> To what extent and in what situations are Australian climatic and topographical conditions so unique as to warrant special technological adaptations?

> What are the likely impacts of new transport technologies on population distribution?

> What are the obstacles to the use of productivity-enhancing transportation solutions, from the provision of technologies by firms to consumer adoption decisions, and how can they be overcome?

> What are the drivers and impediments to the application of data and digital science to the transportation sector? How can the former be accelerated and the latter moderated?

Recommendation 4: Prepare the workforce for the transition to future transport models

To prepare the workforce for the disruption of new transport technologies, workers must be supported to develop STEM skills and obtain the qualifications, skills and training to adapt to changing roles and tasks.

> State and territory departments of education should strengthen the content and teaching of science, technology, engineering and mathematics (including digital and data technologies, design, and engineering principles) during upper primary and compulsory secondary schooling to encourage students to pursue university and VET courses in these areas

> Universities and VET institutions, in collaboration with industry, should provide and promote course options that will assist Australia's current and future workforce to develop the skills required to meet the demands of the future transport sector. These may include, but not be limited to, skills in data analysis and modelling, city planning, software development, geospatial technologies, network and data security, logistics, skilled trades, transport data administration and project management

Research priorities

> What are the skills requirements to meet future transportation needs, and how do these map on to existing incentives, provision, and accreditation processes? How should any gaps be addressed?

Contents

Abbreviations

Acronym	Expansion
ACO	Ant Colony Optimiser
ACOLA	Australian Council of Learned Academies
ACT	Australian Capital Territory
ADAS	Advanced Driver Assistance Systems
ADVI	Australia and New Zealand Driverless Vehicle Initiative
AEMO	Australian Energy Market Operator
AEVA	Australian Electric Vehicle Association
AI	Artificial Intelligence
AIMES	Australian Integrated Multimodal EcoSystem
AIS	Artificial Immune System
ANN	Artificial Neural Networks
AO	Order of Australia
ARA	Australian Railway Association
ARC	Australian Research Council
ARENA	Australian Renewable Energy Agency
ARRB	Australian Road Research Board
ATLAS	ARC Training Centre in Lightweight Automotive Structures
BCO	Bee Colony Optimization
BEV	Battery Electric Vehicles
BSW	Blind Spot/Lane Change Warning
CAV	Connected and Autonomous Vehicle
CAVI	Cooperative and Automated Vehicle Initiative
CBD	Central Business District
CEO	Chief Executive Officer
CFCW	Cooperative Forward Collision Warning
CHAD	Cooperative and Highly Automated Driving
CITI	Cooperative Intelligent Transport Initiative
C-ITS	Cooperative Intelligent Transport System
COAG	Council of Australian Governments
CRC	Cooperative Research Centre
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
CSW	Curve Speed Warning
DPTI	South Australian Planning, Transport and Infrastructure
DSRC	Dedicated Short Range Communications
EEBL	Electronic Emergency Brake Light
ERA	Excellence in Research Australia
EVI	Electric Vehicles Initiative
FASSA	Fellow of the Academy of Social Sciences in Australia
FCV	Fuel Cell Vehicles
FIR	Far Infrared
FLM	Fuzzy Logic Model
FTSE	Fellow of the Australian Academy of Technology and Engineering
GA	Genetic Algorithms
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning Systems
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency

Acronym	Expansion
IMA	Intersection Movement Assist
IMU	Inertial Measurement Unit
INS	Internal Navigation Systems
IoT	Internet of Things
ITS	Intelligent Transport Systems
LASP	Learned Academies Special Projects
LEV	Low and Zero Emission Vehicle
LiDAR	Light Detection and Ranging
Li-ion	Lithium-ion
LTE	Long Term Evolution
MaaS	Mobility-as-a-Service
MEMS	Micro-Electromechanical Systems
MIMO	Multiple-Input-Multiple-Output
ML	Machine Learning
NCAP	New Car Assessment Program
NEM	National Energy Market
NPI	National Positioning Infrastructure
NRMA	The National Roads and Motorists' Association
NSW	New South Wales
NT	Northern Territory
NTC	National Transport Commission
OBUs	On-Board Units
PSM	Public Service Medal
QLD	Queensland
QUT	Queensland University of Technology
R&D	Research and Development
RAC	Royal Automobile Club of Western Australia
RACV	Royal Automobile Club of Victoria
Radar	Radio Detection and Ranging
RFID	Radio Frequency Identification Detectors
RIAWS	Rural Intersection Active Warning System
RNOC	Road Network Operations Centre
RSUs	Roadside Units
RTA	Right Turn Assist
SA	Simulated Annealing
SA	South Australia
SBAS	Satellite Based Augmentation Systems
SLAM	Simultaneous Localisation and Mapping
STEM	Science, Technology, Engineering and Mathematics
TAC	Transport Accident Commission
TAG	Transit Australia Group
TAS	Tasmania
TMR	Queensland Department of Transport and Main Roads
TRB	Transportation Research Board (USA)
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VIC	Victoria
WA	Western Australia

1. Introduction

The Australian Academy of Technology and Engineering (the Academy) is undertaking a major three-year (2018–2020) research project to examine the readiness of Australian industry sectors to develop, adapt and adopt new and emerging technologies, with a horizon out to 2030. The project will identify suitable measures for technology awareness, adoption and impact, and allow measurement of the progress of Australian businesses and governments against defined criteria, metrics and indicators.

The project is primarily funded via an Australian Research Council (ARC) Learned Academies Special Projects (LASP) grant. Over the next three years the project will examine three to five industry sectors, with the transport sector being the first industry sector to be examined by the project.

1.1. The Australian Academy of Technology and Engineering

The Australian Academy of Technology and Engineering is an independent think tank comprised of leaders in the fields of applied science, technology and engineering, who gain Fellowship to the Academy in a highly competitive process. The Academy is one of Australia's four national Learned Academies, but uniquely our 900-strong Fellowship come from industry, government and research organisations, as well as academia. Our Fellowship develops trusted, informed and visionary positions to persuade decision-makers to implement the most progressive policies on the development of technology for the betterment of Australia and its people.

This project is linked to the Academy's major annual innovation policy event, the Academy National Technology Challenges Dialogue. The Dialogue seeks to examine critical topics in technology and innovation by assembling a leading group of experts from academia, government and industry. The Dialogue focuses on debate and discussion, with a view to identifying policy actions that could be taken to address the key challenges in each area.

1.2. Project background

Transport impacts on all sectors of the Australian economy and can facilitate or impede productivity and lifestyle improvements.

Fundamental technological advancements have the potential to revolutionise Australia's transport systems. However, the Australian economy also faces unprecedented disruption due to emerging technologies and global trends. This disruption will impact jobs at every level in the economy and may occur at a rapid pace.

Failure to be prepared will risk a decline in many aspects of our Australian way of life and society. However, with 0.3 per cent of the global population, Australia cannot expect to produce more than three to five per cent of the world's technology. To ensure our readiness, Australia needs to adopt all of the world's emerging technologies that are relevant to our country's needs. It is imperative that best-practice technology adoption/utilisation and technology invention is identified and encouraged in Australia.

The Academy has identified a number of key challenges that will impact on the Australian transport sector over the next decade, together with some enabling technologies and solutions that have the potential to achieve the desired outcomes. Specifically, the transport sector will need to lower emissions, improve the efficient movement of people and freight, and reduce transport-related deaths and serious injuries. The deployment of connected and autonomous vehicles (CAVs), low and zero emission vehicles (LEVs), high frequency mass transport, and intelligent transport systems (ITS) are potential solutions to these challenges. These are outlined in **Figure 2**.

Figure 2: Transport technologies and systems to address key 2030 challenges

CHALLENGES	ENABLING TECHNOLOGIES		POTENTIAL SOLUTIONS	OUTCOMES
SUSTAINABILITY AND CLIMATE CHANGE	Digital and Data Technologies	> Artifical Intelligence > Blockchain > Data management and analytics > Cybersecurity	Low and zero emissions vehicles	Reduced emissions
PRODUCTIVITY	Communications Sensing and Spatial Technologies	> Dedicated short range communications (DSRC) > Sensors > Spatial and mapping technologies > 5G networks > Internet of Things	Connected autonomous vehicles High frequency mass transit	Efficient movement of people and freight
HEALTH	Energy Technologies	> Batteries > Hydrogen > Supercapacitors	Intelligent transport systems	Reduced deaths and serious injuries

1.3.   Project objectives

The purpose of this report is to provide an overview of the development and applications of these transport technologies, and to identify Australia's research and industry strengths and weaknesses in their development and deployment. The report provides an assessment of Australia's readiness to develop, adopt, or adapt technological solutions to support desirable outcomes in the transport system, by examining each of the potential solutions across the following key readiness parameters:

> Infrastructure readiness

> Skills availability

> Social readiness

> Economic and commercial feasibility

> Policy and regulatory readiness

The key objectives of this project are therefore to:

> Examine the readiness of the transport sector to use new and emerging transport technologies to address key 2030 challenges, including sustainability and climate change, productivity, and health

> Gauge the technology readiness of the transport sector by undertaking targeted consultations with representatives from government, industry, academia and research

> Highlight future research opportunities to address the challenges that the sector will face in the decade to come

> Provide advice and recommendations to policy makers to assist with utilising existing and upcoming transport technologies for the purposes of facilitating industry readiness, and to address the issues of:

– Climate change and reducing emissions

– The efficient movement of people and freight

– Health, wellbeing and reducing deaths and serious injuries

1.4.   Project Steering Committee

The project has been guided by a committee of Fellows of the Academy and external experts:

> Ms Kathryn Fagg FTSE (Chair, Boral; former Board Member, Reserve Bank of Australia), co-chair

> Mr Drew Clarke AO PSM FTSE (Chair, AEMO; Director CSIRO, nbn; former Commonwealth Secretary), co-chair

> Mr David Thodey AO FTSE (Chair, CSIRO Board; former CEO, Telstra)

> Mr Michael Edwards FTSE (General Manager, Boeing Research Australia)

> Professor Edwina Cornish AO FTSE (former Provost, Monash University)

> Mr Phil Butler FTSE (Chairman, Textor Technologies)

> Professor Beth Webster FASSA (Pro Vice Chancellor Research Policy, Swinburne University)

> Professor Mark Dodgson AO FASSA (Professor of Innovation Studies, University of Queensland/Imperial College London)

> Professor Hugh Bradlow FTSE (Academy President; former Chief Scientist, Telstra)

> Professor Graham Currie FTSE (Professor of Public Transport, Monash University)

> Mr Ian Christensen (Managing Director, iMove Australia)

> Ms Marion Terrill (Transport Program Director, Grattan Institute)

2. Enabling technologies

Fundamental technological advancements have the potential to revolutionise Australia's transport systems[1]. Key groups of enabling technologies include:

> Digital and data technologies

> Communications, sensing and spatial technologies

> Energy technologies

This chapter gives an overview of new and emerging technologies that have the potential to affect the sustainability, productivity and safety of Australia's urban mobility and logistics sectors, and the potential applications of these enabling technologies. This chapter also considers Australia's research and industry strengths and weaknesses in regard to the development and deployment of these technologies.

2.1. Digital and data technologies

2.1.1. Artificial intelligence technologies

Applications

The development of artificial intelligence (AI) algorithms has the potential to affect many aspects of transport and logistics systems. In addition to the use of AI in autonomous vehicles, AI could be applied to support better planning and decision making in freight transport systems, or to automate traffic flow controls to streamline traffic and relieve congestion in connected transport systems. AI for maintenance of autonomous vehicles is a further opportunity for industry, with organisations such as SAP, IBM and Pivotal Labs already investing in this technology with a strong focus on data collection[2]. AI technologies also have potential cybersecurity applications, such as detecting whether an autonomous system has been compromised.

The successful application of AI will help relieve congestion, improve the reliability of travel time and improve the economics and productivity of the transport sector. To achieve this there must be a good understanding of the relationships between AI and data, and transportation system characteristics and variables[3].

The three primary capabilities of AI algorithms can be described as perception, prediction, and decision making:

> **Perception algorithms** process data from sensors such as cameras, microphones, radio detection and ranging (radar) and light detection and ranging (LiDAR) to form an understanding of the environment. AI technologies such as deep learning neural networks can be used to interpret images and language. The performance of object detection algorithms now surpasses the object detection ability of humans[4]

> **Prediction algorithms** analyse data to forecast travel choices, travel times, transport demand, the relationships between transport modes and behavioural choices. This data is used to plan, design, evaluate and regulate transport and supply chain systems[5]

> **Decision making algorithms** can use the insights from perception and prediction algorithms to automate actions or make suggestions. Examples of this include controlling vehicle speed and direction, suggesting faster travel routes, and making traffic control decisions to optimise traffic flow

Examples of AI methods that are finding their way to the transport field include Artificial Neural Networks (ANN), Genetic Algorithms (GA), Simulated Annealing (SA), Artificial Immune System (AIS), Ant Colony Optimiser (ACO), Bee Colony Optimization (BCO), and Fuzzy Logic Model (FLM)[6].

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Platforms

It is anticipated that AI technologies will be utilised by:

> Connected autonomous vehicle (CAV) platforms. For example, through Advanced Driver Assistance Systems (ADAS) (including sensors such as camera-based machine vision systems, radar-based detection units and sensor fusion engine control units), speech and gesture recognition, eye tracking, driver monitoring, virtual assistance and natural language interfaces[7]

> High frequency mass transit platforms. For example, the driving and scheduling of driverless buses and trains, and Mobility-as-a-Service (MaaS) solutions

> Intelligent transport system platforms. For example, through smart traffic lights that use machine vision and sensor data to adapt to road conditions in real-time[8]

Barriers and challenges

While AI technologies have great potential, significant challenges remain to be addressed, including:

> **Overcoming technical challenges.** It is essential that AI algorithms for autonomous vehicles have low latency and resilience to faults, and the ability to identify and react appropriately to uncommon objects and situations

> **Building trust.** A recent study of Australians' attitudes towards driverless vehicles reported that 37 per cent of survey respondents are positive about CAVs, 23 per cent are negative, and the remaining 40 per cent are neutral[9]. A survey poll of 28 countries found that Australians are less optimistic about the perceived benefits of CAVs than the global average. They are also more likely to trust governments to regulate CAVs over the companies that design and manufacture them[10]

Emerging technologies and ten year outlook

Australia has strong capacity in research and development (R&D) relating to AI technologies in the transport sector. The 2015 Excellence in Research for Australia evaluations show that many Australian universities are undertaking world class research in the field of *Artificial Intelligence and Image Processing*. While only the Australian National University was ranked 'well above' world standard (Excellence in Research Australia [ERA] Score 5), 12 institutions are ranked 'above' world standard (ERA Score 4) and a further 12 are considered to be 'at' world standard (ERA Score 3). Only three Australian universities performed below world standard (ERA Score of 2)[11].

Universities including Flinders University, La Trobe University, Curtin University, the University of New South Wales, University of Sydney and the University of Melbourne are running trials of autonomous vehicles[12–17], while the University of Western Australia has built two autonomous vehicles[18]. The Smart Rail Route Map, which includes a partnership between Rail Manufacturing Cooperative Research Centre, the Australasian Railway Association, and Deakin University, outlines a vision for technology in the rail industry over the next 30 years[19].

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The Gartner Hype Cycle assesses whether technologies or applications are based on hype or commercially viable through an analysis of the maturity and adoption of technologies and applications and their potential to evolve over time to solve real business problems and create new opportunities[20]. The 2017 *Gartner Hype Cycle for Emerging Technologies* placed many AI technologies, including autonomous vehicles, at the 'Peak of Over-Inflated Expectations'[21]. This indicates that although early publicity of these technologies may have produced a number of success stories, they are also accompanied by a large number of failures[22].

Data61, the Commonwealth Science and Industrial Research Organisation (CSIRO)'s data science consultancy, is another hot spot of AI R&D in Australia. Data61 has the highest concentration of data scientists in Australia, and emphasises industry engagement and the application of data science, including AI and machine learning (ML) to real world problems[23]. Data61, in partnership with Chinese company ZongMu Technology, have developed algorithms to estimate the space between objects according to a vehicle's motion and predict the potential hazards of moving objects, essentially allowing the vehicle to see via computer vision[24].

The Federal Government's Cooperative Research Centre (CRC) Program has provided funding to establish the iMOVE CRC, a consortium of 44 stakeholders undertaking collaborative R&D projects that seek to apply digital, data and other emerging technologies to improve Australia's transport and mobility systems.

Current trials include the Cooperative and Highly Automated Driving (CHAD) Pilot, a partnership between the Queensland University of Technology (QUT) and the Queensland Government Department of Transport and Main Roads, supported by iMOVE CRC[25]. The trial will involve an electric car fitted with high-tech AI sensors being driven around Queensland for three months covering 1200 kilometres. The project will look at how the automated vehicle's AI system adapts to Australian road conditions in four main areas:

> Lane markings

> Traffic lights

> Street signage

> Overcoming the limitations of Global Positioning Systems (GPS) for vehicle positioning in built-up areas and tunnels

2.1.2. Blockchain

Applications

A blockchain is a decentralised and distributed digital public ledger that validates and records transactions in a form that is permanent and unalterable. The technology was originally developed for use with the cryptocurrency bitcoin, but has since been applied to an ever-expanding list of cryptocurrencies and commercial applications.

Blockchain has the potential to greatly impact transport systems, especially in the logistics sector. Advocates of blockchain suggest that it will be able to provide solutions such as efficient and secure smart contracts, real-time tracking of freight, and proof of provenance in long supply chains. Blockchain also has potential for major disintermediation. Its capacity to automate the creation of trust prospectively enables direct transactions between unrelated and remote parties without the need for agents and banks to intermediate. This presents major opportunities to improve the productivity of international trade.

Platforms

It is anticipated that blockchain will be utilised by:

> CAV platforms, through the management of vehicle data, increased communications between vehicles, communication between vehicles and the network, and the mitigation of cybersecurity risks[26]

> High frequency mass transit platforms to improve MaaS platforms, integrated journeys and smart ticketing

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26. Dagan, G. How blockchain might augment the self-driving revolution. *Medium*. https://medium.com/orbs-network/intersections-per-second-how-blockchain-might-drive-the-self-driving-revolution-346112f8e0d1 16 July 2018.

> Intelligent transport system platforms, through transit payment systems and the use of data to track maintenance issues, vehicle tracking and safety issues[27]

Barriers and challenges

While many believe that blockchain has great potential, most initiatives are in the early stages and there are few proven use cases[28]. In 2018, the *Gartner Hype Cycle for Emerging Technologies* placed blockchain in the 'Trough of Disillusionment'[29] but predicted that it would reach maturity within 5-10 years. Others have described blockchain as a powerful "proof of concept" that is not yet commercially ready[30]. A key challenge for blockchain's use in logistics is data standardisation. In 2017, Standards Australia released a *Roadmap for Blockchain Standards*[31].

Emerging technologies and ten year outlook

A Swiss technology firm has demonstrated the use of a blockchain-style ledger system, sensors and internet-of-things technology to monitor and record temperature, humidity and location of cold-chain airfreight containers for biopharmaceutical products. After successful trials of blockchain technology, IBM and Danish shipping company Maersk announced a joint venture to commercialise a blockchain-based freight tracking system designed to replace paperwork with tamper-resistant digital records[32].

The Blockchain in Transport Alliance are an international membership organisation working on development of a common framework and standards for blockchain applications in the freight industry[33]. Data61 has also conducted research into blockchain technology, including the technical opportunities and challenges of using blockchain to improve supply chain visibility and efficiency and track provenance in an agricultural supply chain[34].

Blockchain also has potential applications in transport infrastructure management. Data61 suggests that distributed ledgers could be used "to better predict infrastructure failures, and consequently prioritise preventative maintenance through the analysis of data from their own, and third-party devices"[35].

A number of Australian universities are conducting research on blockchain technologies. The University of Sydney has created a blockchain technology suitable for both public and private uses that is claimed to be one of the fastest available[36]. RMIT University's Blockchain Innovation Hub is focused on the social and economic consequences of blockchain technology[37]. RMIT also launched Australia's first course on blockchain in 2018[38]. The University of New South Wales has an interdisciplinary Interest Group in Blockchain, Smart Contracts and Cryptocurrency which is engaging with stakeholders around these distributed ledger technologies. The Australian Government is also taking blockchain's potential seriously, committing $700,000 in the 2018-19 Federal Budget for the Digital Transformation Agency to investigate the benefits of using blockchain for government services[39].

Australia has a number of businesses and start-up companies developing blockchain-based offerings[40]. A small number of these are addressing challenges in the logistics sector. Examples include:

> TBSx3, a start-up applying blockchain, internet-of-things, and other technologies to provide product tracking and provenance information to logistics chains[41]

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27. Mire, S. Blockchain in public transportation: 7 possible use cases. *Disruptor Daily.* https://www.disruptordaily.com/blockchain-use-cases-public-transportation/ 3 December 2018.
28. Panetta, K. Top trends in the Gartner Hype Cycle for Emergeing Technologies, 2017. *Garnter.* https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/ 15 August 2017
29. "Interest wanes as experiments and implementations fail to deliver. Producers of the technology shake out or fail. Investments continue only if the surviving providers improve their products to the satisfaction of early adopters." https://www.gartner.com/en/research/methodologies/gartner-hype-cycle
30. Fitzgerald, S. Blockchain and the supply chain. *iMove CRC.* https://imovecrc.com/news-articles/freight-and-logistics/blockchain-and-the-supply-chain/ 22 May 2018.
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33. Blockchain in Transport Alliance. https://bita.studio/
34. Staples, M., Chen, S., Falamaki, S., Ponomarev, A., Rimba, P., Tran, A. B., Weber, I., Xu, X., Zhu, J., (2017) Risks and opportunities for systems using blockchain and smart contracts. Data61 (CSIRO), Sydney.
35. Hanson RT, Reeson A, Staples M (2017) Distributed Ledgers, Scenarios for the Australian economy over the coming decades, Canberra.
36. McLean, A. University of Sydney builds new Red Belly Blockchain technology. *ZDNet.* https://www.zdnet.com/article/university-of-sydney-builds-new-red-belly-blockchain-technology/ 3 July 2017.
37. https://sites.rmit.edu.au/blockchain-innovation-hub/
38. Australian Associated Press. You can now study Blockchain at university. *Sydney Morning Herald.* https://www.smh.com.au/business/markets/you-can-now-study-blockchain-at-university-20180220-p4z0wz.html 20 February 2018
39. Digital Transformation Agency. Budget 2018-19 for the DTA. https://www.dta.gov.au/news/Budget-2018-19-for-the-DTA/ 9 May 2018
40. Australian Trade and Investment Commission. Australian blockchain mission to consensus 2018, https://www.austrade.gov.au/ArticleDocuments/1422/Austrade%20Consensus%20Directory%20FINAL%2020180508.pdf.aspx?Embed=Y 13-16 May 2018
41. TBSx3. https://tbsx3.com/

> Blockgrain, a start-up developing blockchain solutions for the agriculture sector including supply chain tracking and automation, proof of origin, smart contracting, and stock management[42]

> DOCKX, a blockchain-based shipping and logistics solution[43]

2.1.3. Data management and analytics

Applications

The increased availability of data and powerful tools for its management and analysis presents opportunities for the improved management of transport systems. The analysis of historical and real-time data presents diverse opportunities include proactive maintenance planning, enhanced journey planning, and improved traffic management and urban planning. Managing the availability of open data while ensuring appropriate privacy and security measures is important[44]. The Federal Government has committed to releasing more non-sensitive public data to support private sector innovation and to using this data to improve service delivery and to inform policy.

Cybersecurity is a critical element of autonomous vehicle and traffic control data and analytics technologies due to the high safety risk that could be posed by a hacked vehicle or traffic control system. Cybersecurity provides protection against unwanted access, control, damage, or theft of private digital property by unauthorized third parties, and is a crucial issue for digital systems.

Platforms

It is anticipated that data management and analytics will be utilised by:

> CAV platforms, through the management of vehicle data, increased communications between vehicles, and vehicles and the network, and the mitigation of cybersecurity risks[45]

> High frequency mass transit platforms to improve MaaS platforms, timetables and scheduling, integrated journeys and smart ticketing

> Intelligent transport system platforms, through transit payment systems and the use of data to track maintenance issues, vehicle tracking and safety issues[46]

Barriers and challenges

The United States, the United Kingdom and the European Union have established best practices, principles and recommendations to address the cybersecurity of modern vehicles. Australia has not yet established similar guidelines[47], although significant progress is being made, with the Commonwealth's Department of Infrastructure, Regional Development and Cities working to strengthen the cybersecurity of automated vehicles, and ensuring the information and data produced by automated vehicles is not misused and people's privacy is protected[48]. There is widespread acceptance by Australian road authorities that the European approach to cybersecurity of intelligent transport systems will be adopted.

Emerging technologies and ten year outlook

At the University of Melbourne, the Transport Technologies research group has established the Australian Integrated Multimodal EcoSystem (AIMES) in collaboration with other members of the iMOVE CRC. AIMES is a real-world transport test bed, incorporating 100 kilometres of Melbourne roads on the fringe of Melbourne's central business district (CBD). Up to 1,000 sensors will collect data on vehicle and pedestrian movement, and public transport use within the AIMES area. Data from these sensors is being collected and analysed to evaluate how it can be used to improve journey reliability, mitigate congestion, and improve transport management[49].

42. AgriChain. https://blockgrain.io/
43. DOCKX. https://www.dockx.io/
44. Transport for NSW. Future transport technology roadmap 2016. https://future.transport.nsw.gov.au/sites/default/files/media/documents/2018/Future-Transport-Technology-Roadmap_2016_.pdf 2016
45. Dagan, G. How blockchain might augment the self-driving revolution. *Medium.* https://medium.com/orbs-network/intersections-per-second-how-blockchain-might-drive-the-self-driving-revolution-346112f8e0d1 16 July 2018.
46. Mire, S. Blockchain in public transportation: 7 possible use cases. *Disruptor Daily.* https://www.disruptordaily.com/blockchain-use-cases-public-transportation/ 3 December 2018.
47. Zia, T. Australia's car industry needs cybersecurity rules to deal with the hacking threat. *The Conversation.* https://theconversation.com/australias-car-industry-needs-cybersecurity-rules-to-deal-with-the-hacking-threat-82268 21 August 2017.
48. Commonwealth of Australia. Automated vehicles in Australia. *Department of Infrastructure, Regional Development and Cities.* https://infrastructure.gov.au/transport/automatedvehicles/index.aspx 1 December 2017.
49. Fitzgerald, S. Data use for improved transport management and journey reliability. *iMove CRC.* https://imovecrc.com/project/data-use-for-improved-transport-management-and-journey-reliability/ 7 May 2018.

Cubic Transport Systems is also undertaking a similar exercise for the Roads and Maritime Service in New South Wales, while the Road Network Operations Centre (RNOC) in Perth has opened a high-tech Main Roads operations centre[50], and Monash University's Public Transport Research Group is undertaking research exploring the availability of big data sets and how they can be mined and visualised to usefully inform decision making[51].

SAGE Automation collaborate with industry, research and government to plan, trial and integrate technologies required for the uptake of CAV technologies[52]. In Victoria, SAGE Automation delivered the longest stretch of continuous managed motorway ever completed in a single intelligent transport system (ITS) project[53]. In New South Wales SAGE Automation developed lane changing technologies to reduce congestion and provide seamless experience to road users, managing bi-directional traffic flow of 160,000 vehicles per day as they cross the Sydney Harbour Bridge[54].

Additionally, in collaboration with iMOVE CRC, the Queensland Department of Transport and Main Roads (TMR) is developing the world's first operational credential management system for CAVs as part of their Cooperative and Automated Vehicle Initiative (CAVI) program[55].

2.2. Communications, sensing and spatial technologies

The successful deployment of autonomous vehicles is dependent on the ability of the control system to exceed the capabilities of human drivers[56]. Communications, sensing and spatial technologies are fundamental to the safe and efficient operation of autonomous vehicles and driver assisted systems. Rapidly developing technologies each have their own strengths and limitations, and subsequently have the most power when used in combination with one another.

2.2.1. Cooperative Intelligent Transport Systems and Dedicated Short Range Communication

Applications

Cooperative Intelligent Transport System (C-ITS) is a rapidly developing transport technology that allows drivers to receive alerts about potential road hazards and traffic information. Dedicated Short Range Communications (DSRC) is a communications protocol that has been developed to support low latency vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) communications. The purpose of this technology is to provide high speed, low latency communications between vehicles, and between vehicles and infrastructure. DSRC also benefits road users by providing real-time advisories alerting drivers to imminent hazards, resulting in the development of safer vehicles and roads, enhanced mobility, decreased traffic congestion and reduced environmental impacts[57,58].

DSRC is effective for communicating between fast-moving vehicles (V2V), stationary infrastructure (V2I), and a range of mobile devices (V2X), as it allows reliable, secure, high-speed and low latency communication via short-to-medium range wireless vehicle on-board units (OBUs) or roadside units (RSUs) operating on the 5.9GHz band[59]. DSRC can also compete with, or complement 5G communication systems.

C-ITS and DSRC functions include collision avoidance and hazard detection. Some of the key applications of these technologies include Intersection Movement Assist (IMA), Right Turn Assist (RTA), Cooperative Forward Collision Warning (CFCW), Electronic Emergency Brake Light (EEBL), Overtake/Do Not Pass Warning, Blind Spot/Lane Change

50. Government of Western Australia. High-tech control room for Perth's roads open. https://www.mediastatements.wa.gov.au/Pages/McGowan/2018/10/High-tech-control-room-for-Perths-roads-opens.aspx 5 October 2018.
51. Public Transport Research Group. Mining Big data and visualisation. http://publictransportresearchgroup.info/portfolio-item/mining-big-data-and-visualisation/ 27 February 2017
52. https://www.gotosage.com/industries-smart-transportation
53. https://www.sageautomation.com/our-work-smart-transportation-stories/delivering-victorias-longest-managed-motorway-project
54. Sage Automation. Sydney Harbour Bridge smart signs allow faster incidence response time. https://www.sageautomation.com/our-work-smart-transportation-stories/sydney-harbour-bridge-smart-signs-allow-faster-incident-response-time
55. Fitzgerald, S. C-ITS pilot security credential management system: evaluation and research. *iMove CRC*. https://imovecrc.com/project/c-its-pilot-security-credential-management-system/ 17 April 2018.
56. Gilbertsen, C. Here's how the sensors in autonomous cars work. *The Drive*. http://www.thedrive.com/tech/8657/heres-how-the-sensors-in-autonomous-cars-work 27 March 2017.
57. Austroads (2017). Safety benefits of C-ITS and automated driving in Australia and New Zealand. https://researchmgt.monash.edu/ws/portalfiles/portal/241124499 October 2017.
58. Transport for NSW. Cooperative Intelligent Transport Systems. http://roadsafety.transport.nsw.gov.au/research/roadsafetytechnology/cits/index.html 21 August 2017
59. Pearce, R. ACMA releases class licence for intelligent transport systems. *Computerworld*. https://www.computerworld.com.au/article/632053/acma-releases-class-licence-intelligent-transport-systems/ 11 January 2018.

Warning (BSW), Emergency Vehicle Approach Warning, Red Light Violation Warning, Rail Level Crossing Warning, Curve Speed Warning, Roadworks Warning and Queue Warning[60].

Platforms

It is anticipated that C-ITS and DSRC technologies will be utilised by:

> CAV platforms, through the use of V2V, V2I and V2X communications. For example, V2V communications can provide warnings that the car ahead is braking suddenly, while V2I communication can alert a driver to upcoming sharp curves in the road. V2I technology also has the capacity to communicate the availability of e-parking services and process toll payments

> High frequency mass transit platforms, through the use of DSRC to collect, process, integrate, and sort data to better inform decisions and optimise the performance of traffic networks in real time

> Intelligent transport system platforms, through the use of DSRC to collect, process, integrate, and sort data to better inform decisions and optimise the performance of traffic networks in real time

Barriers and challenges

Challenges facing the deployment of DSRC technologies in Australia include:

> Differences in the regional allocation of the radiofrequency bands used by DSRC technologies mean that some vehicles imported into Australia may still transmit on different frequencies, rendering their DSRC technologies obsolete[61]

> Some vehicles may include radiocommunications equipment that is not licensed for use in Australia, and could cause interference to other existing licensed users

Emerging technologies and ten year outlook

DSRC systems are anticipated to undergo further development as their transfer of information with other technologies becomes more advanced.

Toyota and Lexus will begin deployment of DSRC systems on vehicles sold in the United States starting in 2021, with the goal of adoption across most of its line-up by the mid-2020s[62]. However, with the upcoming 5G update to the cellular network, cellular technology is emerging as a possible alternative to DSRC[63]. A hybrid of both technologies is also possible.

2.2.2. 5G wireless networks

Applications

The 5G wireless network represents an upgrade to the currently operating 4G network, and is expected to be available in Australia by 2019 (**Table 3**)[64]. As communication networks are a key component in the effectiveness of automation, the continuous connectivity provided by 5G is considered to be critical in enabling a transport system of the future, and will significantly enhance the capabilities and evolution of autonomous vehicles.

5G is less developed than DSRC, but it has the backing of telecommunications companies who hope to support 5G via their existing 3G/4G infrastructure. DSRC also differs from 5G to the extent that the DSRC band has been allocated to safety critical operations, whereas 5G has the potential for safety critical signals such as V2V and V2I to be crowded out by general traffic.

A key issue for both 5G and DSRC is that they both operate at high frequencies. This means they both need 'line of sight' visibility to maintain connection, and they are prone to obstruction by buildings and infrastructure. This subsequently makes it difficult and expensive to establish ubiquitous coverage (as a lot of base stations are required), impacting on the deployment and effectiveness of both technologies.

60. Austroads (2017). Safety benefits of C-ITS and automated driving in Australia and New Zealand. https://researchmgt.monash.edu/ws/portalfiles/portal/241124499 October 2017.

61. Austroads (2014). Austroads Submission to the 2014 Review of the Motor Vehicle Standards Act 1989. https://infrastructure.gov.au/vehicles/mv_standards_act/files/Sub136_Austroads.pdf

62. Sharma, R. Toyota and Lexus to add V2X and DSRC technology to vehicles starting 2021. *The Fast Mode.* https://www.thefastmode.com/technology-solutions/12458-toyota-and-lexus-to-add-v2x-and-dsrc-technology-to-vehicles-starting-in-2021 18 April 2018

63. Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2017, Costs and benefits of emerging road transport technologies, Report 146, BITRE, Canberra ACT. https://bitre.gov.au/publications/2017/files/research-report-146-emerging-road-transport-technologies.pdf

64. Reilly, C. Telstra is promising 5G services in Australia by 2019. *cnet.* https://www.cnet.com/au/news/telstra-is-promising-5g-services-in-australia-by-2019/ 26 February 2018.

It is anticipated that the deployment of 5G could have the potential to improve safety, situational awareness and efficiency in the transportation sector, through the delivery of high reliability, high bandwidth, low latency and accurate position determination of vehicles, and the enhancement of communications, sensing and spatial technologies[65]. The integration of 5G technology within autonomous vehicles will also allow technical problems within the vehicles to be reported to the manufacturers, and allow for remote updates to be made to vehicle firmware[66].

The deployment of the 5G network will also allow connectivity and the transfer of data between vehicles and infrastructure via the cloud. Data in the cloud will be constantly updated by the collective intelligence of the vehicles. The utilisation of data stored in the cloud by autonomous vehicles will essentially extend the physical reach of data provided by sensors, by providing vehicles with an up to date image of their surrounding environment[67].

However, 5G and the development and deployment of autonomous vehicles won't necessarily go hand-in-hand, with not all applications used within autonomous vehicles requiring connectivity[68]. Although autonomous vehicles can operate effectively without connectivity, for instance using high-precision maps and sensors, the addition of connectivity can significantly enhance functionality. Successful rollout of connected automated vehicles functioning at the highest level requires mobile internet coverage across the whole road network.

Table 3: Summary of wireless networks

Jurisdiction	Year of Deployment	Characteristics
5G		Proposed improved connectivity, greater network speeds and bandwidth, very low latency
4G	Deployed 2009	Long Term Evolution (LTE) introduced supporting improved mobile broadband (increased capacity and speed for data)
3G	Deployed 2001	Introduced data services
2G	Deployed 1991	> Switched to digital standards > Improved voice messaging > Introduction of short message service (SMS)
1G	Deployed early 1980's	> First generation > Basic voice service using analogue transmission

Steps towards launching the use of 5G in the transport sector in Australia have included the launch of the Telstra 5G Innovation Centre on the Gold Coast, and the first trial of 5G in a moving vehicle in early 2018[69]. The Australian Government is also supportive of the deployment of 5G networks, and has established the 5G Working Group to identify opportunities and emerging issues on 5G[70].

Platforms

It is anticipated that 5G wireless networks will be utilised by:

> CAV platforms, through the rapid and reliable processing and analysis of data generated sensors, spatial technology and mapping, and IoT technologies. CAV platforms will also be significantly enhanced by 5G through the collection, transfer and analysis of data between the vehicle, transport infrastructure and the cloud

> High frequency mass transit platforms, through the provision of real-time information to commuters through smart phones, and the capability to book on-demand transport services through mobile applications for the flexible planning of journeys

65. 5G Americas. White Paper: Cellular V2X Communications Towards 5G http://www.5gamericas.org/files/9615/2096/4441/2018_5G_Americas_White_Paper_Cellular_V2X_Communications_Towards_5G_Final_for_Distribution.pdf March 2018.
66. Kasniqi, X. and Hajrizi, E. (2016). Use of IOT technology to drive the automated industry from connected to full autonomous vehicles. 17th IFAC Conference on International Stability, Technology and Culture TECIS 2016: Durres, Albania, 26-28 October 2016. IFAC-PapersOnLine. 49, 29: 269-274. https://doi.org/10.1016/j.ifacol.2016.11.078
67. Gilbertsen, C. Here's how the sensors in autonomous cars work. *The Drive.* http://www.thedrive.com/tech/8657/heres-how-the-sensors-in-autonomous-cars-work 27 March 2017.
68. Santo, B. 5G and autonomous vehicles might not go hand-in-hand. *EDN Network.* https://www.edn.com/electronics-blogs/5g-waves/4461460/5G-and-autonomous-vehicles-might-not-go-hand-in-hand 10 January 2019.
69. Reilly, C. 5G future nears as Telstra completes first Australian live test. *cnet.* https://www.cnet.com/au/news/5g-future-nears-as-telstra-completes-australia-first-live-test/ 20 September 2016.
70. Commonwealth of Australia. Australian Government response to the House of Representative Standing Committee on Industry, Innovation, Science and Resources report: Social iisues relating to land-based automated vehicles in Australia. https://infrastructure.gov.au/department/ips/files/government-response-automated-vehicles.pdf June 2018.

> Intelligent transport systems, through the use of connected and integrated information platforms to rapidly inform active traffic network management and planning

Barriers and challenges

Challenges that have been identified in the use of the 5G network and cloud based technologies in the transport sector in Australia include:

> Reliability of connection to 5G network (dependent on line of sight connection)

> Predicted future gaps in 5G network coverage, particularly in rural areas

> Processing times of big data. Industry forecasters expect the first generation of autonomous vehicles to generate and consume up to 4 terabytes of data per day[71]

> Real time data updates

Emerging technologies and ten year outlook

With the anticipated deployment of 5G in 2019, attention is already turning to the development of a 6G network and how it will impact on autonomous vehicles. While 5G aims to connect high-speed devices such as computers, smartphones and connected cars, 6G will be mostly an Internet of Things (IoT) network. It is anticipated that 6G will provide speeds in the tens of terabytes per second[72].

The introduction of 6G will further revolutionise the transport industry through its support of autonomous vehicles, platooning and intelligent roads. This will likely be achieved through wideband inter-car links, which communicate data and measure vehicle locations, and anticipate movement and proximity to avoid collisions[73].

2.2.3. Sensors

Sensor technologies are crucial to enabling smart cities and autonomous vehicles. While camera, radar and LiDAR[74] systems are the key sensor types in current autonomous vehicles[75], they may also include ultrasonic sensors, odometery sensors and infrared sensors.

The types of sensors and sensor driven actuators that enable autonomous vehicles can be classified by the purpose for which their signal is used; navigation and guidance, driving and safety, and performance[76]. These different sensors communicate with each other and integrate various sources of sensor-derived data, to better handle and respond to complex data and changing conditions that would otherwise affect the functionality of individual sensors[77].

Cameras

Applications

Cameras are one of the key sensors used in autonomous vehicles. An array of cameras is situated around the vehicle so as to create a 360 degree view, allowing the vehicle to see and interpret its surroundings.

In contrast to other sensors, cameras largely imitate human eyesight. They are able to identify and interpret traffic signs, signals and lane markings, distinguish between variations in colour, and act as a reliable backup system should the other sensors fail[78]. However, computers can struggle to correctly interpret camera images under some circumstances. The car's control system attempts to compensate by comparing images from multiple cameras and its other sensors. When the control system suffers too much internal ambiguity it will revert to one of its safe modes (including reverting to manual control).

71. Sistani, B. 5G connectivity helps pave the wave for full autonomous driving. *Samsung*. https://www.samsungsemiblog.com/insights-on-innovation/5g-connectivity-helps-pave-the-way-for-full-autonomous-driving/ 6 December 2018.
72. Valerio, P. 5G is already here; 6G will arrive soon. *IoT Times*. https://iot.eetimes.com/5g-is-already-here-6g-will-arrive-soon/ 19 June 2018.
73. Valerio, P. 5G is already here; 6G will arrive soon. *IoT Times*. https://iot.eetimes.com/5g-is-already-here-6g-will-arrive-soon/ 19 June 2018.
74. Muoio, D. Google just made a big move to bring down the cost of self-driving cars. *Business Insider*. https://www.businessinsider.com.au/googles-waymo-reduces-lidar-cost-90-in-effort-to-scale-self-driving-cars-2017-1?r=US&IR=T 9 January 2017.
75. Rudolph, G. Three sensor types drive autonomous vehicles. *Sensors Online*. https://www.sensorsmag.com/components/three-sensor-types-drive-autonomous-vehicles 10 November 2017.
76. Schweber, Bill. The autonomous car: a diverse array of sensors drives navigation, driving and performance. *Mouser Electronics*. https://au.mouser.com/applications/autonomous-car-sensors-drive-performance/ 2019
77. Altaweel, M. Spatial challenges of navigating rural roads for self-driving cars. *GIS Lounge*. https://www.gislounge.com/spatial-challenges-navigating-rural-roads-self-driving-cars/ 15 May 2018.
78. Gilbertsen, C. Here's how the sensors in autonomous cars work. *The Drive*. http://www.thedrive.com/tech/8657/heres-how-the-sensors-in-autonomous-cars-work 27 March 2017.

Platforms

It is anticipated that camera technologies will be utilised by:

> CAV platforms, in combination with other on board sensors to navigate and interact appropriately with its environment
> High frequency mass transit platforms
> Intelligent transport systems platforms, through the use of cameras to collect and manage data on autonomous public transport, including planes, trains and buses

Barriers and challenges

Challenges facing the use of camera-based sensor technologies in Australia include:

> Cameras face the same challenges as human eyes when faced with the difficult environmental conditions encountered in Australia, such as bright sunlight, glare and low light conditions
> Cameras may face mechanical issues, such as correct setup and being kept clean. This may prove difficult in dusty and dirty environments[79]
> Significant graphic processing is required to interpret the images produced by cameras

Emerging technologies and ten year outlook

With future technologies anticipated to use increasingly larger amounts of data, there is a challenge to keep processing times to a minimum. Researchers from Stanford University have created a hybrid optical-electrical computer designed specifically for image analysis that utilises AI for faster image classification and greater energy efficiency[80].

To improve visibility in cameras, Israeli company Foresight Autonomous Holdings have created the QuadSight detection system. This stereoscopic automotive vision system uses two sets of stereo cameras, one infrared and the other working with visible light, to detect any obstacles on the road[81]. The system can detect obstacles regardless of adverse weather and lighting conditions, as well as shape, material and colour, making it a highly reliable option for autonomous vehicles.

Tesla has also been undertaking trials with trifocal mono cameras which aim to expand the system's detection capacity by considering views at varying distances[82].

Seeing Machines is an Australian-based company that uses computer vision algorithms, optics and processing technologies to accurately measure a driver's visual attention to their environment, gauge if the driver is becoming drowsy, and alert the driver and the vehicle to their risk level in real-time[83].

Radar

Applications

Radar is an object-detection system that uses radio waves to determine how far away an object is, and how fast it is approaching.

The use of radars in autonomous vehicles is key in the development of ADAS, which constitute an intermediate stage in the development of self-driving vehicles[84]. Short and long-range radars are primarily used in autonomous vehicles for the monitoring of blind spots, lane change and parking assistance, collision avoidance, emergency braking and automatic distance control.

Platforms

It is anticipated that radar technologies will be utilised by:

79. Schweber, Bill. The autonomous car: a diverse array of sensors drives navigation, driving and performance. *Mouser Electronics.* https://au.mouser.com/applications/autonomous-car-sensors-drive-performance/ 2019
80. Myers, A. Stanford engineers create new AI camera for faster, more efficient image classification. *Stanford News.* https://news.stanford.edu/2018/08/17/new-ai-camera-revolutionize-autonomous-vehicles/ 17 August 2018.
81. NetworkNewsWire. Sensor system companies take center stage in a seflf-driving future. *Cision.* https://www.prnewswire.com/news-releases/sensor-system-companies-take-center-stage-in-a-self-driving-future-683317551.html 22 May 2018.
82. NetworkNewsWire. Sensor system companies take center stage in a seflf-driving future. *Cision.* https://www.prnewswire.com/news-releases/sensor-system-companies-take-center-stage-in-a-self-driving-future-683317551.html 22 May 2018.
83. Seeing Machines. https://www.seeingmachines.com/technology/ 2019
84. Pickering, P. The radar technology behind autonomous vehciles. *ECN Mag.* https://www.ecnmag.com/article/2017/12/radar-technology-behind-autonomous-vehicles 12 July 2017.

> CAV platforms, through the use of connected on-board cameras, radars, LiDAR, thermal and ultrasonic sensors to obtain and analyse information using complex computer algorithms, so that the vehicles may respond appropriately in safety-critical situations

> High frequency mass transit platforms, through the use of connected sensors in autonomous public transport including trains and buses

> Intelligent transport systems, through connected ticketing systems, such as radio frequency identification detectors (RFID) for contactless ticketing

Barriers and challenges

Challenges facing the use of radar based sensor technologies in Australia include:

> Radar interference

> Radars may also experience perception problems or errors. Humans will be requested to resume control when the automated driving system is no longer capable of maintaining appropriate control. This may or may not be an automatic response to degraded performance by the radar

> As 2D radars are only capable of scanning horizontally, they cannot determine an object's height. This may cause issues when driving beneath a structure. 3D radars currently being developed would solve this issue[85]

Emerging technologies and ten year outlook

Over the next decade radar technologies in autonomous vehicles will render more information, be more flexible and will also be smaller, cheaper and more reliable. To achieve this, future radar signal processing will be enhanced by machine learning, image understanding and pattern recognition concepts[86]. As such, the number of radar sensors in cars is expected to significantly increase. Multiple-Input-Multiple-Output (MIMO) radars are one such technology that will improve the coverage, data rate and/or signal quality[87], while Israeli developer Arbe Robotics are looking to test four-dimensional high-resolution imaging radar. It is anticipated that this technology will have the capability to outperform LiDAR[88].

Other new opportunities for radar that are currently emerging include vital-sign driver monitoring systems, chassis-to-ground monitoring, and hands-free trunk opening[89].

LiDAR

Applications

Rapid decision making in response to changing situations is paramount to the safety of autonomous vehicles.

LiDAR technology uses high-speed and high-power pulses of laser light to create a 3D map of the vehicle's surroundings, allowing the vehicle to detect static and moving objects in detail in daylight and night time[90].

LiDAR is able to capture a 360 degree view around the vehicle, which is primarily achieved using a rotating, scanning mirror assembly on the top of the car[91]. When used in combination with data obtained from other sensors, the vehicle's position, speed, and direction relative to external objects, such as other vehicles or pedestrians, can be used to determine, and act upon, the probability of collision[92,93].

85. Gilbertsen, C. Here's how the sensors in autonomous cars work. *The Drive.* http://www.thedrive.com/tech/8657/heres-how-the-sensors-in-autonomous-cars-work 27 March 2017.

86. Dickmann, Juergen. (2016). Automotive Radar the Key Technology For Autonomous Driving: From Detection and Ranging to Environmental Understanding. https://www.researchgate.net/publication/301960180_Automotive_Radar_the_Key_Technology_For_Autonomous_Driving_From_Detection_and_Ranging_to_Environmental_Understanding?enrichId=rgreq-80433b6d9ce3c856b22fe5f98063007b-XXX&enrichSource=Y292ZXJQYWdlOzMwMTk2MDE4MDtBUzozNjQ4NDE1Mzg3MzYxMjhAMTQ2Mzk5NjQwOTI3NQ%3D%3D&el=1_x_2&_esc=publicationCoverPdf

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91. Lloyd, M. Driverless cars are now tested on our roads, so should we be worried? *ABC News.* http://www.abc.net.au/news/2018-03-23/should-we-worry-about-driverless-cars-being-tested-on-our-roads/9569056 23 March 2018.

92. Schweber, Bill. The autonomous car: a diverse array of sensors drives navigation, driving and performance. *Mouser Electronics.* https://au.mouser.com/applications/autonomous-car-sensors-drive-performance/ 2019

93. Gilbertsen, C. Here's how the sensors in autonomous cars work. *The Drive.* http://www.thedrive.com/tech/8657/heres-how-the-sensors-in-autonomous-cars-work 27 March 2017.

Platforms

It is anticipated that LiDAR technologies will be utilised by:

> CAV platforms, through the use of connected on-board cameras, radars, LiDAR, thermal and ultrasonic sensors to obtain and analyse information using complex computer algorithms, so that the vehicles may respond appropriately in safety-critical situations
> High frequency mass transit platforms, through the use of connected sensors in autonomous public transport including trains and buses

Barriers and challenges

Challenges facing the use of LiDAR based sensor technologies in Australia include:

> The specifications of the current LiDAR technology have a slow response time[94]
> LiDAR may also experience perception problems or errors[95]
> LiDAR is unreliable in adverse weather conditions, such as rain, fog and snow
> LiDAR technology must be used in combination with other sensors, as it is not as effective when approaching an object, such as in heavy traffic[96]
> LiDAR technology is expensive. Research is currently being undertaken to redesign the technology to significantly decrease the cost of the product, while enhancing the detection distance[97]

Emerging technologies and ten year outlook

Emerging LiDAR technologies developed by Australian company, Baraja, have replaced the use of rotating lasers and moving mirrors with Spectrum Scanning LiDAR technologies. This technology utilises lasers and prism-like optics to scan the surrounds of the vehicle, providing a new and cheaper way to integrate LiDAR into autonomous vehicles[98].

Israeli startup, Innoviz Technologies, have partnered with Mazda to develop InnovizOne, a solid-state LiDAR sensor which uses micro-electromechanical systems (MEMS) to redirect a fixed laser beam in multiple directions via a tiny spinning mirror. The result is a compact, cost-effective system that offers equivalent coverage to larger spinning lasers[99]. This system is anticipated to be integrated into BMW vehicles through Magna's autonomous driving system by 2021.

Ultrasonic

Applications

Ultrasonic sensors produce ultrasonic waves which detect the presence of objects close to the vehicle. When the waves hit an object, they produce echoes, enabling the vehicle sensors to detect obstacles in the immediate vicinity of the vehicle, such as curbs, pedestrians or other vehicles. Ultrasonic sensors are used for short-range applications at low speeds, and are used primarily for the purpose of automated parking.

Ultrasonic sensors serve their intended purpose, and there is currently no requirement for further development of the technology[100].

Platforms

It is anticipated that ultrasonic technologies will be utilised by:

94. Condliffe, J. LiDAR just got way better – but it's still too expensive for your car. *MIT Technology Review.* https://www.technologyreview.com/s/609526/lidar-just-got-way-better-but-its-still-too-expensive-for-your-car/ 28 November 2017.
95. Shaharabani, Y. Why FIR sensing technology is essential for achieving fully autonomous vehicles. *Embedded.* https://www.embedded.com/electronics-blogs/say-what-/4460777/Why-FIR-sensing-technology-is-essential-for-achieving-fully-autonomous-vehicles 12 June 2018.
96. Schweber, Bill. The autonomous car: a diverse array of sensors drives navigation, driving and performance. *Mouser Electronics.* https://au.mouser.com/applications/autonomous-car-sensors-drive-performance/ 2019
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98. Baraja. Secptrum-SCanb: defining a new category of LiDAR. *Baraja.* https://www.baraja.com/technology/ 2018.
99. Nichols, G. BMW's solid-state LiDAR offers a glimpse of the future of autonomous vehicles. *ZDNet.* https://www.zdnet.com/article/bmws-solid-state-lidar-offers-a-glimpse-of-the-future-of-autonomous-vehicles/ 27 April 2018.
100. Gilbertsen, C. Here's how the sensors in autonomous cars work. *The Drive.* http://www.thedrive.com/tech/8657/heres-how-the-sensors-in-autonomous-cars-work 27 March 2017.

> CAV platforms, through the use of connected on-board cameras, radars, LiDAR, thermal and ultrasonic sensors to obtain and analyse information using complex computer algorithms, so that the vehicles may respond appropriately in safety-critical situations

> High frequency mass transit platforms

Emerging technologies and ten year outlook

Vehicle manufacturers are already including ultrasonic sensors on their vehicles. Tesla's Autopilot system makes use of 12 long-range ultrasonic sensors that are positioned to allow the vehicle to sense 16 feet around it in all directions and at all speeds. Mercedes-Benz is trialling automated lane changing through the use of 12 ultrasonic sensors, six radar sensors and eight cameras to monitor 360 degrees around the car[101]. Ultrasonic sensors have also been deployed in the 2018 Cadillac Super Cruise semi-autonomous vehicle, with eight to 10 ultrasonic sensors positioned around the vehicle.

Infrared

Applications

Far infrared (FIR) sensors are used to detect differences in heat emitted by objects. Unlike cameras that only capture images perceptible to the human eye, FIR sensors scan the infrared spectrum just above visible light and can detect objects that may not otherwise be perceptible to a camera, radar, or LiDAR[102]. The sensors work to highlight heat-emitting objects, such as pedestrians, animals and oncoming vehicles, and with a range of up to 200 metres, are particularly useful in identifying hazards beyond the range of a car's headlights and under low light conditions.

The use of FIR sensors may also help to resolve some of the perception issues found in the use of other vehicle sensors.

Platforms

It is anticipated that infrared technologies will be utilised by:

> CAV platforms, through the use of connected on-board cameras, radars, LiDAR, thermal and ultrasonic sensors to obtain and analyse information using complex computer algorithms, so that the vehicles may respond appropriately in safety-critical situations

> High frequency mass transit platforms

Barriers and challenges

Challenges facing the use of infrared based sensor technologies in Australia include temperature anomalies, which may decrease the effectiveness of the sensors. For example, it may be difficult to identify objects on bitumen or concrete roadways on hot days.

Emerging technologies and ten year outlook

FIR cameras are the only technology that can deliver complete classification, identification, and detection of a vehicle's surroundings in any environment or weather condition and make the adoption of fully autonomous vehicles a reality[103]. The development of FIR technologies over the next decade is therefore essential for the successful deployment of autonomous vehicles.

There are three leading FIR sensor companies: Swedish based Autoliv, USA based FLIR Systems, and Israeli startup AdaSky. Autoliv has pioneered camera and thermal based vision systems and continues to develop algorithms that allow the cameras to track objects and alert drivers when the car is at risk of collision[104]. FLIR recently released the Starter Thermal Imaging Dataset for Machine Learning Advanced Driver Assistance Development[105]. AdaSky has recently developed Viper, a high-resolution thermal camera that collects FIR signals, converts it to a high-resolution VGA video, and applies deep-learning computer vision algorithms to sense and analyse its surroundings[106].

101. Goel, A. What tech will it take to put self-driving cars on the road? *Engineering.com*. https://www.engineering.com/IOT/ArticleID/13270/What-Tech-Will-it-Take-to-Put-Self-Driving-Cars-on-the-Road.aspx 3 October 2016.

102. Shaharabani, Y. Why FIR sensing technology is essential for achieving fully autonomous vehicles. *Embedded*. https://www.embedded.com/electronics-blogs/say-what-/4460777/Why-FIR-sensing-technology-is-essential-for-achieving-fully-autonomous-vehicles 12 June 2018.

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104. https://www.autoliv.com/products/electronics/vision-systems

105. FLIR. FLIR releases starter thermal imaging dataset for machine learning advanced driver assistance development. *FLIR*. https://www.flir.com/news-center/press-releases/flir-releases-starter-thermal-imaging-dataset-for-machine-learning-advanced-driver-assistance-development/ 19 June 2018.

106. Shaharabani, Y. Why FIR sensing technology is essential for achieving fully autonomous vehicles. *Embedded*. https://www.embedded.com/electronics-blogs/say-what-/4460777/Why-FIR-sensing-technology-is-essential-for-achieving-fully-autonomous-vehicles 12 June 2018.

FIR technologies are currently being trialled in prototype autonomous vehicles. Osram Opto Semiconductors has developed high-power infrared pulse lasers for use in autonomous vehicles[107]. BMW, Audi and Mercedes-Benz use thermal-imaging cameras as part of their sensor suites[108]. Cadillac has also incorporated infrared cameras in the Super Cruise model to monitor the attention of the driver. The infrared camera detects if the driver's eyes have been away from the windscreen for more than 30 seconds, and sends out a series of alerts to get the driver to pay attention to the road again[109].

Inertial Measurement Unit

Applications

An inertial measurement unit (IMU) is a device that directly measures the changing movements of the vehicle through linear acceleration and rotational rate components. Simply put, the utilisation of IMU technologies in autonomous vehicles provides a source of accurate short-term position and motion information to mitigate any errors that may occur in other positioning sensors as a result of external environmental challenges[110].

An IMU is unique among the sensors typically found in an autonomous vehicle as an IMU does not need to be connected to operate[111]. These independent properties of the unit make it a core technology for supporting other sensors, such as GPS, to enhance the precision, reliability and safety of autonomous vehicles[112].

Platforms

It is anticipated that IMU technologies will be utilised by:

> CAV platforms, through the use of connected on-board cameras, radars, LiDAR, thermal and ultrasonic sensors to obtain and analyse information using complex computer algorithms, so that the vehicles may respond appropriately in safety-critical situations

> High frequency mass transit platforms, through the use of connected sensors in autonomous public transport including trains and buses

Barriers and challenges

Challenges facing the use of IMU technologies in Australia include:

> The IMU unit may return cumulative errors[113]

> Used on its own, IMU cannot provide an exact location, only the motion of the vehicle, therefore the initial location of the vehicle must first be determined manually or by GPS[114]

Emerging technologies and ten year outlook

USA based ACEINNA is a leading developer of IMU technology in autonomous vehicles. In mid-2018, the company announced the development of innovative IMU technologies that allow the company to provide the technology at a significantly cheaper price point than previously developed systems[115]. This development will allow for the widespread integration of IMU systems into autonomous vehicles, and help to accelerate the autonomous vehicle market, particularly over the next five years[116].

107. Rees, M. Infrared lasers integrated into autonomous vehicle technology. *Unmanned Systems Technology.* http://www. unmannedsystemstechnology.com/2018/01/osram-lasers-integrated-autonomous-vehicle-technology/ 15 January 2018.

108. Taylor, M. Fatal Uber crash was 'inevitable', says BMW's top engineer. F*orbes.* https://www.forbes.com/sites/michaeltaylor/2018/03/22/fatal-uber-crash-inevitable-says-bmws-top-engineer/#22e9207b5568 22 March 2018.

109. Seeing Machines (2018). Seeing Machines bolsters safety for GM Cadillac. https://www.seeingmachines.com/blog/2018/04/17/seeing-machines-fovio-driver-monitoring-technology-features-in-gm-cadillac-ct6-super-cruise/ 17 April 2018.

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115. ACEINNA. ACEINNA emerges as $50 million sensor technology spin out. *ACEINNA.* https://www.aceinna.com/about-aceinna/news-room.cfm?nid=ACEINNA%20Emerges%20as%20%2450%20Million%20Sensor%20Technology%20Spin%20Out&newsyear=2018 2 January 2019.

116. ACEINNA. ACEINNA emerges as $50 million sensor technology spin out. *ACEINNA.* https://www.aceinna.com/about-aceinna/news-room.cfm?nid=ACEINNA%20Emerges%20as%20%2450%20Million%20Sensor%20Technology%20Spin%20Out&newsyear=2018

2.2.4. Spatial technology and mapping

Applications

The safe and reliable operation of autonomous vehicles is heavily reliant on a broad range of spatial and mapping technologies for vehicle positioning, orienting the vehicle on a base map and for avoiding obstacles. These may include GPS, Satellite Based Augmentation Systems (SBAS), Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), Internal Navigation Systems (INS), Simultaneous Localisation and Mapping (SLAM) and prebuilt maps.

Autonomous vehicles must be aware of their surrounding environment at all times, which is why localisation of data is fundamental to their safe and reliable operation. However, as well as using geospatial data to locate and position the vehicle, autonomous vehicles will also be used as geospatial data collecting machines, allowing the vehicles to map and report road conditions in real time[117,118].

The base map is central to the navigation of autonomous vehicles, and requires constant updates from aerial imagery, vehicle sensors, and mobile and aerial driven LiDAR data[119]. The accuracy of base maps must be defined in the range of millimetres to centimetres to ensure the vehicle is able to ascertain road infrastructure such as lanes, road edges, dividers, traffic signals and poles, surrounding infrastructure and aspects of the physical environment[120].

Ultimately, as more autonomous vehicles are deployed on the roads, and more geospatial data is produced by the use of these vehicles, cars will not only be able to navigate from point A to point B more efficiently, but they will also know the curvature and elevation of the roads[121]. Using autonomous vehicles to help inform the development of maps will provide a look around the corner at what the sensors cannot see[122].

Platforms

It is anticipated that spatial technologies will be utilised by:

> CAV platforms, through the use of vehicle positioning, orientating the vehicle on a base map, creating live geospatial data and for avoiding obstacles
> High frequency mass transit platforms, through the use of positioning data to locate and route buses, trains, ferries and planes; the analysis of commuter travel patterns; and the identification of hotspots that have regular heavy passenger loads during peak hours
> Intelligent transport systems, through the use of integrated spatially enabled information platforms to inform active traffic network management and planning

Barriers and challenges

Challenges facing the use of infrared based sensor technologies in Australia include:

> GPS requires communication with external infrastructure, such as satellites, which is not always reliable in demanding environments such as canopy, obstruction and jamming[123]
> The use of spatial and mapping technologies in the transport sector in Australia has identified that some emerging safety applications that require satellite positioning and mapping services may not be currently supported in Australia[124]. These challenges can be addressed by ensuring that the Vehicle Import Scheme gives appropriate consideration to safety systems that rely on satellite positioning and mapping data, to ensure that no safety systems are compromised by positioning or mapping systems that do not meet local requirements[125]

117. Geonovum and Geosptial Media and Communications. Self-driving vehicles and geo-information. https://www.geonovum.nl/uploads/documents/Self-DrivingVehiclesReport.pdf
118. Luccio, M. LiDAR is key to autonomous vehicles. *ApoGeospatial.* http://apogeospatial.com/lidar-is-key-to-autonomous-vehicles/ 9 February 2017.
119. Geonovum and Geosptial Media and Communications. Self-driving vehicles and geo-information. https://www.geonovum.nl/uploads/documents/Self-DrivingVehiclesReport.pdf
120. Geonovum and Geospatial Media and Communications. Self-driving vehicles and geo-information. https://www.geonovum.nl/uploads/documents/Self-DrivingVehiclesReport.pdf
121. Lai, R. Here's updated mapping vehicle paves way for self-driving cars. *Engadget.* https://www.engadget.com/2017/06/03/here-collection-vehicle-v3-hd-mapping-computex/ 6 March 2017.
122. Luccio, M. LiDAR is key to autonomous vehicles. *ApoGeospatial.* http://apogeospatial.com/lidar-is-key-to-autonomous-vehicles/ 9 February 2017.
123. Cameron, A. 2017 State of the GNSS Industry Report. *GPS World.* http://gpsworld.com/2017-state-of-the-gnss-industry-report/ 14 October 2017.
124. Austroads (2014). Austroads Submission to the 2014 Review of the Motor Vehicle Standards Act 1989. https://infrastructure.gov.au/vehicles/mv_standards_act/files/Sub136_Austroads.pdf
125. Austroads (2014). Austroads Submission to the 2014 Review of the Motor Vehicle Standards Act 1989. https://infrastructure.gov.au/vehicles/mv_standards_act/files/Sub136_Austroads.pdf

> Data sharing and GPS data are liable to privacy concerns

> The creation of base maps has the potential to be time consuming and expensive

Emerging technologies and ten year outlook

The rise of sensing technology is significant in terms of vehicle positioning and mapping, but also for the large amounts of data sensors will generate[126]. The future development of geospatial intelligence in autonomous vehicles will have a significant focus on leveraging this data to allow vehicles to perceive, compute, analyse, collaborate, and learn from the surrounding environment[127]. Developments in spatial systems over the next decade will also focus on meeting the challenge of performing in demanding environments.

Cohda Wireless have developed the vehicle-based system, V2X-Locate, which has successfully identified the position of a vehicle to sub-metre accuracy in environments that degrade GPS accuracy, such as tunnels, underground carparks and between high-rise buildings[128].

2.2.5. Internet of Things

Applications

The Internet of Things (IoT) is a wireless technology that connects everyday objects to a vast network of sensors, enabling continuous communication between people and objects[129]. The integration of the IoT within the transport sector is anticipated to make significant changes to how we travel and navigate our way through cities, through the collection and communication of data.

The use of the IoT within the transport sector refers to connected transport, or an internet connection during travel. IoT technologies may encompass the modes of transport, such as autonomous vehicles, buses, trains and planes, as well as transport infrastructure, such as roadside cameras and traffic sensors. These devices all gather data to inform traffic management, parking, the planning of road related infrastructure, and to enhance the journey of an individual. This data can then be used to send alerts for adaptive signal control and communication via V2V and V2I technologies.

The integration of the IoT into the transport system will optimise public transit routes, improve transport safety, reduce vehicle congestion and reduce response times to crashes[130].

Platforms

It is anticipated that IoT technologies will be utilised by:

> CAVs platforms, through enabling the communication between DSRC, sensors, spatial technology and mapping technologies, and the vehicle, transport infrastructure and the cloud

> High frequency mass transit platforms, through smart mass transit systems and sensors that detect speeds and helps reroute traffic[131]

> Intelligent transport systems, through the use of connected and integrated information platforms to rapidly inform active traffic network management and planning

Barriers and challenges

Challenges facing the use of the IoT in the transport sector in Australia include:

> Reliability of connection to 5G network and cloud processing

> Predicted future gaps in 5G network coverage, particularly in rural areas

> Little research has been conducted on how to identify a security threat in a connected vehicle environment or how to counter the threat[132]

126. Juergen Dold & Jessica Groopman (2017) The future of geospatial intelligence, Geo-spatial Information Science, 20:2, 151-162, DOI: 10.1080/10095020.2017.1337318 https://www.tandfonline.com/doi/full/10.1080/10095020.2017.1337318

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128. Cohda Wireless. World-first Cohda system beats GPS blackspots. *Cohda Wireless.* http://www.cohdawireless.com/updates/press-releases/world-first-cohda-system-beats-gps-blackspots/ 16 April 2018.

129. Barr, J. The Internet of Things and transportation. *Miovision.* https://miovision.com/blog/internet-things-transportation-2/ 9 August 2017.

130. Technavio. Future of transportation hinges on the Internet of Things. *Technvaio Blog.* https://www.technavio.com/blog/future-transportation-internet-things 4 April 2018.

131. Technavio. Future of transportation hinges on the Internet of Things. *Technvaio Blog.* https://www.technavio.com/blog/future-transportation-internet-things 4 April 2018.

132. Fitzgerald, S. C-ITS pilot security credential management system: evaluation and research. *iMOVE CRC.* https://imovecrc.com/project/c-its-pilot-security-credential-management-system/ 17 April 2018.

Emerging technologies and ten year outlook

The future of IoT in the transport sector will see most vehicles on the road communicating with satellites, smart devices, pedestrians, cyclists, homes and business, traffic management centres, other cars on the road and transport infrastructure[133]. The level to which this technology advances will be dependent on the deployment of 5G and eventually 6G networks.

A number of the leading global automakers such as BMW, Audi, Volkswagen, General Motors and Toyota are working with companies such as Google and Apple to utilise IoT technology within autonomous vehicles[134]. Over the next decade, these companies will continue to develop automotive IoT solutions to both assist drivers and to deploy a fully autonomous Level 5 vehicle.

2.3. Energy technologies

A number of new and emerging energy storage technologies are presenting opportunities for improved efficiency and environmental performance in the urban mobility sector. The development of technologies that enable efficient storage and recovery of energy has paved the way for the development of vehicles that use electric motors rather than internal combustion engines. This will be key to enabling decarbonisation of the road transport sector. Rapid improvements in battery technology, particular in Lithium-ion (Li-ion) batteries, have already enabled the development and deployment of hybrid and fully electric vehicles across the world, and vehicles that use hydrogen fuel cell technology to generate electricity are now commercially available in some international markets.

Key energy technologies for the transport sector include batteries, hydrogen fuel cells, super capacitors and the enabling infrastructure for each, such as battery chargers and electrolysers to produce hydrogen from water.

The Australian Council of Learned Academies report *The Role of Energy Storage in Australia's Future Energy Supply Mix* provides an overview of Australia's research and industry strengths and opportunities in energy storage technologies, with a particular focus on the electricity system[135]. The report details Australia's strengths in the research and development of batteries and fuel cell systems. Australia has research strengths in many energy storage technologies, but there is limited industry activity at this stage.

2.3.1. Electrochemical batteries

Batteries of various forms have existed for decades and are ubiquitous in modern society. Most use reversible chemical reactions to convert electricity into a store of chemical energy, and vice versa. There are a wide variety of battery technologies available with different maturities, strengths and weaknesses.

Battery electric vehicles (BEV) (also referred to as low and zero emission vehicles [LEVs]) are powered only by energy stored in batteries, which are charged with energy from the electricity grid. The most common technologies used in the transport sector are currently lead-acid batteries and Li-ion batteries. Lead-acid batteries have historically dominated transport applications and are used in most conventional automotive vehicles to supply current to start the engine. However, Li-ion batteries (of which there are many variants) are becoming a common replacement for lead-acid batteries due to their superior energy density and are expected to be the dominant battery technology for most applications in the future[136]. Li-ion batteries are the most common battery type used in modern electric vehicles.

Significant research efforts in Australia and abroad are focused on improving the capabilities of battery storage technologies, and reducing their costs. Key efforts include power rating, energy density, safety, and the efficiency of storing and retrieving energy. Waste management is an important challenge for the battery industry[137]. Opportunities to improve the sustainability of battery systems through enhanced recyclability are being investigated by researchers[138].

133. Wired Brand Lab. Autonomous vehicles – Watson IoT helps pave and industry revolution. *IBM*. https://www.ibm.com/blogs/internet-of-things/iot-autonomous-vehicles/ 1 November 2017.

134. Sam Solutions. IoT in automotive industry: the creation of self-driving cars. S*am Solutions*. https://www.sam-solutions.com/blog/iot-in-automotive-industry-the-creation-of-self-driving-cars/ 18 April 2018.

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137. Godfrey, B., Dowling, R., Forsyth, M., Grafton, R.Q. and Wyld, I., (2017) The Role of Energy Storage in Australia's Future Energy Supply Mix. Report for the Australian Council of Learned Academies., www.acola.org.au.

138. CSIRO. Australia to lead lithium-ion battery recycling charge. *CSIRO*. https://www.csiro.au/en/News/News-releases/2018/Australia-to-lead-lithium-ion-battery-recycling-charge 17 July 2018.

Due to their chemical composition, batteries present potential health and safety risks. The nature and severity of these risks varies between battery chemistries. Safety is a particular concern for Li-ion battery technologies as most of the common Li-ion chemistries have potential to catch fire if they overheat or are punctured. Finally, there are also human rights concerns related to common battery components. For example, most of the world's cobalt supplies come from the Democratic Republic of Congo, which has a record of poorly-enforced labour standards and child exploitation[139].

Risk analysis by the Australian Council of Learned Academies (ACOLA) found that while lithium nickel manganese cobalt oxide batteries are currently expected to see the highest levels of deployment they also present the highest risk profile.

2.3.2. Hydrogen

Alternative fuel sources such as hydrogen are serious contenders in a low and zero emission vehicle (LEV) future[140]. The vehicles themselves rely on electrolysed natural gas or energy from sources such as solar, which would enable them to be emissions-free. Vehicles with fuel cells also rely on battery technology.

Currently most hydrogen is produced from fossil fuels but this process releases carbon dioxide to the atmosphere. Hydrogen can be sustainably produced by using renewable energy to split water molecules into hydrogen and oxygen through a process called electrolysis. Hydrogen fuel cells can then be used to produce electricity through an electrochemical reaction of hydrogen fuel with oxygen. This provides an effective means of storing energy. However, losses during electrolysis, storage, transport, and power generation, mean that the production and use of hydrogen has a relatively low round-trip efficiency[141].

The Hydrogen Strategy Group, chaired by the Chief Scientist of Australia Dr Alan Finkel, prepared a briefing paper investigating the opportunity for Australia to produce hydrogen for export and domestic use. The export of renewable hydrogen/ammonia has been identified as potential economic opportunity for Australia[142]. A non-exhaustive scan of Australian hydrogen research identified 15 institutions covering a broad range of topics including hydrogen production, engines, ammonia reconversion, vehicles and turbines[143]. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed announced the successful development of a membrane technology allowing ammonia (a stable way of storing and transporting hydrogen) to be converted to hydrogen[144].

There are a number of government-supported trials of hydrogen technologies occurring across Australia:

> The Australian Capital Territory (ACT) Government, through the Next Generation Renewables auction, have secured a $55 million investment by Neoen and Megawatt Capital in partnership with Siemens and Hyundai to establish a 1.25MW hydrogen electrolyser in the ACT. This investment will also include a refuelling station and service centre and a fleet of 20 hydrogen fuelled cars[145]

> In South Australia, trials are underway to assess the viability of hydrogen fuel cell-powered buses within the Adelaide Metro system[146]. The South Australian State Government has also committed $4.9 million to support the development of an $11.4 million demonstration plant that will produce hydrogen from renewable energy, which will be built in Adelaide[147]. While in Victoria, the Moreland City Council is transitioning local government vehicles to a zero emissions fleet[148]

139. Lavoipierre, A, Smiley, S. and Evlin, L. Children mining cobalt in slave-like conditions as global demand for battery material surges. *ABC News*. http://www.abc.net.au/news/2018-07-25/cobalt-child-labour-smartphone-batteries-congo/10031330 25 July 2018.

140. Nightingale, T. Melbourne Council to build emissions free rubbish trucks by 2020. *ABC News*. http://www.abc.net.au/news/2017-08-05/zero-emissions-garbage-trucks-moreland-city-council/8777900 5 August 2017.

141. Cavanagh K, Ward J K, Behrens S, Bhatt A I, Ratnam E L, Oliver E and Hayward J. (2015). Electrical energy storage: technology overview and applications. CSIRO, Australia. EP154168. https://www.aemc.gov.au/sites/default/files/content/7ff2f36d-f56d-4ee4-a27b-b53e01ee322c/CSIRO-Energy-Storage-Technology-Overview.pdf

142. Godfrey, B., Dowling, R., Forsyth, M., Grafton, R.Q. and Wyld, I., (2017) The Role of Energy Storage in Australia's Future Energy Supply Mix. Report for the Australian Council of Learned Academies., www.acola.org.au.

143. Commonwealth of Australia (2018). Hydrogen for Australia's Future. https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf

144. CSIRO. CSIRO tech accelerates hydrogen vehicle future. *CSIRO*. https://www.csiro.au/en/News/News-releases/2018/CSIRO-tech-accelerates-hydrogen-vehicle-future 8 August 2018.

145. ACT Government. ACT Government brings hydrogen energy storage to Canberra. *ACT Government*. http://www.cmd.act.gov.au/open_government/inform/act_government_media_releases/corbell/2016/act-government-brings-hydrogen-energy-storage-to-canberra 30 August 2016.

146. Fitzgerald, S. South Australia to trial hydrogen-powered buses by 2019. *iMOVE CRC*. https://imovecrc.com/news-articles/personal-public-mobility/south-australia-hydrogen-powered-bus-trial/ 8 September 2017.

147. Australian Gas Infrastructure Group. Australian-first, $11.4 million hydrogen demonstration plant to be built in Adelaide. *Australian Gas Infrastructure Group*. https://www.australiangasnetworks.com.au/our-business/about-us/media-releases/australian-first-hydrogen-pilot-plant-to-be-built-in-adelaide 21 February 2018.

148. Carroll, B. (Minister for Industry and Employment). Hydrogen to fuel transport manufacturing innovation. Media release. https://www.premier.vic.gov.au/wp-content/uploads/2018/05/180516-Hydrogen-To-Fuel-Transport-Manufacturing-Innovation.pdf 16 May 2018

> In August 2018, CSIRO successfully tested two cars powered by ultra-high purity hydrogen derived from ammonia[149]. This was the first time in the world that hydrogen cars were fuelled with hydrogen derived from ammonia. Ammonia can be derived from solar and wind energy, and hydrogen derived from this ammonia is therefore a sustainable, carbon-free fuel. Ammonia is also far more easily transported than hydrogen

> In November 2018, Toyota Australia ran a 12-week real-world trial of three hydrogen-electric vehicles in partnership with a Melbourne council, using a mobile hydrogen refueller. Toyota are also trialling two hydrogen fuel cell forklifts at their former manufacturing site in Melbourne[150]

Hybrid vehicles are also being introduced to the market, such as the Mercedes-Benz GLC F-Cell model, which is proposing to be 'the first plug-in electric that also runs on hydrogen'[151].

2.3.3. Supercapacitors

Capacitors are electrical components that are able to store potential energy by means of a static charge as opposed to an electrochemical reaction. Supercapacitors (also referred to as ultracapacitors) have a very high capacitance, which is a measure of the capacitor's ability to store this charge. Supercapacitors provide much higher power ratings than batteries, which means that they have much faster charge and discharge cycles. Because of this they have been used to enable regenerative braking and start-stop functionality in conventional auto systems. Compared to common battery chemistries they are typically safer, more environmentally friendly and can withstand more charge/discharge cycles. However, they have significantly lower energy densities than most battery technologies.

As such, supercapacitors have mostly been applied as companions to batteries (such as the Ultrabattery developed in collaboration with CSIRO, which combines an ultracapacitor with a lead-acid battery[152]), or in niche applications with high power and low storage requirements. The energy density of supercapacitors has increased dramatically and some predict that they may eventually be able to compete with batteries. CSIRO has historically been a world leader in supercapacitor research[153]. Swinburne University and Monash University are conducting research into graphene-based supercapacitors[154,155]. Internationally, buses with both supercapacitors and batteries have been deployed to allow for very rapid recharging at each bus stop[156], while supercapacitors are used in the Nanjing Trams in China[157].

2.4. Advanced materials

Advances in materials and manufacturing technology have potential to enable weight reductions and safety improvements in vehicles.

Many Australian universities undertake materials engineering research. RMIT University was awarded a $3 million grant in 2017 to start an ARC Training Centre in Lightweight Automotive Structures (ATLAS). ATLAS involves 16 partners, including Ford Australia[158]. Deakin University has undertaken collaborative research with Victorian company Carbon Revolution, and has successfully commercialised carbon manufacturing technology and now supplies a one-piece carbon fibre wheel to global automotive companies[159]. Researchers at the University of South Australia collaborated with SMR Automotive to develop a lightweight plastic automotive mirror which provides a highly reflective, distortion-free and shatterproof alternative to glass-based mirrors[160].

149. CSIRO. CSIRO tech accelerates hydrogen vehicle future. *CSIRO.* https://www.csiro.au/en/News/News-releases/2018/CSIRO-tech-accelerates-hydrogen-vehicle-future 8 August 2018.

150. Toyota. Toyota partnering with Melbourne Council for Australian first hydrogen FCEV trials. *Toyota.* https://www.toyota.com.au/news/toyota-partnering-with-melbourne-council-for-australian-first-hydrogen-fcev-trials 5 November 2018.

151. Mercedes-Benz. https://www.mercedes-benz.com/en/mercedes-benz/vehicles/passenger-cars/glc/the-new-glc-f-cell/

152. CSIRO. UltraBattery. https://www.csiro.au/en/Research/EF/Areas/Energy-storage/UltraBattery

153. CSIRO. Supercapacitors. https://csiropedia.csiro.au/supercapacitors/

154. Engineers Australia. Graphene-based supercapacitors are a viable battery replacement. *Engineers Australia.* https://www.engineersaustralia.org.au/News/graphene-based-supercapacitors-are-viable-battery-replacement

155. Ionic Industries. Super Capacitors. http://www.ionicindustries.com.au/products/super-capacitors/ 2015.

156. SupercapTech.com. The supercapacitor electric bus is adopted in China. *SupercapTech.com.* https://www.supercaptech.com/the-supercapacitor-electric-bus-is-adopted-in-china 14 May 2015.

157. Metro Report International. Nanjing to get catenary-free trams. *Metro Report International.* https://www.metro-report.com/news/single-view/view/nanjing-to-get-catenary-free-trams.html 22 April 2013.

158. Porter, I. RMIT to lead light-weighting research program. *GoAuto.* https://premium.goauto.com.au/rmit-lead-light-weighting-research-program/ 24 November 2017.

159. Carbon Revolution. http://www.carbonrev.com/

160. University of South Australia. 2016 Clunies Ross Award reflects success of plastic mirror innovation. *University of South Australia.* http://www.unisa.edu.au/Media-Centre/Releases/2016-Media-releases/2016-Clunies-Ross-Award-reflects-success-of-plastic-mirror-innovation-/ 15 June 2016.

2.5. Research and industry

There are currently a number of trials taking place in Australia that are examining the enabling technologies and potential solutions in the transport sector. These are summarised in **Table 4**.

Table 4: Trials taking place in Australia

Jurisdiction	Description of trial
Australian Capital Territory	> The CAN Drive – Automated vehicle trial is a two year trial focusing on the reactions of the driver as they re-assume control from a vehicle in automated mode[161]
New South Wales	> The Sydney Metro Driverless Train Trial is a trial of fully-automated trains, from French manufacturer Alstom, for use on 3 new Sydney Metro lines, that will see trains arrive at each stop every 4 minutes[162] > Trialling CAVs on Transurban Roads[163]. The program is run in partnership with Transurban and NSW Department of Transport, Roads and Maritime Services, and is the state's most comprehensive CAV trial to date > Cooperative Intelligent Transport Initiative (CITI)[164]. The initiative is trialling heavy vehicle safety applications using Cooperative ITS > Heavy Vehicle Priority Project[165]. The project is trialling applications to provide heavy vehicle priority at signalised intersections > In 2016, the Smart Innovation Centre announced the development of an R&D hub for emerging transport technologies, including CAVs[166] > The NSW Smart Shuttle[167] is an indicative of the Department of Transport in collaboration with the Smart Innovation Centre[168], The project is working with industry and research partners to trial a highly automated passenger shuttle at Sydney Olympic Park > Cohda Wireless, with the development and trialling of V2I in freight trucks in NSW. The trials involved fitting out of freight vehicles with Cohda Wireless technology to allow them to communicate with traffic lights, enabling the lights to remain green as the vehicle approaches to decrease the amount of traffic congestion[169] > On-demand bus shuttle service, Sydney. A partnership between Transdev and Transport for New South Wales will see 10 Mercedes-Benz Sprinter Transfer Minibus trialled in an on-demand service[170]
Northern Territory	> An Autonomous Passenger Vehicle trial commenced in 2016 as Australia's first fully operational autonomous vehicle transport trial. The trial transported people at Darwin Waterfront[171]
Queensland	> Cooperative and Automated Vehicle Initiative (CAVI) incorporates two main projects – a large scale pilot of Cooperative ITS in Ipswich, and a smaller pilot of cooperative and highly automated vehicles driven on selected roads[172] > iMove CRC together with the Queensland Department of Transport and Main Roads is conducting a Cooperative and Highly Automated Driving (CHAD) Safety Study. It will deliver a cooperative and (highly) CAV prototype, research platform and local expertise base, to conduct a comprehensive safety study to inform government policy and direction. This iMOVE project is intended to prepare for the arrival of CAVs with safety, mobility and environmental benefits on Australian roads[173] > iMove CRC together with the Queensland Department of Transport and Main Roads and Queensland University of Technology (QUT) is undertaking on-road testing to evaluate new state-of-the-art perception and algorithm technologies (including deep learning) likely to play a critical role in any technology solution[174]

161. Fitzgerald, S. Canberra commences a driver-centric automated vehicle trial. *iMove CRC*. https://imovecrc.com/news-articles/intelligent-transport-systems/canberra-automated-vehicle-trial/ 26 April 2018.
162. NSW Government. Sydney Metro. https://www.sydneymetro.info/
163. Transurban. Testing CAVs on the Sydney Orbital Network. https://cavs.transurban.com/trials/new-south-wales/partial-automation 2019
164. Transport for NSW. Centre for Road Safety, Cooperative Intelligent Transport Initiative. https://roadsafety.transport.nsw.gov.au/research/roadsafetytechnology/cits/citi/index.html 6 November 2018.
165. NSW Government, Roads and Maritme Service. Future Transport: trucks will 'talk' to traffic lights to tackle congestion. http://www.rms.nsw.gov.au/about/news-events/news/ministerial/2016/160419-future-transport-trucks-talk-to-traffic-lights.html 19 April 2016.
166. Transport for NSW. Smart Innovation Centre. https://www.transport.nsw.gov.au/projects/programs/smart-innovation-centre 10 August 2018.
167. Transport for NSW. Autonomous Vehicle Trials. https://www.transport.nsw.gov.au/projects/programs/smart-innovation-centre/projects 2019
168. Transport for NSW. Smart Innovation Centre. https://www.transport.nsw.gov.au/projects/programs/smart-innovation-centre 10 August 2018.
169. Cohda Wireless. Big wheels keep on turning – Cohda Wireless technology in innovative trial to keep traffic moving in Sydney, Australia. *Cohda Wireless*. http://www.cohdawireless.com/updates/press-releases/big-wheels-keep-on-turning-cohda-wireless-technology-in-innovative-trial-to-keep-traffic-moving-in-sydney-australia/ 19 June 2018
170. Fitzgerald, S. Sydney to trial on-demand bus shuttle service later this year. *iMove CRC*. https://imovecrc.com/news-articles/personal-public-mobility/sydney-on-demand-bus-shuttle-service-trial/ 12 September 2017.
171. Northern Territory Government. New era of modern travel to hit waterfront. Media release. http://newsroom.nt.gov.au/mediaRelease/22676 15 December 2016.
172. Queensland Government. CAVI: Cooperative and Automated Vehicle Initiative. https://www.qld.gov.au/transport/projects/cavi 2019
173. Fitzgerald, S. Cooperative and highly automated driving safety study. *iMove CRC*. https://imovecrc.com/project/cooperative-highly-automated-driving-safety-study/ 29 August 2018.
174. Fitzgerald, S. How automated vehicles will interact with road infrastructure. *iMove CRC*. https://imovecrc.com/project/automated-vehicles-interact-road-infrastructure/ 29 August 2018.

Jurisdiction	Description of trial
South Australia	> The South Australian Government's Rural Intersection Active Warning System (RIAWS) is an Australian-first safety measure to reduce the speed limit at four rural locations > South Australia's Future Mobility Lab Fund a $10M program over three years for development, testing and demonstrations of CAV technology, connected V2V and V2I pilots and demonstrations, and research and development[175] > In mid-2017, Telstra and Cohda Wireless conducted Australia's first test of Vehicle-to-Pedestrian (V2P) technology over a mobile network in South Australia, demonstrating vehicles successfully interacting directly with pedestrians and cyclists via smart phones to provide early-warning collision detection and alerts[176] > In 2017, Cohda Wireless, in partnership with Telstra, also successfully trialled Cohda's Connected Vehicle (V2I) technology over Telstra's 4G network in South Australia[177] > Cohda's recent DSRC trials in Australia used V2X technology to analyse data from sensors on nearby vehicles and roadside infrastructure to equip autonomous vehicles with "360-degree awareness". The purpose of these trials are to use V2X technology to detect possible obstacles or issues by extending the horizon of awareness beyond what the driver can see or on-board sensors can detect, thus extending the vehicle awareness zone[178] > In 2018, Australian company Transit Australia Group (TAG) and global electric driverless technology company EasyMile announced a partnership to be based at TAG's joint venture Precision Buses in Adelaide to trial EasyMile's EZ10 autonomous buses[179] > The South Australian Department of Planning, Transport and Infrastructure (DPTI) has also developed the traffic intelligence system, AddInsight, to provide real-time road traffic analysis using Bluetooth sensor technology and analytics software[180] > The Flinders Autonomous Shuttle Trial is a five year, three stage, $4 million driverless last mile shuttle project, using Navya's 15-passenger ARMA electric shuttle around the Tonsley Innovation Precinct, in Adelaide[181] > The Aurrigo Driverless Cargo Pod Trial, which trialled a four-person driverless cargo pod, transporting goods at the Tonsley precinct in Adelaide[182]
Victoria	> Victorian CAV Trials[183]. The Victorian trial program is in three phases and investigates how CAVs interact with motorway infrastructure > The ITS Grants Program includes the trialling of CAVs in highway scenarios, C-ITS to support tram priority, and in-vehicle connected vehicle services using cellular communications[184] > The Road Safety Action Plan has assigned $10M to trial connected and automated vehicle technologies[185] > The La Trobe University Driverless Bus Trial is a trial of the HMI Autonobus, on the Bundoora campus of Melbourne's La Trobe University in partnership with VicRoads, Keolis Downer, La Trobe, University, HMI, RACV, Australian Road Research Board (ARRB), and the Victorian Government Smarter Journeys Program[186] > Bosch has been awarded a $2.3 million grant from the Victorian government to put the first driverless car on the state's roads, following the passing of enabling legislation in 2018. The first permit under the new Automated Driving System (ADS) authorisation scheme was awarded to Bosch, who plan to test a highly autonomous vehicle on high-speed rural roads by the middle of 2019[187]

175. Government of South Australia. Future Mobility Lab Fund. https://www.dpti.sa.gov.au/transportinnovation

176. Cohda Wireless. Telstra and Cohda Wireless conduct Australian first V2P technology trial. *Cohda Wireless.* http://www.cohdawireless.com/updates/press-releases/telstra-and-cohda-wireless-conduct-australianfirst-v2p-technology-trial/ 27 June 2017

177. Cohda Wireless. Telstra 4G trial. *Cohda Wireless.* http://www.cohdawireless.com/case-studies/telstra-4g-trial/ July 2017.

178. Government of South Australia. Autonomous vehicles. South Australia, mobility for the future. https://invest.sa.gov.au/wp-content/uploads/2017/11/Autonomous-Vehicles.pdf November 2017.

179. Richards, S. Autonomous vehicle hub announced in South Australia. *The Lead.* http://theleadsouthaustralia.com.au/innovation/autonomous-vehicle-hub-planned-for-northern-adelaide/ 28 June 2018.

180. Government of South Australia. Future Mobility Innovation in Transport. http://www.dpti.sa.gov.au/transportinnovation

181. Government of South Australia. Flinders Autonomous Shuttle Trial. https://dpti.sa.gov.au/news?a=371235 10 November 2017.

182. Government of South Australia. Aurrigo Driverless Cargo Pod Trial. https://dpti.sa.gov.au/news?a=371229 10 November 2017.

183. Transurban. Partially automated vehicle trials. https://cavs.transurban.com/trials/victoria/partial-automation 2019

184. Premier of Victoria. Tech trials to bust congestion on our road network. Media release. https://cavs.transurban.com/trials/victoria/partial-automation 30 August 2016.

185. Towards Zero. Towards Zero 2016-2020 road safety strategy and plan. https://www.towardszero.vic.gov.au/what-is-towards-zero/road-safety-action-plan

186. Fitzgerald, S. La Trobe University driverless bus trial set for early 2018. *iMove CRC.* https://imovecrc.com/news-articles/personal-public-mobility/melbourne-autonomous-bus-trial-la-trobe-uni/ 14 November 2017.

187. Johnston, M. Victoria readies for first autonomous car to hit the road. *IT News.* https://www.itnews.com.au/news/victoria-readies-for-first-autonomous-car-to-hit-the-road-518181 21 January 2019.

Jurisdiction	Description of trial
Victoria (continued)	> The Eastlink Driver Assist Technology is a partnership with Victorian Government, Australian Road Research Board and La Trobe University to test network and driver assisted vehicles[188] > Victoria leading the way on Automated Vehicles is a collaboration between the Royal Automobile Club of Victoria (RACV), Transurban and VicRoads to trial vehicles on the Monash-CityLink-Tullamarine corridor[189] > The University of Melbourne's AIMES project is a world first urban test bed for multimodal connected transport on a large scale in a complex urban environment[190] > The ITS Grants Program in Victoria includes trialling CAVs in highway scenarios, cooperative ITS to prioritise trams, and in-vehicle connected vehicles services using cellular communications[191] > Monash University partnered with EasyMile and Transdev to run a two-day trial of a self-driving shuttle bus at the Monash University Clayton campus[192]
Western Australia	> With the support of the WA State Government, RAC is trialling the RAC Intellibus, a fully driverless, fully electric shuttle bus in South Perth[193] > Main Roads WA had previously planned to partner with industry to launch a trial of autonomous heavy vehicle platooning through the Autonomous Heavy Vehicle Platooning Trial[194] > Scania is testing an autonomous transport system at Rio Tinto's Dampier Salt operation in Western Australia. Rio Tinto will add more autonomous Scania trucks in subsequent phases to develop vehicle-vehicle awareness and intelligent fleet supervisory controls[195] > Perth is one of three worldwide locations for testing the Navya Autonom, an automated vehicle providing on-demand transport[196] > A project in Perth is looking to improve network performance through data-driven analytics and simulation. The project aims to improve the ability of road authorities to predict network performance in the short-term using data-driven analytics and to estimate the impact of CAVs in longer-term predictions[197] > The Curtin University Bus Trial, which is an 11 person Navya driverless shuttle in operation on the Bentley campus of Curtin University[198]
National	> As part of the Australian Government's National Positioning Infrastructure (NPI) Capability, Geoscience Australia is leading a test project of SBAS for the Australasia region[199]. This initiative aims to improve the accuracy of GPS in Australia to as little as three centimetres will help pave the way for autonomous vehicles within four years[200] > New Zealand will join Australia in a world-leading satellite technology test-bed, the Australasian satellite technology test-bed[201] > AustRoads Connected and Automated Vehicle trials[202]. The next generation of motor vehicles are planned to include an increased level of wireless connectivity and automated driving capability

188. EastLink. EastLink demonstrates automated speed plus steering control. https://www.eastlink.com.au/news-media/269-eastlink-demonstrates-automated-speed-plus-steering-control 6 April 2018.

189. Premier of Victoria. Victoria leading the way on automated vehicles. https://www.premier.vic.gov.au/victoria-leading-the-way-on-automated-vehicles/ 11 August 2017.

190. University of Melbourne. Australian Integrated Multimodal Ecosystem (AIMES). https://eng.unimelb.edu.au/industry/transport/aimes

191. ITS Australia. Smart Transport for Australia. https://www.its-australia.com.au/wp-content/uploads/Smart-Transport-for-Australia.pdf March 2017.

192. Monash University. All aboard the future of sustainable transport. *Monash University.* https://www.monash.edu/engineering/about-us/news-events/latest-news/articles/2018/all-aboard-the-future-of-sustainable-transport 9 May 2018.

193. RAC. RAC automated vehicle program. https://rac.com.au/about-rac/advocating-change/initiatives/automated-vehicle-program

194. Bartels, C. Opinion: will Australia ever see platooning? *Fully Loaded.* https://www.fullyloaded.com.au/industry-news/1711/will-australia-ever-see-platooning 21 November 2017.

195. Australian Mining. Rio Tinto trials autonomous Scania truck. *Australian Mining.* https://www.australianmining.com.au/news/rio-tinto-trials-autonomous-scania-truck/ 20 December 2018.

196. Fitzgerald, S. RAC WA to trial on-demand automated vehicles in Perth. *iMove CRC.* https://imovecrc.com/news-articles/personal-public-mobility/perth-on-demand-automated-vehicle-trial/ 4 December 2017.

197. Fitzgerald, S. RAC Improved network performance prediction through data-driven analytics and simulation. *iMove CRC.* https://imovecrc.com/project/improved-network-performance-prediction-through-data-driven-analytics-simulation/ 28 February 2018.

198. Curtin University. Curtin's driverless bus steering students towards an even brighter student experience. https://news.curtin.edu.au/stories/curtins-driverless-bus-steering-students-towards-even-brighter-student-experience/ 29 March 2017.

199. Geoscience Australia. Staellite Based Augmentation System test-bed project. *Geosceince Australia* http://www.ga.gov.au/scientific-topics/positioning-navigation/positioning-for-the-future/satellite-based-augmentation-system

200. Hammerton, R. Shaprer GPS to aid autonomous driving. *GoAuto.* https://www.goauto.com.au/news/general-news/autonomous-technology/sharper-gps-to-aid-autonomous-driving/2018-05-09/72499.html 9 May 2018.

201. New Zealand Government. NZ to participate in Australasian satellite technology test-bed. https://www.beehive.govt.nz/release/nz-participate-australasian-satellite-technology-test-bed 18 February 2017.

202. Austroads. Connected and automated vehicle trials. https://austroads.com.au/drivers-and-vehicles/connected-and-automated-vehicles/trials 2019

Jurisdiction	Description of trial
National (continued)	> The Australia and New Zealand Driverless Vehicle Initiative (ADVI) is led and coordinated by the Australian Road Research Board (ARRB). ADVI is a cooperative partnership program comprising more than 100 Australian and international organisations, and is funded by partners from a range of sectors[203]. The purpose of ADVI is to manage the safe and successful introduction of driverless vehicles onto Australian roads, and to ultimately position Australia as an international role model in the development of new technologies and attract developers, innovation and investors[204] > Siemens launched an ITS portfolio in Australia in 2016 that included an intelligent sensor-based parking system, and V2I technology[205]. Coordinated ramp signals on freeway entrances are an example of an ITS that is already commonly used to optimise traffic flow > The Smart Rail Route Map, which includes a partnership between Rail Manufacturing Cooperative Research Centre, the Australasian Railway Association, and Deakin University, outlines a long-term vision for technology in the rail industry over the next 30 years[206]

203. ADVI Centre of Excellence. Submission to NTC discussion paper – clarifying control of automated vehicles. https://s3-ap-southeast-2.amazonaws.com/cdn-advi/wp-content/uploads/2017/07/ADVI-submission-NTC-Clarifying-control-of-AVs-SUBMITTED-26June.pdf June 2017.

204. ADVI Centre of Excellence. Submission to NTC discussion paper – clarifying control of automated vehicles. https://s3-ap-southeast-2.amazonaws.com/cdn-advi/wp-content/uploads/2017/07/ADVI-submission-NTC-Clarifying-control-of-AVs-SUBMITTED-26June.pdf June 2017.

205. Siemens. Siemens launches ITS technologies in Australia. *Siemens.* https://corporate.siemens.com.au/en/home/news-centre/press-releases/siemens-launches-intelligent-transport-systems-in-australia.html October 2016.

206. Australasian Railway Association. Work to establish an Australian rail technology map commences. https://ara.net.au/content/work-establish-australian-rail-technology-map-commences 11 July 2018.

3.   Potential solutions

Four potential technology solutions were identified by the Academy as being important in the consideration of Australia's readiness to develop, adopt and adapt transport technologies. These solutions were selected on the basis of having the greatest potential to cause disruption in an Australian urban environment over the next decade.

This chapter analyses each of the four platforms against the key readiness parameters, including infrastructure readiness, skills availability, social readiness, economic and commercial feasibility and policy and regulatory readiness, and highlights where action needs to be taken.

3.1.   Low emission vehicles

Climate change and fuel security combined with increasing efficiency and performance in battery and fuel cell design is driving the push towards low and zero emission vehicles[207-209]. These factors signal a strong and irreversible change for road users, both domestic and commercial, as countries across the world commit to banning internal combustion engines by as early as 2025[210], major car manufacturers move to manufacture electric vehicles only within the next two years[211-214], and car manufacturers in Japan and Germany roll out cars with hydrogen fuel cells[215].

The International Energy Agency (IEA) has released data demonstrating an increase in global sales of electric cars by 54 per cent in 2017, with China representing almost half of electric car sales and Norway representing the highest per capita ownership[216].

Although electric vehicles are already on the market in Australia, the uptake has been slow, with electric vehicles contributing to approximately 0.1 per cent of annual vehicle sales in 2016[217]. In 2017, approximately 2,400 electric vehicles were sold in Australia, representing 0.2 per cent of new light vehicle sales[218]. Businesses are the largest buyers of electric vehicles in Australia, accounting for 63 per cent of sales in 2017, while private buyers account for 34 per cent of sales, and government fleets remain limited at only 3 per cent of sales[219].

3.1.1.   Infrastructure readiness

The predicted increase in uptake of LEV and autonomous vehicles in the coming decades will necessitate a significant change in infrastructure. Forecasts by the Electric Vehicles Initiative (EVI) indicate an average of 30 per cent market share in electric vehicles by 2030[220]. The Australian Electric Vehicle Market Study indicated that LEV uptake could account for 20 per cent of new vehicle sales by 2030, and represent 90 percent of all cars and light commercial vehicles on Australian roads by 2050, but would require $1.7 billion in private investment in new charging infrastructure[221,222].

207. Blackburn, J. Australia's liquid fuel security. Part 2. https://www.aph.gov.au/DocumentStore.ashx?id=677ff8dd-ce35-40ee-9af8-bfec1e43d125&subId=301736 February 2014.
208. US Department of Energy. Electric vehicle benefits and considerations. *US Department of Energy.* https://afdc.energy.gov/fuels/electricity_benefits.html 2017.
209. Doherty, B. National fuel security can be enhanced by EVs and PHEVs. *Renew Economy.* https://reneweconomy.com.au/national-fuel-security-can-enhanced-evs-phevs-15566/ 6 November 2014.
210. US Department of Energy. Electric vehicle benefits and considerations. US Department of Energy. https://afdc.energy.gov/fuels/electricity_benefits.html 2017.
211. Roberston, J. Queensland to build one of the world's longest electric vehicle highways. *The Guardian Australia.* https://www.theguardian.com/australia-news/2017/jul/27/queensland-to-build-one-of-worlds-longest-electric-vehicle-highways 27 July 2017.
212. Williams, B. Here's how every major automaker plans to go electric. *Mashable Australia.* https://mashable.com/2017/10/03/electric-car-development-plans-ford-gm/#BamzuoBwuiqN 4 October 2017.
213. Express UK. End of petrol cars: Volvo becomes first major car manufacturer to go all electric. *Express UK.* https://www.express.co.uk/life-style/cars/824866/Volvo-cars-electric-from-2019 6 July 2017.
214. Express UK. End of petrol cars: Volvo becomes first major car manufacturer to go all electric. *Express UK.* https://www.express.co.uk/life-style/cars/824866/Volvo-cars-electric-from-2019 6 July 2017.
215. Galeon, D. Hyundai's hydrogen-powered, self-driving SUV runs on level 4 autonomy. *Futurism.* https://futurism.com/hyundai-hydrogen-powered-suv-level-4-autonomy/ 18 February 2018.
216. International Energy Agency. Electric vehicles: tracking clean energy progress. *International Energy Agency.* http://www.iea.org/tcep/transport/evs/ 6 July 2018.
217. International Energy Agency. Electric vehicles: tracking clean energy progress. *International Energy Agency.* http://www.iea.org/tcep/transport/evs/ 6 July 2018.
218. AEMO. 2018 Electricity Statement of Opportunities. https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2018/2018-Electricity-Statement-of-Opportunities.pdf August 2018.
219. Electric Vehicle Council. Australia's electric vehicle industry gains momentum - report. http://electricvehiclecouncil.com.au/australias-electric-vehicle-industry-gains-momentum-report/ 15 June 2018
220. International Energy Agency. Electric vehicles: tracking clean energy progress. *International Energy Agency.* http://www.iea.org/tcep/transport/evs/ 6 July 2018.
221. Energeia. Australian Electric Vehicle Market Study. https://arena.gov.au/assets/2018/06/australian-ev-market-study-report.pdf May 2018.
222. Clean Energy Finance Group (CEFC). Australia set for surge in electric vehicles and infrastructure in just four years: new modelling. Media release. https://www.cefc.com.au/media/files/australia-set-for-surge-in-electric-vehicles-and-infrastructure-in-just-four-years-new-modelling/ 21 June 2018.

Planning for and adapting to these changes to Australia's vehicle fleet will require integrated land use and transportation planning through coherent and consistent policies. Changes are already underway with some Australian roads designed for electric vehicle use. For example, Queensland is introducing 2000 kilometres of road supported by charging infrastructure[223]. New South Wales (NSW) and Victorian governments are currently investigating the future role of electric vehicles in their respective states. In addition, the South Australian government has developed a hydrogen roadmap[224].

Charging points

Fuel cell technology

Charging infrastructure for fuel cell technology can be installed in existing service stations, or bus depots for hydrogen bus fleets; or it can be sourced via direct connection to gas networks. Each site will require an electrolyser. The act of charging occurs in a similar manner to petrol or diesel, with a dispenser and gauge. There are currently only two hydrogen refuelling points in Australia[225], with no plans of installing additional refuelling stations until there are more hydrogen vehicles on the road. However, vehicles are not being committed to Australia until there are more charging stations. It has been estimated that $3.2 billion would need to be invested into the development of charging infrastructure to support the roll out of three million LEVs in Australia by 2030[226].

Battery technology

As with fuel cells, battery technology requires charging points. However, these do not need to be limited to centralised sites such as existing petrol stations. Charging points can be located at any point on the electricity network (subject to grid stability) and in most instances will be charged at private property, given the ability to 'plug-in'. Key barriers include the lack of standardised charging connectors, which triggers consumer uncertainty through concerns over vehicle interoperability. Standardising charging connectors has the potential to build confidence in consumers around the availability of charging infrastructure and range anxiety, which in turn has the potential to encourage LEV adoption and the rollout of charging infrastructure[227].

Although the number of public LEV charging points available across Australia has increased from 476 in 2017 to 783 in 2018[228], Australia is still lagging behind the rest of the world with respect to vehicle charging infrastructure. Australia has only 32 public charge points per million people, versus the Netherlands and Norway which lead the world with over 1500 public charge points per million people[229].

However, the number of charging stations is increasing. The Victorian Government announced funding for rapid LEV charging stations in five additional locations throughout Melbourne and regional Victoria. Additionally, a project to create a renewable energy-powered LEV charging network between Sydney, Melbourne, Canberra Brisbane, and Adelaide, and in Western Australia has been announced. The Australian Renewable Energy Agency (ARENA)-funded project is being run by Chargefox and will develop 21 ultra-rapid charging stations[230]. To encourage uptake of both BEV and fuel cell vehicles (FCV), a commitment to recharging infrastructure is critical.

Grid connections

Electricity grid

Infrastructure needs for LEVs must consider how the technology will integrate with the electricity grid. Effective grid integration will balance the role of batteries as peak-demand energy generators (supply) as well as exporters of energy from the grid (demand). In a strong uptake and utilisation scenario, the Australian Energy Market Operator (AEMO) predicts a 30,000GWh draw on the grid, based on 10 million LEVs on the road by 2037[231].

223. Robertson, J. Queensland to build one of the world's longest electric vehicle highways. *The Guardian Australia.* https://www.theguardian.com/australia-news/2017/jul/27/queensland-to-build-one-of-worlds-longest-electric-vehicle-highways 27 July 2017.
224. Government of South Australia. A Hydrogen Roadmap for South Australia. https://virtualpowerplant.sa.gov.au/sites/default/files/public/basic_page_attachments/12/19/1844568320/hydrogen-roadmap-11-sept-2017.pdf 11 September 2017.
225. Hydrogen Mobility Australia, 2018
226. Blakiston, M. Uncertainties with electric vehicles in Australia. *Gilbert and Tobin.* https://www.gtlaw.com.au/insights/uncertainties-electric-vehicles-australia 30 April 2018.
227. Wong, J. FCAI proposes EV charging standards for Australia. *Car Advice.* https://www.caradvice.com.au/603962/fcai-proposes-ev-charging-standards-for-australia/ 25 November 2017.
228. ClimateWorks Australia. The state of electric vehicles in Australia. Second report: driving momentum in electric mobility. https://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_australia_state_of_electric_vehicles2_june_2018.pdf June 2018.
229. Hall, D. and Lutsey, N. Emerging best practices for electric vehicle charging infrastructure. *ICCT.* https://www.theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf October 2017.
230. Reichert, C. Australian government invests AU$6m in EV charging network. *ZDNet.* https://www.zdnet.com/article/australian-government-invests-au6m-in-ev-charging-network/ 22 October 2018.
231. Parkinson, G. AEMO has just doubled its forecast for EV uptake in Australia. *Renew Economy.* https://reneweconomy.com.au/aemo-just-doubled-forecast-ev-uptake-australia-66789/ 19 April 2018.

The forecasts for demand on the grid vary in accordance with changes in the uptake of LEVs, reflective of market availability/price and technology (**Figure 3**)[232].

Figure 3: Predicted energy consumption for LEVs in neutral, weak, and strong uptake scenarios[233]
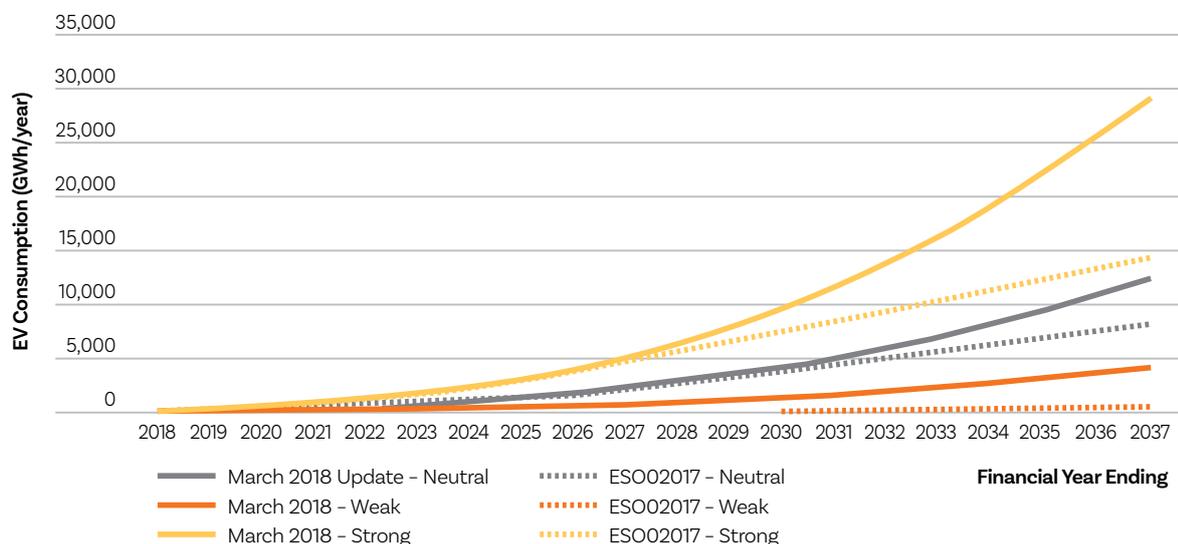
Gas networks

Hydrogen can be distributed using existing gas networks. Energy Networks Australia and Future Fuels CRC (established April 2018) are undertaking trials to investigate how hydrogen can be distributed using existing gas networks[234,235].

3.1.2. Skills availability

Examples of roles likely to be required in a transition to LEVs may include various engineering roles, such as automotive and mechanical engineering, to assist in both the development of the technology and the integration of the technology into current infrastructure and operations.

Apprenticeships and bachelor degrees with foundations in science and engineering will be important to gain skills to work with battery and hydrogen fuel cell technology[236].

Future skill requirements of mechanics will change with the transition to increasingly computerised systems in LEV and autonomous vehicles. A range of additional skills, potentially accessed through vocational education training facilities, will be necessary as the technology develops, such as skills in cybersecurity or Hybrid Electric Vehicle Inspection and Servicing[237]. An understanding of energy networks and their integration with future road infrastructure will also be needed.

Non-science, technology, engineering and mathematics (STEM) skills, such as design or urban planning, will likely also be important in the development and implementation of LEVs.

232. AEMO. AEMO EV Insights. http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/EFI/2018/FINAL---AEMO-EV-Insights---September-2017.pdf September 2017.

233. AEMO. AEMO EV Insights. http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/EFI/2018/FINAL---AEMO-EV-Insights---September-2017.pdf September 2017.

234. Energy Networks Australia. $26M funding to advance hydrogen fuelled network. Media release. https://www.energynetworks.com.au/sites/default/files/12041018_ffcrc_announcement.pdf 12 April 2018.

235. Long, B. Future Fuels to ease Australia's transition to low-carbon economy. *University of Wollongong.* https://media.uow.edu.au/releases/UOW245339.html 12 April 2018.

236. Cavendish Energy. Emerging occupations and skills in the hydrogen/fuel cell economy and associated education and training requirements. http://www.cavendish-e.com/uploads/7/5/7/3/75738781/hydrogen_and_fuel_cell_economy_jobs_1.pdf September 2016.

237. The Good Universities Guide. Hybrid Electric Vehicle Inspection and Servicing. https://www.gooduniversitiesguide.com.au/course-provider/uta-institute-of-technology-pty-ltd/hybrid-electric-vehicle-inspection-and-servicing-skill-set 2019

3.1.3. Social readiness

Consumer attitudes

A number of studies have examined consumer attitudes toward electric cars. Key findings about consumer concerns include:

> Distance range anxiety (i.e. access to charging infrastructure and confidence in mileage/distance)[238]

> Purchase price[239]

> Having to pay a premium[240]

Recent consumer surveys of 1086 residents from the Australian Capital Territory (ACT), New South Wales and Victoria conducted by the RACV and the National Roads and Motorists' Association (NRMA) provided similar results[241].

The decisions that drive the adoption of technologies may be guided by socially contextual and emotional factors, as well as costs, utility, and technical functionalities[242]. For example, one aspect that might drive consumers to adopt a new technology is the need to demonstrate a comparative advantage over existing products. Fuel cell vehicles are currently more expensive to purchase compared to an internal combustion engine vehicle (ICEV) or LEV, although their running costs are expected to be similar to an ICEV. Therefore the vehicles will need functional benefits for consumers to be prepared to adopt. The advantages of FCVs are their low environmental impact, high fuel economy, performance compared to ICEVs, status as technologically advanced, and their operational quietness. However, a UK study on consumer attitudes to FCVs found that they are mostly seen as similar to ICEVs, and require greater benefit to convince consumers to adopt the vehicles given their current high costs[243].

Consumer education and empowerment

Education regarding the evolving price benefits of LEVs as technology advances is important for influencing purchasing behaviour. With advances in battery range and the longer-range alternatives of hydrogen vehicles, consumers need to be regularly updated on the progression of these technologies, and their attitudes re-examined. Currently, LEVs have a higher purchase price but lower fuel costs than ICEVs. Forecasts predict LEV costs to reach parity with ICEVs by the mid-2020s.

Additionally, consumers need to be engaged in the advancement of technological changes in vehicles, with information around safety a factor for FCVs[244].

Vehicle replacement patterns

Decreasing battery costs have increased the number of LEV models into the market, and support from government and industry is predicted to drive greater uptake over the coming decade[245]. Forward projections indicate that the uptake of electric vehicles could increase exponentially, with the number of vehicles estimated to double between 2028-29 and 2030-31, from one million vehicles to two million vehicles in Australia[246] (**Figure 4**).

238. Rezvani, Z., Jansson, J., and Bodin J. Advances in consumer electric vehicle adoption research: a review and research agenda. Transp. Res. D: Transp. Environ., 34 (2015), pp. 122-136. https://doi.org/10.1016/j.trd.2014.10.010

239. Rezvani, Z., Jansson, J., and Bodin J. Advances in consumer electric vehicle adoption research: a review and research agenda. Transp. Res. D: Transp. Environ., 34 (2015), pp. 122-136. https://doi.org/10.1016/j.trd.2014.10.010

240. Larson, P.D.; Viáfara, J.; Parsons, R.V.; Elias, A. Consumer attitudes about electric cars: Pricing analysis and policy implications. Transp. Res. Part A Policy Pract. 2014, 69, 299–314. https://doi.org/10.1016/j.tra.2014.09.002

241. ClimateWorks Australia. The state of electric vehicles in Australia. Second report: driving momentum in electric mobility. https://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_australia_state_of_electric_vehicles2_june_2018.pdf June 2018.

242. Ozaki, Ritsuko & Dodgson, Mark. (2014). Consumption of Innovation. In The Oxford Handbook of Innovation Management, Publisher: Oxford University Press, Editors: Dodgson, M, Gann, D. and Phillips, N, pp.271-289

243. Hardman, S., Chandan, A., Shiu, E., Steinberger-Wilckens, R., 2016a. Consumer attitudes to fuel cell vehicles post trial in the United Kingdom. Int. J. Hydrogen Energy 41, 6171–6179. https://doi.org/10.1016/j.ijhydene.2016.02.067

244. Parkinson, G. AEMO has just doubled its forecast for EV uptake in Australia. *Renew Economy.* https://reneweconomy.com.au/aemo-just-doubled-forecast-ev-uptake-australia-66789/ 19 April 2018.

245. AEMO. AEMO EV Insights. http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/EFI/2018/FINAL---AEMO-EV-Insights---September-2017.pdf September 2017.

246. AEMO. 2018 Electricity Statement of Opportunities. https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2018/2018-Electricity-Statement-of-Opportunities.pdf August 2018.

Figure 4: National Energy Market (NEM) forecast number of electric vehicles by sector, 2017-18 to 2037-38[247]
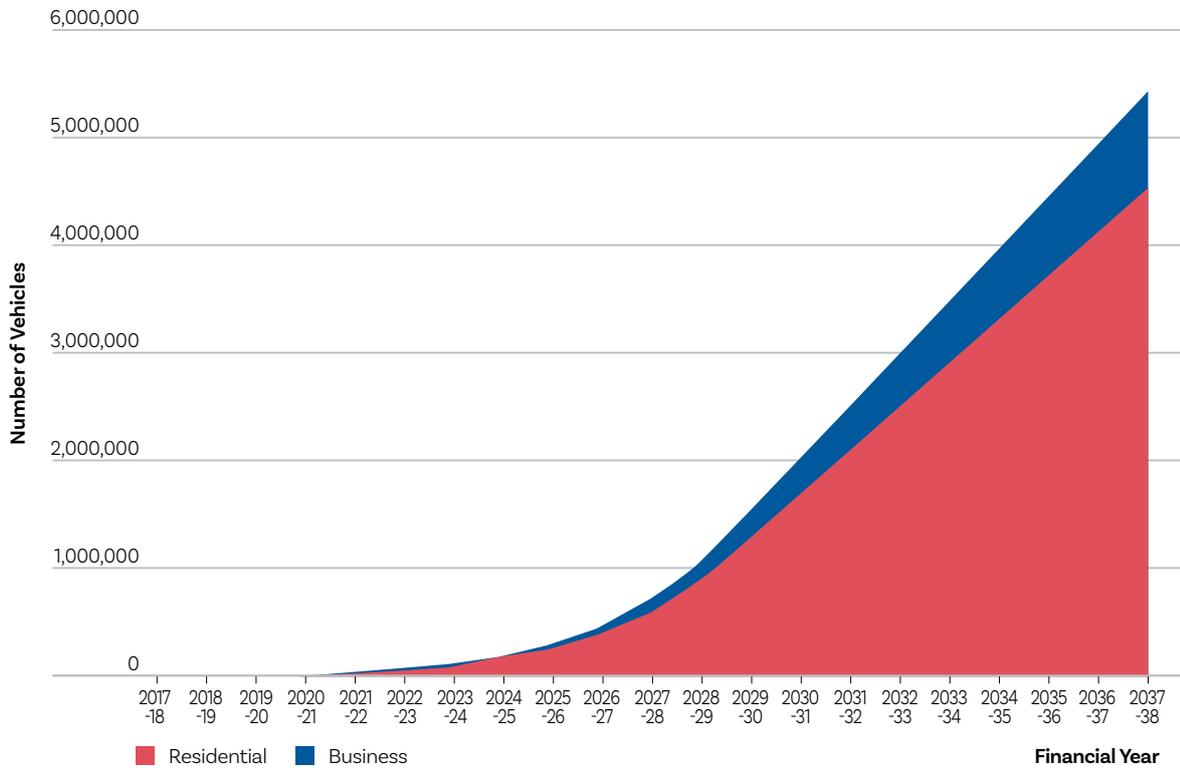
Currently in Australia 1.2 million old cars are being replaced with new cars each year. Based on this, even with 50 per cent uptake of LEVs in Australia, it would take 30 years to convert the current fleet of 18.8 million ICEV vehicles to LEVs[248]. This pace could change if EVs reach price parity or even fall below the cost of ICEVs[249].

Environmental benefits

There are significant benefits to LEVs compared to ICEVs, including cleaner air, reduced traffic noise and reduced greenhouse gas emissions resulting from a reduction in exhaust emissions. Where LEVs are charged using electricity derived from renewable sources, whole-of-system emission reductions can be gained, rather than just from the vehicle exhaust. FCV are also entirely zero emissions where hydrogen is derived from ammonia that has been generated using solar or wind energy.

The end-of-life treatment of car components may also be a concern for consumers. The contents of batteries can be environmentally damaging if not disposed of correctly, but many components are easily recycled with appropriate infrastructure. Historically, Australia recycled more than 90 per cent of lead-acid batteries. Opportunities to develop technologies to recycle components of lithium batteries (including cobalt, nickel and lithium) could be further encouraged and supported to minimise the environmental impacts of LEVs[250].

247. AEMO. 2018 Electricity Statement of Opportunities. https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2018/2018-Electricity-Statement-of-Opportunities.pdf August 2018

248. Parkinson, G. AEMO has just doubled its forecast for EV uptake in Australia. *Renew Economy.* https://reneweconomy.com.au/aemo-just-doubled-forecast-ev-uptake-australia-66789/ 19 April 2018.

249. Greber, J. One million electric cars by 2030? You're dreaming without big spending. *Australian Financial Review.* https://www.afr.com/news/economy/one-million-electric-cars-by-2030-youre-dreaming-without-big-spending-20180522-h10ep3 22 May 2018.

250. Godfrey, B., Dowling, R., Forsyth, M., Grafton, R.Q. and Wyld, I., (2017) The Role of Energy Storage in Australia's Future Energy Supply Mix. Report for the Australian Council of Learned Academies., www.acola.org.au.

3.1.4. Economic and commercial feasibility

Niche/high value industries

Although Australia is unlikely to become a manufacturer of existing battery technologies, there are potential opportunities for manufacturing next-generation battery technologies[251]. This is particularly true in niche markets, for example, where safety is paramount and for Australia's high temperatures. There are also opportunities to capitalise on Australia's existing automotive engineering expertise.

Resources

Australia has the resources to participate in the materials market, most notably with lithium. With increased uptake of LEVs, demand for the components that make up lithium-ion batteries will also increase[252]. Australia has the third-largest lithium resource in the world, and is the largest producer of hard-rock spodumene[253]. The potential for Australia to be a leader in the lithium battery supply chain is well-recognised[254].

Vehicle to grid technology

There are three main charging profiles for LEVs:

> **Convenience charging**, with vehicles being predominantly charged as soon as drivers get home, including during peak hours

> **Smart day charging**, with vehicles being predominantly charged in the middle of the day during the solar peak

> **Overnight charging**, with vehicles being predominantly charged overnight, after the evening demand peak[255]

Electricity costs will result in some consumers charging their vehicles overnight, but convenience charging will most likely be the most common type of charging.

With appropriate infrastructure, vehicles can reinject energy into the grid at a time of peak demand, acting as a battery for the energy grid. However, as this will only be possible if all the vehicles can be continuously connected to the grid while not being used, and there aren't currently enough connection points to charge all the vehicles that people want to charge, this remains a significant challenge. Identifying further opportunities to optimise the grid, such as using vehicles as a residential power source[256], will be critical to manage the forecast increase in LEVs.

Increased uptake of LEVs will have significant fuel security benefits as a result of shifting away from ICEVs. This is extremely important, as Australia currently has liquid fuel supplies for 22 days, forecast to reduce to less than 20 days by 2030[257].

3.1.5. Policy and regulatory readiness

Fuel standards

The Ministerial Forum on Vehicle Emissions was established by the Australian Government in 2015 to examine fuel standards, emission standards and the efficiency of vehicles, and is preparing a draft plan on potential measures to encourage electric vehicle uptake.

251. Godfrey, B., Dowling, R., Forsyth, M., Grafton, R.Q. and Wyld, I., (2017) The Role of Energy Storage in Australia's Future Energy Supply Mix. Report for the Australian Council of Learned Academies., www.acola.org.au.

252. Bloomberg New Energy Finance. Electric Vehicle Outlook 2018. https://about.bnef.com/electric-vehicle-outlook/#toc-download 2018

253. Britt, A., Summerfield, D., Senior, A., Roberts, D., Kay, P., Hitchman, A., Champion, D., Huston, D., Simpson, R., Smith, M., Sexton, M. and Schofield, A. Geoscience Australia 2016. Australia's Identified Mineral Resources 2016. Geoscience Australia, Canberra. http://d28rz98at9flks.cloudfront.net/100121/100121_AIMR%202016_V2.pdf

254. Austrade. The lithium-ion battery value chain. New economy opportunities for Australia. https://www.austrade.gov.au/ArticleDocuments/5572/Lithium-Ion%20Battery%20Value%20Chain%20report.pdf.aspx December 2018.

255. AEMO. 2018 Electricity Statement of Opportunities. https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2018/2018-Electricity-Statement-of-Opportunities.pdf August 2018

256. Stapczynski, S. Your future home might be powered by car batteries. *Bloomberg.* https://www.bloomberg.com/news/articles/2018-04-08/cities-running-on-car-batteries-just-so-crazy-it-might-work 9 April 2018.

257. Blackburn, J. Australia's liquid fuel security. Part 2. https://www.aph.gov.au/DocumentStore.ashx?id=677ff8dd-ce35-40ee-9af8-bfec1e43d125&subId=301736 February 2014.

Trend setting

Government can lead wide spread uptake by introducing LEVs into their fleets, using their procurement policies to encourage innovation, and demonstrating new technologies and building markets. As an example, the ACT is considering introduction of an electric vehicle adoption target with policy incentives[258], to transition to low-emissions transport.

Standards and safety

Standards development

An increasing number of LEVs are entering the Australian market, from producers such as Tesla, Nissan, Hyundai, Mitsubishi and Holden[259]. There is no universal charging connector standard, and as such, there are a number of different charging connectors and plugs[260]. An Australian standard for charging connections may encourage adoption of LEV technology by removing some of the concerns around range by presenting more opportunities to charge.

Safety

Consumer concerns about refuelling for hydrogen vehicles need to be managed through implementation of standards, safety procedures and regulations.

3.2. Connected autonomous vehicles

CAVs are vehicles where some aspects of a safety-critical control function such as steering, throttle control or braking occurs without direct driver input. They use on-board sensors, cameras, GPS and telecommunications to obtain and analyse information using complex computer algorithms, and respond appropriately by effectuating control in safety-critical situations.

The level of autonomy can range from driver assistance, where in some circumstances the system can steer or accelerate/decelerate for the driver (Level 1), to fully automated vehicles (Level 5), where the system is in constant control[261]:

> **Level 1 and 2 (Driver Assistance and Partial Automation)** technologies such as automatic brake assist have been fitted to vehicles since the mid-2000s
> **Level 3 (Conditional Automation)** is capable of overseeing the driving task in limited situations with a driver present behind the wheel
> **Level 4 (High Automation)** removes the need for a driver; however, the technology cannot fully operate under all road conditions
> **Level 5 (Full Automation)** negates the need for pedals and a steering wheel, completely removing the driver from the driving task under all conditions

CAVs are capable of autonomously communicating with each other (V2V), with roadside infrastructure, such as traffic control signals (V2I), or with other devices, such as mobile phones (V2X).

Effective and efficient logistics of goods and services require optimal connectivity and a robust relationship between inter- and cross-modal transportation and transit systems. Accordingly, it is essential that transport modes have the ability, capability, and flexibility to connect to each other.

3.2.1. Infrastructure readiness

Connectivity, coverage and reliability are central to the successful deployment of CAVs[262]. Although autonomous vehicles can operate effectively without connectivity (for instance using high-precision maps and sensors), the addition of connectivity can significantly enhance functionality. For this reason, the successful rollout of connected automated vehicles that are capable of functioning at the highest level will require mobile internet coverage across the whole road network.

258. Vorrath, S. ACT eyes electric vehicle target, after 'nation-leading' renewables success. *Renew Economy*. https://reneweconomy.com.au/act-eyes-electric-vehicle-target-after-nation-leading-renewables-success-36073/ 26 October 2017.

259. EVSE. What is the electric vehicle charging standard in Australia? *EVSE*. https://www.evse.com.au/blog/evchargingaustralia/ 10 August 2016.

260. Jetcharge. Vehicle plug types. *Jetcharge*. https://jetcharge.com.au/resources/ev-guide/vehicle-plug-types

261. SAE International. Taxonomy and definitions for terms related to driving automated systems for on-road motor vehicles. *SAE International*. https://www.sae.org/standards/content/j3016_201609/ 30 September 2016.

262. SMMT International Automotive Summit. Connected and autonomous vehicles. Revolutionising mobility in society. https://www.smmt.co.uk/wp-content/uploads/sites/2/Connected-and-Autonomous-Vehicles-Revolutionising-Mobility-in-Society.pdf

Connectivity

Some elements that make up the connected car are not new. Nearly all cars being produced today have various computers that run self-diagnosis or have the ability to collect data about their performance and how they are driven. Connected car packages are currently offered to customers of high end manufacturers such as Tesla, BMW and Audi[263]. As the technology develops, connected CAVs will have the ability to book and take themselves to services, and forecast maintenance requirements. Existing and planned infrastructure is largely sufficient to support the introduction of CAVs, but further investment in connecting the CAVs to other vehicles and infrastructure could increase the benefit of CAVs.

Types of communication for CAVs include:

> Vehicles with internet capability

> V2I, which provide optimum speed and route for travel. This technology is used for:
  – Speed limits
  – Hazardous location notifications
  – Traffic signal violations
  – Overtaking vehicle warnings
  – Incident detections

> V2V. This technology is used for:
  – Spatial awareness
  – Incident detection and communication to other vehicles

> V2X. This technology is used for:
  – Information for the passenger
  – Smart phone applications/website

Communications technologies for CAVs include:

> DSRC, which is used for short pieces of information such as location and speed of vehicles within a short to medium range

> 4G/5G wireless network, which is used for real-time information such as traffic congestion and high-end services for passengers

Mobile coverage

In 2013, the level of mobile coverage in Australia was only 25 per cent of the landmass[264]. This figure is relatively unchanged today, with coverage spanning only cities and larger regional centres (**Figure 5**). The Department of Communications launched the Black Spot Program, the main focus of which is to extend and improve mobile phone coverage through establishing an additional 867 mobile base stations. The planned rollout of 5G services in Australia in 2019 will assist connectivity of highly functional autonomous vehicles in urban areas, but they will not be feasible across the whole of Australia until mobile coverage spans the entire landmass. However, mobile coverage is not essential for operation of CAVs.

263. NRMA. The future of car ownership. https://www.mynrma.com.au/-/media/documents/reports-and-subs/the-future-of-car-ownership.pdf?la=en August 2017.
264. Commonwealth of Australia (2013). Mobile coverage programme discussion paper. https://www.communications.gov.au/file/3215/download?token=0_Yw3VEG 16 December 2013.

Figure 5: Map showing mobile coverage of 4G and 3G in Australia[265]
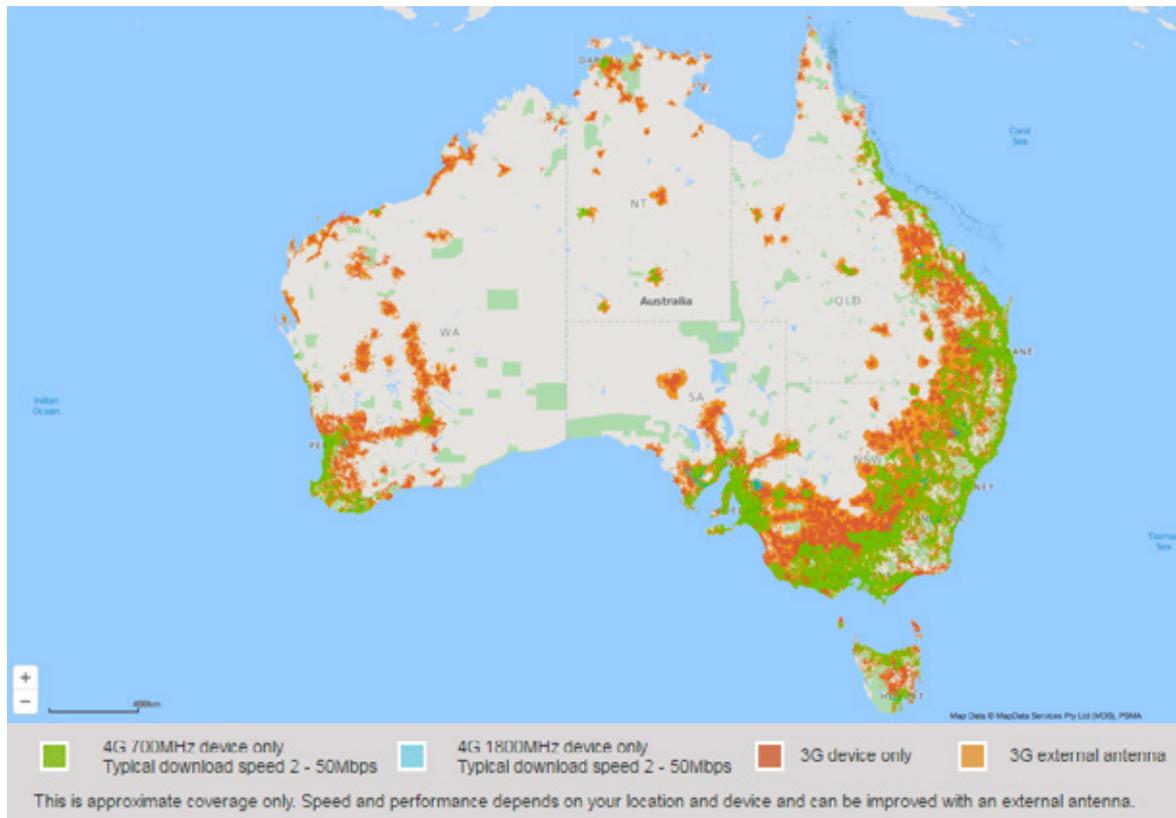
Intelligent transport systems

CAVs will need to share data wirelessly with other vehicles, infrastructure, transport management systems, and mobile devices.

Human drivers have the ability to respond appropriately to changes in road layout as a result of roadworks or vehicle crashes, however, autonomous driver systems cannot read road signs and may have difficulty navigating changed road conditions. Consideration needs to be given to future traffic management measures for autonomous vehicles. This could take the form of a connected roadworks warning system that communicates the details of the work, including the location of workers, configuration of the worksite, and speed of vehicles around the site[266]. However, this is only feasible for planned roadworks; unplanned traffic incidents will still require special sensing of unusual circumstances by the CAV.

Road conditions and signage

A number of CAV technologies require good road conditions and road markings, and clear and consistent signage to navigate effectively. When there are long cracks in roads or markings are faded, CAVs have difficulty staying in the correct lane. This may be mitigated in the future by implementation of digital road marking and signage infrastructure, but until then, road markings and signage will require regular maintenance to support CAVs. However, even with regular maintenance, traditional road signs and markings may become difficult for CAVs to recognise in inclement weather. Additionally, methods need to be developed for humans to direct CAVs with hand gestures in the case of incident first response teams.

Car parking

If humans are taken out of the car parking process, significant space savings can be made, allowing for a greater number of (autonomous) vehicles to be parked in a car park facility at any given time (**Figure 6**). Allowing vehicles to move as directed by the car parking system will require remote control access of the vehicle by the car park operator. However, allowing vehicle systems to be accessed and controlled in this way could expose the vehicle to cyber security threats.

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265. http://mobilemaps.net.au/maps/mcm/4G.html
266. Transport Systems Catapult. Future proofing infrastructure for connected and automated vehicles. Technical Report. https://s3-eu-west-1. amazonaws.com/media.ts.catapult/wp-content/uploads/2017/04/25115313/ATS40-Future-Proofing-Infrastructure-for-CAVs.pdf February 2017.

Figure 6: Conventional car park design (left) and possible AV parking design (right)[267]

Self Parking / Valet Parking

Driverless Parking
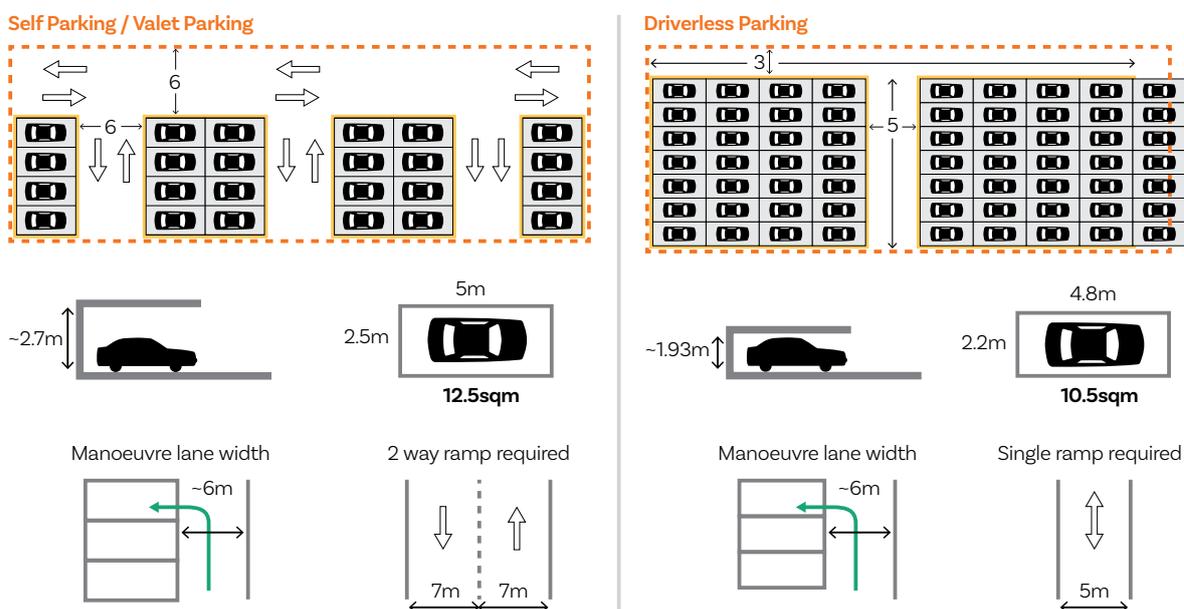
Road capacity

Significant increases in efficiency and potentially reductions in road congestion can be gained by having CAVs on the road, particularly if they are using V2X technology and car-share services[268]. Research undertaken by Infrastructure Victoria indicated that if 50 per cent of road trips were taken in automated vehicles and all other trips were taken by human drivers, then it was possible to see a 70 per cent reduction in average delay on the network[269]. However, stakeholders indicated that it would be unlikely that such impacts on the flow of the network would be realised by 2030, with some researchers questioning whether CAVs will reduce delays at all. Co-ordination with traffic lights and avoidance of congestion could further lead to a reduction in travel and idling time. Affordable car-share services using CAVs could also lead to less people owning private cars and therefore less road congestion.

City-shaping potential

It is anticipated that one of the greatest impacts of CAVs will be on how they gradually shape and transform cities and mobility. With the deployment of CAVs likely resulting in the lowering of road space requirements, reduced space allocated to parking, and smaller clearances and platooning, there is a significant opportunity to modify and repurpose city spaces and to enhance shared mobility offerings and other convenient transport options[270,271]. Benefits associated with changes to urban spaces could include:

> Increased safety of passengers, pedestrians and other urban area users

> More efficient road use and decreased congestion

> Enhanced access and mobility

> Decreased emissions associated with vehicles

To realise these benefits, changes to the use of urban spaces could include:

> Conversion of parking spaces to other urban infrastructure, such as green spaces, transport hubs, etc.

267. Transport Systems Catapult. Future proofing infrastructure for connected and automated vehicles. Technical Report. https://s3-eu-west-1. amazonaws.com/media.ts.catapult/wp-content/uploads/2017/04/25115313/ATS40-Future-Proofing-Infrastructure-for-CAVs.pdf February 2017.

268. Advancing Public Transport. Policy brief. Autonomous vehicles: a potential game charger for urban mobility. https://www.uitp.org/sites/default/files/cck-focus-papers-files/PolicyBrief_Autonomous_Vehicles_LQ_20160116.pdf January 2017.

269. Infrastructure Victoria (2018). Advice on Automated and Zero Emissions Vehicles Infrastructure. http://www.infrastructurevictoria.com.au/sites/default/files/files/AVZEV/Advice%20on%20automated%20and%20zero%20emissions%20vehicles%20-%20October%202018.PDF October 2018.

270. City of Melbourne. How driverless cars could shape Melbourne's future. *City of Melbourne.* https://www.melbourne.vic.gov.au/news-and-media/Pages/How-driverless-cars-could-shape-Melbournes-future-.aspx 10 May 2018.

271. Transport for NSW (2019). Connected and automated vehicles plan. https://www.future.transport.nsw.gov.au/sites/default/files/media/documents/2019/Connected_and_Automated_Vehicles_Plan.pdf

> Development of satellite self-parking infrastructure for CAVs

> Increased urban density or growth in city fringe areas

However, if not properly regulated and managed, there is a risk that increased traffic congestion, reduced urban amenity and operational safety and data confidentiality could outweigh the benefits[272].

3.2.2. Skills availability

General employability skills for the CAV industry include communication skills, research, planning, troubleshooting, collaboration, problem solving, leadership, mathematics, creativity, organisation, and computer skills[273].

The job types, technical skills and qualifications required for each area of the CAV industry are outlined below.

Vehicle design and testing

Job types

Electrical and mechanical engineers, and commercial and industrial designers.

Specialised skills such as specific computer languages, and well-rounded workers with the ability to research, communicate and solve problems in teams are often requested[274].

Technical skills required

Electrical/systems/computer/mechanical engineering, MATLAB, C++, physics, image processing, validation, software development, LINUX, Python, UNIX.

Vehicle IT design

Developing hardware and writing software for use in connected and autonomous vehicles.

Types of qualifications

Computer science, general engineering, computer engineering, electrical engineering, physics, information systems, mechanical engineering, systems engineering, information technology, business administration and management.

Technical skills required

Software development, software/computer/electrical/systems engineering, C++, LINUX, JAVA, Python, image processing, MATLAB, UNIX, software architecture, information assurance, information systems.

Quality control

Job types

Quality control systems managers, quality control analysts, inspectors, and testers.

Types of qualifications

Computer science, general engineering, chemistry, telecommunications technology, business administration and management, computer/mechanical/electrical engineering, quality control technology, industrial management.

Technical skills required

Inspection, software development, biology, supervisory skills, chemistry, LINUX, project management, Cisco.

Data management and cyber security

Job types

Data warehousing specialists, information security specialists, and other computer- and network-related occupations protect data being collected and communicated by connected infrastructure and automated vehicles.

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272. City of Melbourne. How driverless cars could shape Melbourne's future. *City of Melbourne*. https://www.melbourne.vic.gov.au/news-and-media/Pages/How-driverless-cars-could-shape-Melbournes-future-.aspx 10 May 2018.

273. Workforce Intelligence Network (2017). Connected and automated vehicles skills gap analysis. Workforce Intelligence Network for Southeast Michigan. https://winintelligence.org/wp-content/uploads/2017/03/WIN_ATLAS-UMTRI_Report-singlepages-rs.pdf February 2017.

274. Workforce Intelligence Network (2017). Connected and automated vehicles skills gap analysis. Workforce Intelligence Network for Southeast Michigan. https://winintelligence.org/wp-content/uploads/2017/03/WIN_ATLAS-UMTRI_Report-singlepages-rs.pdf February 2017.

Types of qualifications

Computer science, general engineering, computer/electrical/systems/mechanical engineering, management of information systems, information technology, business administration and management, physics.

Technical skills required

Systems engineering, information systems, information assurance, LINUX, information security, UNIX, software development, network security, project management.

Intelligent transportation systems and infrastructure design

Job types

Telecommunications specialists, civil engineers, transportation planners and engineers and traffic technicians to inform decision making on connected infrastructure and traffic management.

Types of qualifications

General/electrical/computer/systems/transportation and highway/structural engineering, computer science, information technology, construction management, urban/community/regional planning.

Technical skills required

Network engineering, project management, Cisco, routers, civil engineering, switches, Wide Area Network, network security, systems engineering.

3.2.3. Social readiness

Addressing social issues is of critical importance to the uptake of CAVs. A positive public perception of CAVs can be influenced by advertising the results of safe trials and deployment.

A number of researchers have examined the public's perception of CAVs. A 2014 survey of 1533 people from the U.S., U.K. and Australia on attitudes of the general public towards autonomous vehicle technology[275] found:

> A majority (61.0 per cent) of Australians had heard of 'self-driving' vehicles, with a similar number (61.9 per cent) having a positive general opinion of the technology

> 67 per cent of Australian respondents expressed desire to use automated vehicle technology and 25 per cent were willing to pay more than $3,000 for it. About 30 per cent of respondents were unwilling to pay extra for an autonomous vehicle

> Most participants expected better safety, cost of insurance, fuel consumption and environmental outcomes. They did not expect shorter travel times or reduced congestion

> A majority of respondents were 'moderately' or 'very' concerned about some aspects of automated driving technology, including:
  – System failures (including safety and security)
  – Riding in a vehicle with no driver controls
  – Automation of commercial vehicles and public transport
  – Legal liability
  – Automated vehicles not performing as well as human drivers
  – Unoccupied trips by automated vehicles
  – Interactions between automated vehicles and vulnerable road users
  – Data privacy

> A significant percentage (43.4 per cent) would watch the road even when not required or would not ride in an automated vehicle (21.2 per cent)

The main implications are that the general public are highly concerned about travelling in autonomous vehicles, but feel positive about the technology and its benefits, and generally desire the technology when it becomes available to them.

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275. Schoettle, B. and Sivak, M. (2014). A survey of public opinion about autonomous and self-driving vehicles in the US, the UK and Australia. University of Michigan Transportation Research Institute. https://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf?sequence=1&isAllowed=y July 2014.

The attitudes outlined in the study[276] are reflected globally. A survey of 5000 respondents from 109 countries found that respondents were most concerned about software hacking and data misuse, and also legal and safety issues[277]. Interestingly, respondents from more developed countries were less comfortable with their vehicle transmitting data than those from less developed countries.

Legal certainty for consumers is essential for social acceptance of automated vehicles. This includes ensuring autonomous vehicles are legal to drive, that there is insurance available to humans involved in a crash, and that the vehicle owner will not be held responsible for the actions of the automated system[278].

There is a small positive correlation between age and concerns about legal and financial responsibility associated with AVs, suggesting that older people exhibited higher levels of concern than younger people about legal and financial responsibility[279].

In a recent Australian study of 1624 people[280], the majority (40 per cent) of people felt neutral about the widespread use of driverless cars (compared to 23 per cent who had negative feelings, and 37 per cent who had positive feelings). This response changed once participants were asked to contemplate the likelihood of specific social benefits of driverless cars. When asked to consider the benefits of driverless cars without being prompted with specific examples of the benefits, only 21 per cent of respondents thought driverless vehicles would lead to crash reduction, one per cent thought they would cause an emission/pollution reduction, one per cent predicted a stress reduction, three per cent thought driverless cars would improve mobility for elderly or disabled people, and zero per cent predicted improvements in cyclist safety.

After being provided with examples of how autonomous vehicles can improve these factors, respondents' attitudes to benefits for each improved to 49 per cent for crash reduction, 45 per cent for emission/pollution reduction, 54 per cent for stress reduction, 73 per cent for mobility for elderly or disabled people, and 45 per cent for cyclist safety.

An annual self-driving car survey conducted by Eastlink revealed fewer Victorian motorists wanted a fully self-driving car in 2018 compared to 2017. However, more motorists wanted the latest semi-automated driver assistance features such as lane keeping assistance, lane departure warning, cruise control, and automatic emergency braking[281].

Safety

Automated vehicle technology has significant potential to reduce the number of injuries and fatalities caused by road crashes in Australia. Human error may be a factor in up to 90 per cent of road incidents[282], and this would be greatly reduced by automating driving. However, there are already safety issues surrounding an over-reliance on automated technology, which arise when drivers overestimate the abilities of the technology and do not regain proper control of the vehicle when they are required to.

Drivers may also lose vigilance if some aspects of the vehicle are automated, leading to decreased situational awareness[283]. Similarly, drivers may lose some driving skills through lack of use, leading to issues in the case of automation failure. This problem may eventually be solved with the introduction of full (level 5) autonomy of vehicles.

276. Schoettle, B. and Sivak, M. (2014). A survey of public opinion about autonomous and self-driving vehicles in the US, the UK and Australia. University of Michigan Transportation Research Institute. https://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf?sequence=1&isAllowed=y July 2014.

277. M. Kyriakidis, R. Happee, J.C.F. de Winter (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 32, 2015, Pages 127-140, https://doi.org/10.1016/j.trf.2015.04.014

278. Commonwealth of Australia (2017). Social impacts of automation in transport. Submission to the House of Representatives Standing Committee on Industry, Innovation, Sciences and Resources. February 2017. https://www.aph.gov.au/DocumentStore.ashx?id=ebbdd83c-b61e-40ea-8bf5-47ab70cad11d&subId=463736

279. M. Regan, M. Cunningham, V. Dixit, T. Horberry, A. Bender, K. Weeratunga, S. Cratchley, L. Dalwood, D. Muzorewa, A. Hassan (2017). Preliminary findings from the first Australian National Survey of Public Opinion about Automated and Driverless Vehicles. *ADVI*. https://s3-ap-southeast-2.amazonaws.com/cdn-advi/wp-content/uploads/2017/07/ADVI-Public-Opinion-Survey-7June2016.pdf June 2017.

280. Pettigrew, S., Talati, Z. and Norman, R. (2018), The health benefits of autonomous vehicles: public awareness and receptivity in Australia. Australian and New Zealand Journal of Public Health, 42: 480-483. doi:10.1111/1753-6405.12805 https://onlinelibrary.wiley.com/doi/abs/10.1111/1753-6405.12805

281. Eastlink. Eastlink's 2018 annual Victorian self-driving car survey. Media release. *EastLink.com.au*. https://www.eastlink.com.au/images/news/181120-Results-of-2018-Annual-Victorian-Self-Driving-Vehicle-Survey.pdf 20 November 2018.

282. US Department of Transportation. Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115 February 2015.

283. Austroads (2017). Safety benefits of C-ITS and automated driving in Australia and New Zealand. https://researchmgt.monash.edu/ws/portalfiles/portal/241124499 October 2017.

3.2.4. Economic and commercial feasibility

Business models

The introduction of CAVs across all sectors could have a significant impact on the types and numbers of transport related jobs available, and the ways in which many businesses operate.

If car-share services using CAVs reach price parity to human-driven taxis, job losses among taxi drivers could be substantial. Public transport, trucking and courier/delivery businesses would no longer need human drivers. Although fewer people will need to learn how to drive traditional cars, driving instructors will still be required for those driving in CAVs with manual controls (levels 1 – 3). Investment in retraining programs will be important to retrain displaced workers and ensure unemployment rates do not dramatically increase.

The structure of the insurance industry will change dramatically if fully autonomous vehicles are introduced, as collisions will be less frequent and would not be the fault of the human driver (currently 94 per cent are caused by human error[284]). It remains unclear whether the vehicle manufacturer, software provider or road network provider will be responsible for crashes. Depending on the type of uptake, insurance companies' customer base may switch from insuring millions of individual policies to insuring a few mobility fleet operators and CAV manufacturers.

Data protection

Connected AVs will require collection of an enormous amount of data as vehicles are continuously sensing information from their environment. Analysis of this data will be important for ensuring constant improvement of autonomous driver systems. The wealth of information the data contains will make it commercially valuable. The value of this data will need to be balanced with protection of the autonomous vehicle users' privacy.

Cyber security

Cyber security will be the responsibility of governments and industry. Protection against cyberattacks will need to be proven before the public will embrace driverless technology.

In order to protect functionality of autonomous vehicles, critical components such as control systems need to be separated from hackable components such as sensors and Bluetooth by the strongest possible protection.

Today's car features around 100 million lines of programming code and can process up to 25 gigabytes of data an hour[285]. Cars are becoming increasingly digital and connected, providing a greater surface area for cyber attackers to target.

3.2.5. Policy and regulatory readiness

Over 50 Australian federal and state laws will need to be amended to allow for autonomous vehicles due to references to the 'driver', and assumptions that the driver is human[286]. The National Transport Commission is working to address this.

Australian governments recognise the potential of CAVs and are beginning to implement programs to allow for further testing of this technology in Australia. The Queensland Department of Transport and Main Roads has launched the Cooperative and Automated Vehicle Initiative (CAVI), which consists of four components:

> An on-road testing trial of autonomous vehicles with cooperative intelligent transport systems

> A cooperative and highly automated driving pilot to test a small number of highly automated vehicles

> A project to investigate how new technology applications can benefit vulnerable road user safety including pedestrians, motorcycle riders, and bicycle riders

> A change management process for the Department of Transport and Main Roads to consider the change of current business models and practices

284. US Department of Transportation. Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115 February 2015.

285. McKinsey & Company. What's driving the connected car. *McKinsey & Company.* https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-driving-the-connected-car September 2014.

286. NRMA (2017). Transforming mobility. A regulatory roadmap for connected and automated vehicles. http://keolisdowner.com.au/wp-content/uploads/2017/12/Transforming_Mobility_report.pdf November 2017.

The National Transport and Infrastructure Council[287] announced that Australian governments will aim to have end-to-end regulation in place by 2020 to support safe deployment of autonomous vehicles, based on recommendations from the National Transport Commission (NTC). New regulation will need to consider imports and manufacturing, registration, licensing, insurance, roadworthiness, on-road regulation and data.

Imports and manufacturing

All vehicles and parts made in Australia or imported will need to comply with Australian standards.

Registration

New ownership models, such as pay-per-use and car sharing, will require new registration models.

Licensing

In new legislation, governments will need to specify whether humans travelling in AVs will need to have a valid 'drivers' licence, and if so, how licences for autonomous vehicle passengers will differ from tradition drivers' licences.

Insurance

Insurance policies will need to change to reflect the responsibility of the automated system, rather than the human driver, to safely operate the vehicle. This will shift the liability to the manufacturers of automated systems.

Roadworthiness

Legislation will need to create new standards for roadworthiness to encompass the driver system technology in addition to other physical components of the vehicle already considered in current measures of roadworthiness.

Governments and industry must ensure all CAVs are fitted with V2V systems that 'speak the same language' through standardised messaging.

On-road regulation

Governments need to consider who will be liable if autonomous driving systems breach legislation or do harm.

Current laws and regulations prohibit someone driving while under the influence of alcohol or drugs, and some Australian states do not allow passengers to drink alcohol inside a taxi. A potential benefit of automated vehicles is reducing the number of alcohol and drug-related driving crashes and deaths. Alcohol and drug driving offences should not apply to people in a fully automated vehicle (a vehicle that does not have pedals or a steering wheel). However, these regulations should still apply to drivers in CAVs with manual controls (level 1-3), even if the vehicle is operating at full automation, because drivers could suddenly choose to take over the driving task.

In 2017, the NTC and Austroads released guidelines for the trials of automated vehicles in Australia[288]. The purpose of these guidelines is to support state and territory road agencies in providing exemptions or permits for trials, and providing greater certainty to industry on conditions for trials[289].

Data

Data can be used to improve transport system use, provided it is permitted to be used in a variety of ways. For example, giving drivers access to real-time data allows them to plan their journey even if it's already underway.

Giving traffic authorities access to an autonomous vehicle's system could allow them to stop runaway vehicles or eliminate red-light collisions. However, consumers are unlikely to want organisations to be able to access and control their vehicle. Finding an appropriate balance between making use of the data being collected by CAVs and ensuring consumers' privacy will be extremely important.

287. Transport and Infrastructure Council. Communique. http://transportinfrastructurecouncil.gov.au/communique/files/8th_Council_Communique_10-Nov-2017.pdf 10 November 2017.
288. National Transport Commission and Austroads (2017). Guidelines for trials of automated vehicles in Australia. https://www.ntc.gov.au/Media/Reports/(00F4B0A0-55E9-17E7-BF15-D70F4725A938).pdf
289. National Transport Commission. Australian guidelines for automated vehicle trials invite nationwide testing of new-era technology. *National Transport Commission*. https://www.ntc.gov.au/about-ntc/news/media-releases/australian-guidelines-for-automated-vehicle-trials-invite-nationwide-testing-of-new-era-technology/

3.3. High frequency mass transport

Australia's population has been projected to increase to between 28.3 million and 29.3 million by 2027, with between 69 per cent and 70 per cent of the population living in capital cities[290]. It has been estimated that urban congestion currently costs the economy $16.5 billion every year, and will likely rise to between $27.7 and $37.7 billion by 2030[291,292]. Future transport solutions will subsequently require more advanced high frequency mass transit options to improve accessibility, efficiency, effectiveness and productivity, and to reduce greenhouse gas emissions. However, it should be noted that mitigating congestion will also be very costly.

Over the next decade, the mass transport sector will most likely be transformed by on-demand user-centred transport and autonomous vehicles. On-demand transport is responsive to individual temporal needs, and provides real-time information (for example vehicle location and arrival time) to commuters, with flexible on-demand services selected and booked through smart phone applications so commuters can customise their journey to their requirements. This gives public transport users greater control and may encourage increased use of public transport.

Autonomous public transport can provide efficiency gains, reduced operating costs from not having to pay drivers, and improved road safety outcomes[293]. However, driverless vehicles are also likely to have higher capital costs for some time.

3.3.1. Infrastructure readiness

Connected systems

Transport data can be collected through mobile apps that also provide commuters with real-time service updates. Data collected on commuters' travel habits and preferences can be used by service providers to suggest future travel services, or for transport providers and governments to assist in determining where future investment is most required[294].

Mobile applications can allow commuters to sync their travel plans with their calendars, providing alerts and optimal travel routes automatically based on commuters' schedules for the day[295].

Ticketing

A connected transport system will require interoperable electronic ticketing across cities, and could utilise smart phones, digital wallets, wearable technology, or RFID for contactless ticketing, increasing efficiency by eliminating the physical act of tapping or swiping a physical ticket[296].

In mid-2018, the Queensland Government announced it would be rolling out a state-wide interoperable ticketing system over the next four years where commuters can use contactless debit or credit cards, smart phones, and smart watches in addition to the go card and paper tickets[297]. Contactless payment methods are also available as single trip tickets for Sydney Trains, NSW TrainLink Opal ticketed rail services, Sydney Ferries and Sydney or Newcastle light rail services[298].

290. Australian Bureau of Statistics (2018). 3222.0 - Population Projections, Australia, 2017 (base) – 2066. http://www.abs.gov.au/ausstats/abs.nsf/Latestproducts/3222.0Main%20Features52017%20(base)%20-%20 2066?opendocument&tabname=Summary&prodno=3222.0&issue=2017%20(base)%20-%202066&num=&view=

291. Bureau of Infrastructure, Transport and Regional Economics (BITRE), Traffic and congestion cost trends for Australian capital cities, Information Sheet 74, Commonwealth of Australia, Canberra, 2015.

292. Commonwealth of Australia (2016). Smart Cities Plan. https://infrastructure.gov.au/cities/smart-cities/plan/files/Smart_Cities_Plan.pdf

293. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

294. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

295. Deloitte (2015). Transport in the Digital Age – Disruptive Trends for Smart Mobility. https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/bps/deloitte-uk-transport-digital-age.pdf March 2015.

296. Gardner, N. The smart future of public transport. *The Conversation.* https://theconversation.com/the-smart-future-of-public-transport-1815 17 August 2011.

297. Bailey, M. (Minister for Transport and Main Roads). Palaszczuk Government adopts hi-tech transport payment across Queensland. Media release. https://www.its-australia.com.au/wp-content/uploads/Govt-Media-Statement-Palaszczuk-Government-adopts-hitech-transport-payment-across-Qld.pdf 20 June 2018.

298. https://transportnsw.info/tickets-opal/opal/contactless-payments#accordion-when-to-use-contactless-content

Infrastructure for driverless passenger trains

Driverless passenger train trials are currently being finalised on Sydney's new North West Rail Line. Driverless trains and this new line will open to the public in in the second quarter of 2019, with further expansions to open in 2024 onwards[299]. As driverless mass transport is already operating in a number of cities overseas, and the first fully autonomous train is already operating by Rio Tinto in Australia's Pilbara region to haul iron ore, driverless passenger trains may be a good, proven option for first adoption of driverless passenger vehicles in Australia.

Trains are arguably the easiest form of public transport to automate because they operate in a highly controlled environment. The benefits of automating train systems include improved safety by reducing the potential for human error, and increased capacity of the system[300]. Individual train speed profiles can also be controlled to minimise energy consumption, and smoother acceleration and deceleration may increase the lifespan of wheels and braking components, as well as improving passenger comfort. However, a major cost of implementing driverless or autonomous trains will be modification or replacement of existing rolling stock and signalling systems[301]. In addition to usual train infrastructure, special safety equipment and measures, such as emergency brakes, fire extinguishers, emergency lighting, audible signals and door monitoring, will also be required for driverless passenger trains[302].

Some examples of infrastructure required to support the adoption of driverless passenger trains include:

> Platform barrier doors, which are used to shield the platform from the track. Unlike monitoring systems, barrier doors completely remove the risk of passengers on the track

> Platform track monitoring system. The section of track in train stations needs to be equipped with a platform track monitoring system in the absence of platform doors that block the track area. If a person or large object falls onto the track, the monitoring system triggers an alarm that initiates immediate emergency braking in the train. Trains in adjacent stations are also managed accordingly

> Intrusion monitoring, which is installed in underground stations to stop trains should a person enter the tunnel

> Video surveillance of platforms and tracks, which remotely monitors train stations allowing for additional interventions for better assessment of a disruption

> Service personnel. Passengers will require adequate numbers of service personnel as contacts throughout the train system. Workers should be present to rectify issues and provide further help to passengers, and can also control the automated systems manually in the event of a fault[303]

3.3.2. Skills availability

As systems become increasingly automated there will be less demand for public transport operators. Instead there will be greater demand for capabilities in systems engineering, systems integration, asset management, condition monitoring, asset optimisation, and customer service.

3.3.3. Social readiness

As at the 2016 Australian Census, driving was the dominant method of travel to work in Australia, with 74 per cent of people living in cities travelling to work by private car, as either driver or passenger[304]. Train travel was the most common method of public transport, with 5 per cent of the population catching the train as their only method of travel to work[305].

299. NSW Government. Major milestone as Metro Northwest completes its first full test. *NSW Government Sydney Metro.* https://www.sydneymetro.info/article/major-milestone-metro-northwest-completes-its-first-full-test 15 January 2019.

300. Peter Powell, Jonathan & Fraszczyk, Anna & Nok Cheong, Chun & Yeung, Ho. (2016). Potential Benefits and Obstacles of Implementing Driverless Train Operation on the Tyne and Wear Metro: A Simulation Exercise. Urban Rail Transit. 2. 10.1007/s40864-016-0046-9. https://doi.org/10.1007/s40864-016-0046-9

301. Peter Powell, Jonathan & Fraszczyk, Anna & Nok Cheong, Chun & Yeung, Ho. (2016). Potential Benefits and Obstacles of Implementing Driverless Train Operation on the Tyne and Wear Metro: A Simulation Exercise. Urban Rail Transit. 2. 10.1007/s40864-016-0046-9. https://doi.org/10.1007/s40864-016-0046-9

302. Siemens. How does a driverless metro system work? Fact Sheet. https://www.siemens.com/press/pool/de/feature/2012/infrastructure-cities/mobility-logistics/2012-04-metro-paris/factsheet-how-does-a-driverless-metro-work-en.pdf April 2012.

303. Siemens. How does a driverless metro system work? Fact Sheet. https://www.siemens.com/press/pool/de/feature/2012/infrastructure-cities/mobility-logistics/2012-04-metro-paris/factsheet-how-does-a-driverless-metro-work-en.pdf April 2012.

304. Australian Bureau of Statistics. More than two in three drive to work, Census reveals. Media release. http://www.abs.gov.au/ausstats/abs@.nsf/mediareleasesbyReleaseDate/7DD5DC715B608612CA2581BF001F8404?OpenDocument 23 October 2017.

305. Australian Bureau of Statistics. More than two in three drive to work, Census reveals. Media release. http://www.abs.gov.au/ausstats/abs@.nsf/mediareleasesbyReleaseDate/7DD5DC715B608612CA2581BF001F8404?OpenDocument 23 October 2017.

The most important variables likely to encourage the use of public transport are reduced travel time, reduced distance from home to public transportation stations, journey time reliability, service frequency and subsidised fares[306].

Employee attitudes

Public transport companies will need to mitigate the effects of increased automation on employees. The planned introduction of 65 high-capacity trains with semi-automated features to Melbourne's train network caused industrial unrest in 2017. The union that represented workers from Melbourne train operator feared the new trains would lead to de-skilling of train drivers, and advised union members not to cooperate with Metro's preparations for the arrival of the new trains[307].

Cyber security

Optimising transport systems through the introduction of connected, on-demand mass transport with contactless ticketing will require large amounts of data collection to inform decisions of commuters and public transport operators. Much of the public is already hesitant to share data about themselves due to fear of privacy breaches. To overcome this, governments and public transport operators should take measures to ensure their systems are secure.

3.3.4. Economic and commercial feasibility

In coming years, Deloitte[308] suggests successful business models will incorporate the following five disruptive trends for transport: user-centric, integrated data, simple payment transactions, automation, and a visionary business.

Pricing

Pricing can be used to spread demand for transport services over peak and non-peak periods. This is predicted to have a greater influence on demand on the transport system than the impact of building any new major road or rail line[309]. This is already used to some extent. For example, in Sydney, a saving of 30 per cent is applied to train fares if journeys are undertaken on a weekend, public holidays, and before or after peak hour periods[310], while in Melbourne it is free to travel on the metropolitan train network if the entire journey is completed before 7:15 am[311].

Automation of public transport can also reduce operating costs through reduction of staff costs.

3.3.5. Policy and regulatory readiness

Encouraging public transport use

Governments can encourage public transport use in urban areas by focusing infrastructure funding on improving public transport instead of roads. In 2016, the Department of Prime Minister and Cabinet launched the Smart Cities Plan to develop a strategy to maximise the potential of Australian cities[312]. The Plan recognised the importance of utilising smart technologies and investing in smart city and smart transport infrastructure, to support the sustainable growth of public transport networks and rapid transport between cities, as well as encouraging active transport models.

By providing better access to a high quality, safe, reliable, efficient, easy to use, and cost effective public transport system, commuters are more likely to choose public transport over private vehicles. This could be further supported by discouraging private vehicle use by increasing the cost of personal vehicles for travel, reducing the number of vehicles permitted in urban areas, and introducing congestion fees for travel in cities in peak times.

Land use planning

The ability to invest in any future infrastructure relies on identifying potential transport corridors and land sites early. Governments need to work with land use planners to protect transport corridors, ensuring connectivity of outer urban areas in light of increased urban sprawl.

306. Abdullah Nurdden, Riza Atiq O.K. Rahmat and Amiruddin Ismail, 2007. Effect of Transportation Policies on Modal Shift from Private Car to Public Transport in Malaysia. Journal of Applied Sciences, 7: 1013-1018. https://scialert.net/abstract/?doi=jas.2007.1013.1018
307. Carey, A. Union signals rough ride for rollout of government's high capacity trains. *The Age*. https://www.theage.com.au/national/victoria/union-signals-rough-ride-for-rollout-of-governments-highcapacity-trains-20170609-gwo9jm.html 11 June 2017.
308. Deloitte (2015). Transport in the Digital Age – Disruptive Trends for Smart Mobility. https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/bps/deloitte-uk-transport-digital-age.pdf March 2015.
309. Infrastructure Victoria (2016). Victoria's 30 year infrastructure strategy. http://infrastructurevictoria.com.au/sites/default/files/images/IV_30_Year_Strategy_WEB_V2.pdf December 2016.
310. NSW Government. https://www.opal.com.au/en/opal-fares/
311. Public Transport Victoria. https://www.ptv.vic.gov.au/tickets/myki/travel-with-myki/travel-benefits/
312. Commonwealth of Australia (2016). Smart Cities Plan. https://infrastructure.gov.au/cities/smart-cities/plan/files/Smart_Cities_Plan.pdf

3.4. Intelligent transport systems

Intelligent transport systems (ITS) are advanced systems that combine electronics, telecommunications and information technology to increase the efficiency and safety of transportation, and decrease costs. ITS technologies are designed to collect, process, integrate, and sort data to better inform decisions and optimise the performance of traffic networks in real time.

ITS can be categorised by the functions they perform[313]:

> Advanced traffic management systems

> Advanced vehicle control systems

> Advanced public transport systems

> Commercial vehicle operation

These mobility services capitalise on advances in mobile communications, cashless payments, remote monitoring, data collection, analytics, energy storage and artificial intelligence to provide commuters a wider range of transport options at greater efficiencies[314].

The scope of ITS is broad, and incorporates fully connected cities, where public and private transport is connected and coordinated in one central location. It also encompasses individual components such as in-vehicle driver assistance, traveller information, smart phone applications, and technological roadside infrastructure[315]. ITS will be especially important for the predicted uptake of autonomous vehicles. The main benefits of using ITS include:

> Reduced congestion

> Fewer traffic crashes

> Environmental monitoring and protection

> Increased efficiency and productivity

> Increased comfort and safety

There are currently a number of ITS trials taking place in Australia. These include[316]:

> The Cooperative Intelligent Transport Initiative (CITI) trial of heavy vehicle safety applications using cooperative ITS in New South Wales

> In Queensland, the Cooperative and Automated Vehicles Initiative (CAVI) is running a large-scale pilot project of cooperative ITS

> The ITS Grants Program in Victoria includes trialling CAVs in highway scenarios, cooperative ITS to prioritise trams, and in-vehicle connected vehicles services using cellular communications

Use of ITS is already relatively common. In 2016, Siemens launched an ITS portfolio in Australia consisting of an intelligent sensor-based parking system that detects urban parking spaces, and vehicle to infrastructure communication technology[317]. Coordinated ramp signals on freeway entrances are an example of an ITS that is already commonly used to optimise traffic flow.

Transport for New South Wales has contracted Cubic Transportation Systems to provide Sydney with an intelligent congestion management program. The new system will enhance monitoring and management of the road network in New South Wales, coordinate the public transport network, improve planning around events and incident clearance times, and provide real-time information to the public about disruptions. The project will be the first in the world utilising Cubic's fully multimodal Transport Management Platform[318].

313. E. A. Stanciu, "Optimization of urban road traffic in intelligent transport systems," in Proc. Appl. Theor. Electr. (ICATE), 2012, pp. 1–4.

314. Canales, D., Bouton, S., Trimble, E., Thayne, J., Da Silva, L., Shastry, S., Knupfer, S., Powell, M. Connected Urban Growth: Public-Private Collaborations for Transforming Urban Mobility. Coalition for Urban Transitions. London and Washington, DC. Available at: http://newclimateeconomy.net/content/cities-working-papers. https://www.wri.org/publication/connected-urban-growth-public-private-collaborations-for-transforming-urban-mobility

315. ITS Australia (2017). Smart transport for Australia. Enhancing Liveable cities and communities. Report on Australia's future in Intelligent Transport Systems – leveraging the 2016 ITS World Congress in Melbourne Australia. https://www.its-australia.com.au/wp-content/uploads/Smart-Transport-for-Australia.pdf

316. ITS Australia (2017). Smart transport for Australia. Enhancing Liveable cities and communities. Report on Australia's future in Intelligent Transport Systems – leveraging the 2016 ITS World Congress in Melbourne Australia. https://www.its-australia.com.au/wp-content/uploads/Smart-Transport-for-Australia.pdf

317. Siemens. Siemens launches ITS technologies in Australia. *Siemens.* https://corporate.siemens.com.au/en/home/news-centre/press-releases/siemens-launches-intelligent-transport-systems-in-australia.html October 2016.

318. Cubic. Cubic wins contract to provide next generation transport management platform to Sydney. Press release. https://www.its-australia.com.au/wp-content/uploads/Cubic-Sydney-Transport-Management-Contract.pdf 28 August 2018.

3.4.1. Infrastructure readiness

To gain maximum benefit from ITS, systems should be monitored and controlled from a single location to increase efficiencies by coordinating the whole transport system to work in harmony, such as the planned system to be implemented in New South Wales[319]. This will be a challenge for many cities in Australia, where control systems for roads and different types of public transport are coordinated by the different operators of each transport mode in multiple locations.

Enabling infrastructure for ITS includes embedded telematics (long-distance transmission of computerised information), accurate GPS, tamper-evident sensors, and a backhaul network, which transports communication data between end users and the central network and infrastructure.

Sensors

Sensors are a well-developed technology, relatively inexpensive and already widely implemented. They gather the data that informs ITS and planning decisions. Sensors include smart phones, fibre optic cables, cameras, and in-vehicle sensors.

Communications

In order to gain efficiency from the transport system, all forms of transport should be connected to a single national system. This allows coordination of transport modes in consideration with other modes, and enables models such as mobility as a service and a national intermodal ticketing system.

Machine learning in transport

Small-scale trials using machine learning in cars, trains, buses, and trucks for autonomous driving are currently taking place in many locations around the world. This is discussed in greater detail in Chapter 2 of this report. Additional uses of machine learning in transport include traffic signal control and optimisation, traffic and travel time predictions, ramp metering, travel demand modelling, transport safety analysis, design of transport infrastructure, and transport security[320].

3.4.2. Skills availability

Intelligent transport systems are still developing, and many of these technologies are currently in pilot phase. It is therefore likely that the number of people employed in the ITS sector will increase in the coming years[321]. Expertise in software development, systems engineering, information assurance, electrical engineering, data analysis, and urban planning will be in demand for ITS activities.

Vehicle IT design

Vehicle IT design involves developing hardware and writing software for use in connected and autonomous vehicles.

Types of qualifications

Computer science, general engineering, computer engineering, electrical engineering, physics, information systems, mechanical engineering, systems engineering, information technology, business administration and management.

Technical skills required

Software development, software/computer/electrical/systems engineering, C++, LINUX, JAVA, Python, image processing, MATLAB, UNIX, software architecture, information assurance, information systems.

Data management and cyber security

Job types

Data warehousing specialists, information security specialists, and other computer- and network-related occupations protect data being collected and communicated by connected infrastructure and automated vehicles.

319. Cubic. Cubic wins contract to provide next generation transport management platform to Sydney. Press release. https://www.its-australia.com. au/wp-content/uploads/Cubic-Sydney-Transport-Management-Contract.pdf 28 August 2018.

320. Transportation Research Board (2012). Artificial intelligence applications to critical transportation issues. Transportation Research Circular E-C168. http://onlinepubs.trb.org/onlinepubs/circulars/ec168.pdf November 2012

321. Cubic. Cubic wins contract to provide next generation transport management platform to Sydney. Press release. https://www.its-australia.com. au/wp-content/uploads/Cubic-Sydney-Transport-Management-Contract.pdf 28 August 2018.

Types of qualifications

Computer science, general engineering, computer/electrical/systems/mechanical engineering, management of information systems, information technology, business administration and management, physics.

Technical skills required

Systems engineering, information systems, information assurance, LINUX, information security, UNIX, software development, network security, project management.

Intelligent transportation systems and infrastructure design

Job types

Telecommunications specialists, civil engineers, transportation planners and engineers and traffic technicians to inform decision making on connected infrastructure and traffic management.

Types of qualifications

General/electrical/computer/systems/transportation and highway/structural engineering, computer science, information technology, construction management, urban/community/regional planning.

Technical skills required

Network engineering, project management, Cisco, routers, civil engineering, switches, Wide Area Network, network security, systems engineering.

3.4.3. Social readiness

There is a dearth of research on social acceptance of ITS, likely because ITS is commonly implemented without public awareness. One pilot study examined attitudes to MaaS and was conducted by UbiGo[322] in Gothenburg, Sweden. Mobility as a service integrates transport options into one service to provide multimodal door-to-door mobility options. During the pilot, UbiGo provided MaaS to over 70 paying households for six months. The trial resulted in increases in the use of public and active transport for the participants, but also a 50 per cent reduction in private car use, with 20 private cars taken off the road for the duration of the pilot[323].

Safety

ITS can be a valuable tool for reducing traffic crashes. **Table 5** shows the percentage of reductions in crash types with implementation of four applications of C-ITS. However, current C-ITS applications only provide a warning to drivers, and still require the driver to intervene. These alerts can also cause safety issues by startling the driver and drawing their attention away from the road[324].

Table 5: The analysis of Australian real-world crash types demonstrated the following reductions in targeted crash types, and serious injuries based on four C-ITS applications[325]

C-ITS Application	Type	Crash types	Reduction in targeted crash type	Projected annual reduction in the number of fatal or serious injury crashes in Australia
Cooperative Forward Collision Warning (CFCW)	V2V	Same direction	20-30 per cent	515-805
Curve Speed Warning (CSW)	V2I	Run-off-road, head-on (major roads)	20-30 per cent	75-115
Intersection Movement Assist (IMA)	V2V	Adjacent direction	35-50 per cent	940-1470
Right Turn Assist (RTA)	V2V	Right turn against	25-40 per cent	525-825

322. Sochor, J. (2016). Benefits of Mobility as a Service: Evidence form the UbiGo MaaS pilot in Gothenburg, Sweden. Chalmers University of Technology. http://ibec-its.com/wp-content/uploads/sites/18/2016/11/IBEC-2_Sochor_Melbourne-2016.pdf 10 November 2016.

323. Sochor, J. (2016). Benefits of Mobility as a Service: Evidence form the UbiGo MaaS pilot in Gothenburg, Sweden. Chalmers University of Technology. http://ibec-its.com/wp-content/uploads/sites/18/2016/11/IBEC-2_Sochor_Melbourne-2016.pdf 10 November 2016.

324. Austroads (2017). Safety benefits of C-ITS and automated driving in Australia and New Zealand. https://researchmgt.monash.edu/ws/portalfiles/portal/241124499 October 2017.

325. Austroads (2017). Safety benefits of C-ITS and automated driving in Australia and New Zealand. https://researchmgt.monash.edu/ws/portalfiles/portal/241124499 October 2017.

3.4.4. Economic and commercial feasibility

Over 70 per cent of all domestic passenger travel within Australia currently occurs on roads[326]. One in six people in capital cities use public transport for their daily commute, with population growth anticipated to result in this figure increasing by 30 per cent by 2030[327]. In the next decade, rail freight is also anticipated to increase by two thirds, and the number of trucks on the road has been predicted to increase by 50 per cent[328]. Based on these trends, it is inevitable that there will be challenges surrounding congestion and efficiency in both the passenger and freight sectors. To manage these issues and to improve the safety, efficiency, mobility and accessibility of transport over the next decade, the investment in transport infrastructure and city planning will need to be underpinned by smart design and new technologies such as intelligent transport systems.

The Coalition for Urban Transitions (2017)[329] showed that new mobility start-up companies can be divided into four types: consumer experience, product innovation, data-driven decision making, and shared mobility. Oceania has the least (26) mobility start-ups, compared to North America (129), Latin America (62), Europe (98), Africa (57), and Asia (143).

Business models based on ITS include:

> **MaaS.** This door-to-door multi-modal transport model provides a significant collaborative opportunity for transport providers and operators, and much of the infrastructure is already in place. The most commonly proposed interface between commuters and service providers is a smart phone application that incorporates all forms of transport to provide commuters with the most efficient route

> **Vehicle sharing.** 'Ride sharing' has gained popularity in the last decade through companies such as Uber, Lyft and Shebah. On-demand transport gives the user more control. It is responsive to individual temporal needs, and provides real-time information (for example vehicle location and arrival time) to commuters, with flexible on-demand services selected and booked through smart phone applications so commuters can customise their journey to their requirements. The widespread availability of these services in cities may lead to people leaving their car at home, but does not decrease traffic congestion. Other options, such as bike sharing or e-scooter sharing may contribute to reducing congestion on roads, and provide the benefits of active transport

The economic and commercial feasibility of ITS technologies have been demonstrated through a number of successful ITS trials and collaborative programs, including:

> The Australian Integrated Multimodal EcoSystem (AIMES), which utilises a street-based ecosystem to provide a creating a testing ground for the deployment of Connected Intelligent Transport Systems in complex urban environments, including V2V, V2I and V2X communication systems. The ecosystem has the capacity to collect and use large amounts data in real time, providing an analysis of how different transport systems interact and resulting in the ability to make multimodal decisions[330]

> A collaboration between Telstra and Cohda Wireless to test of V2P technology over a mobile network[331]

> Queensland C-ITS Pilot Project which is currently Australia's largest on-road testing trial of cooperative vehicles and infrastructure[332,333]. This program includes a collaboration between the Queensland Department of Transport and Main Roads and Cohda Wireless to retrofit 500 public and fleet vehicles with OBUs, allowing vehicles to communicate via V2V and V2I[334]

326. Commonwealth of Australia (2014). Trends. Infrastructure and transport to 2030. https://infrastructure.gov.au/infrastructure/publications/files/Trends_Infrastructure_and_Transport_to_2030.pdf

327. Commonwealth of Australia (2014). Trends. Infrastructure and transport to 2030. https://infrastructure.gov.au/infrastructure/publications/files/Trends_Infrastructure_and_Transport_to_2030.pdf

328. Commonwealth of Australia (2014). Trends. Infrastructure and transport to 2030. https://infrastructure.gov.au/infrastructure/publications/files/Trends_Infrastructure_and_Transport_to_2030.pdf

329. Canales, D., Bouton, S., Trimble, E., Thayne, J., Da Silva, L., Shastry, S., Knupfer, S., Powell, M. Connected Urban Growth: Public-Private Collaborations for Transforming Urban Mobility. Coalition for Urban Transitions. London and Washington, DC. Available at: http://newclimateeconomy.net/content/cities-working-papers. https://www.wri.org/publication/connected-urban-growth-public-private-collaborations-for-transforming-urban-mobility

330. University of Melbourne. Australian Integrated Multimodal Ecosystem (AIMES). https://eng.unimelb.edu.au/industry/transport/aimes

331. Fitzgerald, S. Australia's first vehicle-to-pedestrian technology trial. *iMOVE CRC*. https://imovecrc.com/news-articles/personal-public-mobility/australia-first-vehicle-to-pedestrian-technology-trial/ 29 July 2017.

332. Fitzgerald, S. CAVI 500-vehicle C-ITS Field Operational Test. *iMOVE CRC*. https://imovecrc.com/project/cavi-500-vehicle-c-its-connected-vehicle-test/ 14 February 2018.

333. Transport and Main Roads, Queensland Government (2018). Cooperative Intelligent Transport Systems Pilot. https://publications.qld.gov.au/dataset/cavi-resources/resource/b8a5ab55-21af-4ab4-9bd0-126c239ced94 9 April 2018.

334. Fitzgerald, S. Cohda Wireless joins TMR's CAVI connected vehicle pilot. *iMOVE CRC*. https://imovecrc.com/news-articles/intelligent-transport-systems/cohda-wireless-joins-cavi-pilot/ 18 December 2018.

> R&D projects undertaken through iMove CRC to create new technologies and solutions to address congestion, road trauma and end-to-end freight movement[335]

> The utilisation of Data61 simulations in the transport sector by Australian industry groups to model ramp signalling on motorways[336]

> The work of ITS Australia, Transport for Victoria, Transport for NSW, TransLink, Department of Transport WA, Royal Automobile Association SA, and iMove CRC to increase the understanding of the impact of MaaS[337]

> The collaboration of Australian companies, Intelematics and MTData, with government and industry to implement telematics technologies[338]

3.4.5. Policy and regulatory readiness

Standards

To harness the full value of C-ITS, national standards will need to be collaboratively developed and enforced to ensure interoperability between ITS devices. This will also be essential for consumers to plan whole trips using one planning method, such as a smart phone application, and streamline transport methods to one system. National uniformity of ITS platforms and regulations would assist in ensuring the safety and efficiency of systems.

Data ownership

Policies around data ownership will need to be continually revised as the amount of transport data collected increases. Data is a valuable commodity, and policies around who owns the data (e.g. transport operator, governments, software provider, etc.), and what they are able to do with it are important to ensure the privacy of transport users.

335. Austrade (2018). Intelligent Transport Systems. https://www.austrade.gov.au/future-transport/intelligent-transport-systems/
336. Austrade (2018). Intelligent Transport Systems. https://www.austrade.gov.au/future-transport/intelligent-transport-systems/
337. Austrade (2018). Intelligent Transport Systems. https://www.austrade.gov.au/future-transport/intelligent-transport-systems/
338. Austrade (2018). Intelligent Transport Systems. https://www.austrade.gov.au/future-transport/intelligent-transport-systems/

4. Industry readiness – stakeholder consultation program

The consultation period ran from September 2018 to January 2019.

Through a combination of targeted interviews and written responses to survey questions, the Academy received input from over 30 representatives and experts from the transport sector located across Victoria, New South Wales, Queensland, Western Australia and the Australian Capital Territory. These included representatives from government, industry, research, not-for-profit and industry associations with exposure to sector wide technology readiness.

Stakeholders were asked to consider the readiness of Australia's transport sector to develop, adopt and adapt transport technologies out to 2030, and how Australia's readiness can be measured with respect to the key readiness parameters (infrastructure readiness, skills availability, social readiness, economic and commercial feasibility and policy and regulatory readiness).

The purpose of this task was to understand the key factors enabling uptake and integration of technology within the transport sector, and to highlight similarities and differences in the opinions of transport industry readiness. Those consulted tended to express views consistent with the sector they represented.

This chapter summarises the views of those representatives and experts that were consulted about Australia's readiness to develop, adopt and adapt transport technologies. This chapter also compares the outcomes of the consultations with the Preliminary Readiness Indicators to highlight the strengths and weaknesses that will impact on Australia's technological readiness by 2030, and summarises the key future research opportunities and policy recommendations identified by stakeholders.

4.1. How likely is it Australia will be ready by 2030?

Three key themes regarding Australia's readiness in the transport sector emerged through the consultation process:

1. Representatives from government and industry generally did not identify any major problems that had the potential to significantly impact on industry technology readiness in Australia's transport sector
2. Stakeholders from government, industry, research and academia all indicated that there could be more effort placed on improving infrastructure readiness, with concern around both physical and data infrastructure. On this basis, actions to improve readiness were directed by stakeholders towards both industry and government
3. It was acknowledged that more emphasis could be placed on training and skills availability to adequately prepare the future workforce

4.2. Key findings from consultations

4.2.1 Low and zero emissions vehicles

Infrastructure readiness

In terms of infrastructure readiness, stakeholders raised the following key points as being important to Australia's readiness to develop, adapt and adopt technologies associated with low and zero emission vehicles by 2030:

> A significant hurdle to the readiness of LEVs in Australia is vehicle charging infrastructure, particularly with respect to the number of available charging points, the recharging speed, and ensuring that there is a focus on linking LEV charging infrastructure with renewable energy sources
> Although LEVs work well over short distances, there is currently not the infrastructure or battery technology to allow the rapid charging of freight vehicles, such as trucks
> Other opportunities to decrease the number of fuel powered vehicles on the road over the next decade may also include the increased availability of micro transport options (i.e. electric scooters and e-bikes), and active transport options for short distance travel

Skills availability

In terms of skills availability, stakeholders raised the following key points:

> Australia has a strong research and development presence and a heavy vehicle manufacturing industry, with Volvo, Kenworth, Iveco and Mac all being manufactured in Australia. Australia therefore has the expertise to develop and optimise recharge technologies to improve range and recharge time specific to Australian conditions, including fast charging for heavy vehicles

> There is a current lack of focus on skills, training and education relating to LEV technologies, and a poor understanding of the future workforce. This has the potential to inhibit growth in the sector

Social readiness

In terms of social readiness, stakeholders indicated that there was a positive interest and awareness of the technology, particularly with respect to health and sustainability benefits. However, perceptions of affordability, charging time and the range of the vehicle were raised as potential barriers to acceptance.

Economic and commercial feasibility

With respect to economic and commercial feasibility, stakeholders indicated that the long distances between major cities in Australia provided an opportunity to adapt technologies to our specific requirements, with the adaption and engineering of heavy vehicles being particularly important.

Policy and regulatory readiness

In terms of policy and regulatory readiness, stakeholders raised the following key points:

> Australia does not currently meet global standards in terms of vehicle emissions. Vehicles that are imported into Australia will subsequently be older models with less up to date technologies that address vehicle emissions. Together with Australia's remote location, small population and geographically specific requirements, this makes Australia a less attractive option for deployment of transport technologies, and makes the adoption of new technologies difficult

> However, a number of initiatives have been developed to increase the adoption of LEVs in Australia, including:
  – Initiatives of the Australian Electric Vehicle Association (AEVA) to develop a network of charging stations around Australia
  – The development of the Queensland Electric Superhighway
  – The development of the Tesla Supercharger Network
  – The development of the Royal Automobile Club of Western Australia (RAC) Electric Highway
  – The proposal by Dr Alan Finkel to the Council of Australian Governments (COAG) Energy Council to develop a national hydrogen strategy[339]
  – The initiative to preferentially include LEVs into government fleets[340]

Regardless of these initiatives, stakeholders noted that a lack of federal policy and regulations surrounding LEVs (particularly the lack of an environmental focus to develop vehicle emission and fuel standards); insufficient vehicle charging infrastructure; low levels of industry support and engagement towards the development of infrastructure; and a lack of vehicle and battery incentives and rebates in Australia were all deemed to be contributing factors. However, it was anticipated that the market for LEV sales would see an increase by 2025-2030, when LEVs reached price parity. This price parity could also be influenced by the decarbonisation of the grid.

Australia's lack of vehicle emissions standards is a 'chicken-and-egg' scenario, where although industry is investing, elements such as electricity generation and storage, refuelling or charging stations, and regulations are dependent on other processes[341]. To advance the uptake of LEVs, leadership from government is therefore required to assist in the collective progress, through investment in charging infrastructure, providing financial incentives to both purchase and charge the vehicles, and building a narrative around the deployment of vehicles.

4.2.2 Connected autonomous vehicles

Infrastructure readiness

Stakeholders indicated that the first priority in terms of developing infrastructure for the deployment of CAVs should be the use of high-resolution data to help plan for the future of transport operations and infrastructure. One way to utilise this data would be to identify areas where the implementation and pricing of priority CAV corridors could reduce traffic congestion.

339. Commonwealth of Australia, Office of the Chief Scientist (2018). A hydrogen industry on the national agenda. Media release. https://www.chiefscientist.gov.au/2018/08/media-release-a-hydrogen-industry-on-the-national-agenda/ 17 August 2018.
340. O'Keeffe, D. Call to mandate electric vehicles in government fleets. *Government News.* https://www.governmentnews.com.au/call-to-mandate-electric-vehicles-in-government-fleets/ 29 October 2018.
341. Hydrogen Strategy Group (2018). Hydrogen for Australia's Future. https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf August 2018.

It was noted that decreased personal vehicle ownership has the potential to have a profound impact on urban landscapes. It is essential that cities are designed and planned to manage this disruption. Furthermore, as Australia has more kilometres of road per person than any other country, improved planning in urban, regional and rural areas will also be essential to realise the benefits of CAVs.

Skills availability

Australia is widely viewed as having a strong research base in the development and adaptation of CAVs, particularly with respect to vehicle trials (refer to Section 2.5).

In terms of skills availability, stakeholders indicated that to prepare for the level of disruption anticipated by CAVs over the next decade, there will need to be a greater focus on the training needs of workers within the transport sector.

Social readiness

In terms of social readiness, stakeholders raised the following key points:

> In general, private vehicle owners and users are ready to move away from the cost and responsibility of driving and car ownership. However, the consumer is not ready for the disruption caused by the deployment of CAVs due to concerns surrounding privacy, safety, cost and ethical issues

> The deployment of CAV technologies will impact on driver skills, including increased complacency resulting in being unable to adequately manually override automated systems if required

> Although the awareness of CAVs has increased and perceptiveness is high, limited campaigns to educate people on these technologies has resulted in lower levels of readiness amongst the general population. Possible approaches to help overcome barriers to social acceptance could include:

   – Allowing people to experience the technology firsthand to help alleviate safety concerns and raise their awareness of the personal benefits of CAVs, such as reduced driving times, fewer vehicle crashes and emissions reductions

   – Ensuring transport technologies are equitable and accessible to all sectors of the community

Economic and commercial feasibility

With respect to economic and commercial feasibility, stakeholders highlighted the following key points:

> A large number of CAV trials are driven by the private sector, resulting in trials being primarily profit driven. As such, there are concerns that the outcomes will not be shared within the industry, and progress may be slowed

> The gradual deployment of CAV technologies will result in a number of decades where there is a mixed fleet of vehicles on the road with various levels of automation and connectivity. Although there will be segments of the network for the exclusive use of CAVs, there are concerns around the complications of having a mixed fleet of vehicles on the road. On this basis, it is likely that the economic and commercial advantages of CAVs won't be realised until a higher proportion of CAVs are on the market

> Australia is an early and rapid adopter of transport technologies and has a strong reliance and interest in following overseas trends. Although this presents an opportunity to adapt technologies to the unique Australian landscape, it also results in Australia being dependent on the progress and accessibility of international programs, and certain technologies not being suitable for the Australian landscape. The development of technologies that are adapted to an Australian setting subsequently has the potential to create the greatest impact. It was noted that one way to achieve this would be through the development of a crash testing facility for autonomous vehicle technologies to ensure that the technology is applicable to Australian conditions

Policy and regulatory readiness

In terms of policy and regulatory readiness, stakeholders raised the following key points:

> There is currently no consistent regulatory approach for transport industry technologies, and no standards or certification regime for CAVs in place. On this basis, stakeholders believed that the government's biggest challenge would be harmonising the regulatory barriers around autonomous vehicles

> To ensure all sectors of the community have access to the benefits of autonomous vehicles, policies should be developed to address the deployment of CAV technologies in the first and last mile, integrating CAVs with LEVs and high frequency mass transit, ensuring accessibility for disadvantaged people, and examining safety issues in rural and regional areas

> A shift to autonomous modes of transport will result in significant changes to liability. As it is anticipated that a large proportion of vehicles will be owned by the provider, the development of different insurance policies will be vital. New South Wales, Queensland and Victoria have already moved to a no-fault scheme to prepare for the introduction of CAVs, however other states and territories are yet to follow

> The standardisation of data and consistency of operational frameworks on a national level is essential for the deployment of CAVs, with regulations required to ensure that governments will have access to important data, while also managing customer privacy. Although Australia has mature governance and institutional arrangements around vehicle safety and standards, such as the New Car Assessment Program (NCAP), there remains a lack of harmonisation. On this basis, it was perceived by several stakeholders that market entry of CAVs would not be possible before 2020

> Decreased personal vehicle ownership has the potential to have a profound impact on urban landscapes, and will require changes to town planning regulations

4.2.3 High frequency mass transit

Infrastructure readiness

Stakeholders indicated that the infrastructural challenges that need to be addressed to maximise the benefits of high frequency mass transit by 2030 include:

> Building infrastructure for driverless passenger trains and buses (platforms and stations)
> Building infrastructure for freight
> Smart city planning
> Strengthening network connectivity, accessibility (5G, V2X, digital signalling) and location services
> Connecting first and last mile passenger and freight transport options with high frequency mass transit
> Connecting sustainable infrastructure with high frequency mass transit
> Strengthening the interoperability between various modes of transport
> Using data to undertake predictive maintenance of freight and passenger vehicles
> The development of infrastructure to support rural, regional, and edge of city areas

However, to plan for larger volumes of freight and passenger customers in the future, stakeholders noted that building more roads and more lanes alone would not solve congestions issues. Instead, the key focus over the next 10 years should be on how to utilise new technologies to improve smart city infrastructure and smart mass transport infrastructure to cope with increased populations.

It was also recognised that although rail will continue to be the mass transit solution for the growing urban population, the collectivisation of transport and platform-mobility service offerings that are technology enabled (i.e. ride sharing and on-demand services) and their potential impact on how transport is solved, will have a more immediate impact. To ensure that future trends in transport usage are managed effectively, stakeholders indicated that the use of high-resolution data to model future transport operations and to make infrastructure decisions should be a first priority.

Skills availability

A study by the Australian Railway Association (ARA) on skills capabilities in the railway sector has predicted that there could be a significant workforce gap in the future, which will have significant impacts on project timelines and budgets[342]. This gap not only relates to skilled workers, but also roles in data management/storage/transfer, data analytics and telecommunications. With people not being aware of the opportunities for work in the rail sector, the rail industry is subsequently examining how to attract and train skilled workers, and also to identify what tasks can be replaced with technology.

342. Australian Railway Association (2018). Australian Railway Association skills capability study. Skills crisis: a call to action. https://ara.net.au/sites/default/files/u647/18-11-26%20BOE%20Report%20Final.pdf November 2018.

Social readiness

In terms of social readiness, stakeholders raised the following key points:

> As traditional high frequency mass transit options are already an accepted form of transport, societal readiness is strong. However, perceptions of safety, affordability, security and privacy, and accessibility were raised as potential barriers to acceptance

> It is important that Australia's readiness in the transport sector addresses the whole community to ensure that everyone has access to and benefits from the technology, including those with lower incomes, disabilities, and across all age brackets. Ensuring rural and regional communities have access to public transport offerings is also essential

Economic and commercial feasibility

With respect to economic and commercial feasibility, stakeholders highlighted the following key points:

> Over $100 billion has been invested by Australian federal and state governments over the next ten years on passenger and freight rail projects such as the Melbourne and Sydney Metros, Brisbane's Cross River Rail, Perth's Metronet, Inland Rail, and multiple light rail infrastructure and rolling stock investment

> In the short to medium term the application of big data will provide the greatest opportunities for mass transit transport modes. From a rail perspective, it was identified that data would be key in both the passenger and freight sectors, and could be utilised to provide a seamless communication system, to integrate rail with other modes of transport (i.e. first and last mile connectivity), and to undertake predictive maintenance

> With public transport services now including platform-mobility service offerings that are technology enabled, such as ride sharing platforms and on-demand services, the line between public and private transport options is becoming increasingly blurred. Although the emergence of ride sharing platforms will be important in the future in terms of mobility, these platforms have the potential to negatively impact on the high frequency mass transit platform, by drawing passengers away from the network and increasing congestion on the roads. As this will have an immediate impact to the transport network, how public transport issues are solved will be a very important issue over the next decade

> It will also be important to integrate platform-mobility service offerings with traditional public transport offerings to retain passengers within the network, particularly with respect to first and last mile transport options

Policy and regulatory readiness

In terms of policy and regulatory readiness, stakeholders raised the following key points:

> A national policy surrounding high frequency mass transit is well established in Australia. In 2017, the Department of Infrastructure, Regional Development and Cities invested $10 billion to establish the National Rail Project. The objectives of the project are to make growing Australian cities more liveable and efficient, reduce congestion on roads, provide more reliable transport networks and to support the growth of regional Australia[343]. An important aspect of this policy is to ensure that rail becomes an integral part of a seamless passenger service (rather than a standalone service)

> In terms of policy surrounding freight, in 2018 the Department of Infrastructure, Regional Development and Cities also agreed on a framework for developing a 20 year National Freight and Supply Chain Strategy to improve efficiency[344]. Stakeholders highlighted the fact that the use of technology and data would be key to improving efficiency in the sector, and agreed that the benefits of such as strategy would help states and territories align operating procedures for the movement of freight between metro, regional and rural areas

4.2.4 Intelligent transport systems

Infrastructure readiness

In terms of infrastructure readiness, stakeholders indicated that Australia is advanced in developing, adopting and adapting ITS technologies, with dynamic variable speed zones, active lane management, ramp metering, automatic incident detection, traffic signal controls, traveller information systems, e-tolling and other well-established systems already in widespread use[345].

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343. Commonwealth of Australia. National Rail Program. https://investment.infrastructure.gov.au/key_projects/initiatives/national_rail_program.aspx 17 July 2018.

344. Commonwealth of Australia. National Freight and Supply Chain Strategy. https://infrastructure.gov.au/transport/freight/national-strategy.aspx 20 February 2019.

345. Commonwealth of Australia and ITS Australia, Report of the Intelligent Transport Systems High Level Policy Round Table, October 2016, https://strasbourg2017.itsineurope.com/wp-content/uploads/2017/03/HLPRT-Report-Final.pdf

However, gaps in digital and connected infrastructure (such as digital coverage and satellite positioning) place Australia at a disadvantage. It was subsequently recommended that investment in the intelligence of infrastructure, such as connectivity and data sharing infrastructure, was essential for effective analysis and response to traffic data.

Skills availability

With transport having one of the oldest industry workforce profiles in Australia, there are concerns that there will be a significant skills shortage in the future[346]. It was noted by a number of stakeholders that the skills required in transport sector are changing from the civil engineering of assets to how the asset is used. On this basis, the most in-demand skills in the transport sector in the future will include data analysis, city planning, smart city skills, logistics and transport data administration and geospatial technologies.

Social readiness

Stakeholders indicated that privacy concerns represented the greatest social barriers to the acceptance and uptake of ITS technologies. It was noted that the use of ITS technologies to track vehicles, people and freight could represent the point at which society will start to question and reject the technology.

Economic and commercial feasibility

With respect to economic and commercial feasibility, stakeholders highlighted the following key points:

> Australia is very good at deploying and operating ITS systems to increase and improve safety, particularly through adaptive transport management along transport corridors

> One of the biggest shifts in transport modes has been in the ways that transport providers communicate with their customers. As it is anticipated that both freight and passenger customers will increasingly use various modes of transport to complete their journey, the use of data to aid connectivity and communication between the transport provider and the customer will be essential

> The development, adoption and adaption of ITS technologies in Australia will result in the collection of a significant volume of transport data, with the analysis, communication and application of this data having a profound effect on improvements to transport efficiency, productivity, safety and accessibility

Policy and regulatory readiness

In terms of policy and regulatory readiness, stakeholders raised the following key points:

> Australia has great success in identifying regulations and laws, and adapting laws for vehicles. However, a lack of standards in certain areas of the transport sector, such as the national standardisation of traffic signs, presents challenges to the deployment of ITS technologies

> It is important that current technologies that have significant impacts on vehicle safety are standardised. For example, standardising emergency braking systems and ABS on motorcycles could have immediate effects on road safety. The European New Car Assessment Programme (Euro-NCAP) could act as a model to help drive this level of standardisation in Australia

> There are a number of challenges relating to the use of data in the transport sector, including:
  – Legislative and regulatory barriers (including privacy regulations) potentially hindering data sharing agreements
  – Ethical challenges of data sharing
  – Privacy regulations around data
  – Difficulties in implementing new technologies that rely on data

346. Commonwealth of Australia (2014). Trends. Infrastructure and transport to 2030. https://infrastructure.gov.au/infrastructure/publications/files/Trends_Infrastructure_and_Transport_to_2030.pdf

4.3. Decadal research priorities identified by stakeholders

Stakeholders identified the topics outlined in **Table 6** as key research priorities over the next decade.

Table 6: Summary of key research priorities identified by stakeholders

Key research topics	Research questions
Data	How do we realise the benefits of big data while also addressing cybersecurity and privacy issues? How can high-resolution data be used to help plan the future of transport operation and infrastructure? How do we increase and optimise data coverage for the greatest benefit of the transport sector?
LEVs	How can recharge technologies be developed and optimised to improve range and recharge time of vehicles, including fast charging for heavy vehicles? How can LEV infrastructure and technology be best linked to sustainable energy sources?
CAVs	What are the primary concerns regarding safety and efficiency, and how can these be managed? What are the management strategies for addressing the disruption potential of CAVs?
City planning	What are the essential components of city planning that are required to ensure cities can be adapted to future transport industry technologies, and that the whole transport ecosystem is connected? How do we plan for cities that are not dependent on ownership of personal vehicles? How can we improve city infrastructure with increased populations? How do we link transport technologies with the social, economic and environmental aspects of cities? What are the digital solutions that can be used to solve traditional infrastructure problems? For example, can digitally spaced platoon vehicles be used to minimise the damage to infrastructure, such as grooves on roads?
Social outcomes and social policy research	What is the disruption potential of future transport solutions and what impacts will it have on society? How will advancements in technology in the transport sector improve access and mobility of the community? How will technology increase mobility for ageing population/people with a disability? What are the requirements for future skills, education and training needs in the transport sector?
Health benefits	As technologies within the transport sector become increasingly advanced, what are the likely benefits and drawbacks for health and safety? What will the economic benefits or losses be as a result of these impacts to health and safety?
Regulatory issues	What regulatory enablers, such as certification, insurance, human ethics, public liability, and regulation exist, or should exist, around sharing infrastructure, and what is the level of disruption associated with each enabler?

4.4. Policy recommendations provided by stakeholders

A summary of the policy recommendations provided by stakeholders is outlined in **Table 7**.

Table 7: Summary of policy recommendations provided by stakeholders

Key policy recommendations	Policy issues
A national strategy for transport is required	The development of regulatory enablers should include certification, standards (e.g. CAV standards and certification regimes, vehicle emissions standards, fuel efficiency standards, standards for digital technologies and infrastructure standards), insurance schemes (e.g. compulsory 3rd party), vehicle safety ratings, human ethics, public liability, and regulation around sharing infrastructure. These should be aligned with international models to make it easier to adopt technologies. A harmonised view across the states and territories should be established to ensure that the correct regulations, integration of algorithms are enabled and transport platforms are able to interact seamlessly. Australian road rules should be adapted so that they are applicable to new and emerging technologies. There should be a greater focus on training, skills, education and public awareness within the transport sector. The development of a national LEV strategy, including a hydrogen strategy. The Commonwealth establish a competitive grants program to assist state government with funding to trial technology where there can be demonstrated a case that climatic/topographical/geographic conditions in that state are sufficiently different to those in the original test environment that not to do so could compromise safety. It is recommended that the states could share that information with one another as a condition of the grant. Use successful international transport models as a blueprint for Australia. For example: > The Transportation Research Board (TRB) in the USA provides a good model for collaboration within the transport sector > Universities play a big role in government advice and industry engagement in the USA. > The use of electronic work diaries by truck drivers in the USA can track and sync all the drivers' hours via a central database > The 5G *Initiative for Germany* is a strong model for the rollout of 5G in Australia. The Initiative represents a framework for action to support the deployment of 5G networks and the development of 5G applications at an early stage[347]
A national strategy for data is required	The development of a national strategy for data to address regulations surrounding the availability, access and sharing of transport data
Development of a social narrative	Government, industry and research all have a shared responsibility to create a social narrative around the future of transport to alleviate concerns and promote growth in the sector
Ensure accessibility to all areas of the community	The development of policies to ensure that areas of the community that are mobility impaired (ageing population, those with disabilities) or live within rural and regional areas have accessibility to transport options

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347. The German Federal Ministry of Transport and Digital Infrastructure (2017). 5G Strategy for Germany. A scheme to promote the development of Germany to become a lead market for 5G networks and applications. https://www.bmvi.de/SharedDocs/EN/publications/5g-strategy-for-germany.pdf?__blob=publicationFile July 2017.

5. Academy recommendations

5.1. Readiness Indicators

To gauge Australia's readiness to address the challenges identified within the transport sector, and to provide context for Australia's readiness to develop, adopt or adapt to and accommodate the pending changes by 2030, each of the potential transport solutions was analysed against the Readiness Indicators, including: infrastructure readiness, skills availability, social readiness, economic and commercial feasibility, and policy and regulatory readiness. The readiness scale is outlined in **Table 8**.

The results of the analysis are provided in **Table 9**, and indicate that Australia is least prepared in terms of infrastructure readiness, with respect to low and zero emission vehicles, high frequency mass transit and intelligent transport systems; and skills availability, with respect to low and zero emission vehicles, connected autonomous vehicles and high frequency mass transit. The key factors that have informed these rankings have been expanded upon in detail in Appendix A.

This represents an opportunity for government, industry and research organisations to develop and plan for future urban environments based on the transport needs and mobility patterns of Australian communities.

Table 8: Readiness Indicator scale

	Not ready	More work still required			Ready
Readiness scale	○	◔	◑	◕	●

Table 9: Readiness Indicators

	Infrastructure readiness	Skills availability	Social readiness	Economic and commercial feasibility	Policy and regulatory readiness
Low and zero emissions vehicles	◔	◔	◕	◑	◑
Connected autonomous vehicles	◑	◔	◑	◑	◑
High frequency mass transit	◔	◔	◕	◑	◑
Intelligent transport systems	◔	◑	◕	◑	◑

5.2. Key policy recommendations and research priorities

To achieve the desired outcomes within the transport sector by 2030, the Academy makes the following key policy recommendations to support emerging transport technologies to address the challenges within the transport sector, including:

> Climate change and reducing emissions

> The efficient movement of people and freight

> Health, wellbeing and reducing deaths and serious injuries

The Academy has also highlighted future research opportunities to address the challenges that the sector will face in the decade to come.

Recommendation 1: Implement mechanisms to drive a widespread shift towards low emission transport options

The challenge

LEVs have become inexpensive enough that widespread uptake in Australia is possible. However, a lack of regulations, standards and inadequate charging infrastructure have impeded the rate of widespread uptake.

Recommendations

The Academy recommends that the Commonwealth Government implement policies to reduce vehicle emissions and to encourage the rapid and widespread uptake of LEVs. This should be driven by the following mechanisms:

> A national target and associated regulatory mechanism to drive the uptake of LEVs in Australia

> Public and private corporations should be incentivised to use LEVs as fleet vehicles

> Industry should lead ambitious uptake of LEVs by ensuring that vehicles imported into Australia meet stringent standards for emissions, supported by government vehicle emission standards

These mechanisms will need to be accompanied by efforts in the energy sector to ensure that LEVs are powered by low emission energy sources, in the context of our national emissions reduction target.

Research priorities

> What will the impact of LEVs on Australian emissions be under various plausible scenarios?

> How can we ensure that EVs have a neutral to positive impact on the electricity grid?

> How will the costs and benefits of LEVs differ between privately owned LEVs and shared fleet ownership models?

Recommendation 2: Provide a framework to regulate new transport technologies

The challenge

The lack of an adaptive regulatory framework within the transport sector could inhibit growth and limit Australia's readiness to develop, adapt and adopt new and emerging transport technologies over the next decade.

Recommendations

The Academy recommends that an adaptive regulatory framework be established to provide guidance to the transport sector to help shape future transport systems.

> Australian governments should introduce flexible and adaptable legislative and regulatory frameworks that can keep pace with the global technology frontier to ensure that Australia becomes, and remains, a key competitive player in the global market of advanced transport technologies

> COAG should set nationally consistent standards and regulations to facilitate the uptake of productivity-enhancing technology. For example:

  – The development of a consistent regulatory approach for transport technologies and infrastructure, such as the development of standards for charging infrastructure and connections for LEVs, the development of standards for data sharing and data privacy, and the selection of standards for V2X communications based on global standards

  – Data aggregation and availability, where this would offer an avenue to insight for the market and consumers. Which data should be collected, the situations in which it needs to be shared in real-time and post real-time, and what can be shared for forensic purposes needs to be specified for key platforms (for example, from CAVs and ITS)

Research priorities

> Where are international good practices within the transport sector found, and what lessons can be transferred to Australia?

> What is the best approach to take a whole-of-government, integrated transport systems view involving industry, technology providers, infrastructure planning and education and training?

Recommendation 3: Develop and adapt transport technologies to an Australian setting

The challenge

Australia is an early and rapid adopter of transport technologies and has a strong reliance and interest in following overseas trends. With transport technologies constantly upgrading, it is important that Australia keeps abreast of international trends so as to maintain productivity growth and to maximise the productivity benefits derived from the new technology.

Although this presents an opportunity to adapt technologies to the Australian landscape, it also results in Australia being dependent on the progress and accessibility of international programs, and certain technologies not being suitable for Australia's geography and climatic conditions.

The use of transport technologies that are developed or adapted to an Australian setting have the potential to create the greatest impact. It is essential that when the technology that sits at the technology frontier does not meet Australia's needs (e.g. due to climate, topography, Australia's cultural values, etc.), Australia does not miss out on the benefits of the technology.

Recommendations

The Academy recommends the following actions are taken:

> The Commonwealth and state governments should establish competitive grants programs that encourage the trial of transport technologies that can be adapted to the geographical or climatic conditions that are unique to Australia

> State, territory and local governments should plan for and adapt to future changes to Australia's vehicle fleet by undertaking integrated land use and transportation planning through coherent and consistent policies that take into account likely network use changes from new technologies

Research priorities

> In terms of prioritising the early adoption of transport technologies to improve Australia's readiness within the transport sector, where should the greatest emphasis be placed, on what transport technologies should Australia be early adopters of, and why?

> To what extent and in what situations are Australian climatic and topographical conditions so unique as to warrant special technological adaptations?

> What are the likely impacts of new transport technologies on population distribution?

> What are the obstacles to the use of productivity-enhancing transportation solutions, from the provision of technologies by firms to consumer adoption decisions, and how can they be overcome?

> What are the drivers and impediments to the application of data and digital science to the transportation sector? How can the former be accelerated and the latter moderated?

Recommendation 4: Prepare the workforce for the transition to future transport models

The challenge

The application of new technologies in the transport sector will result in significant disruption to the workforce. As such, it is important to ensure that STEM skills are developed to encourage employment growth within transport related jobs, and workers have the qualifications, skills and training support to adapt to changing roles and tasks in the transport sector.

Recommendations

The Academy recommends the following actions are taken:

> State and territory departments of education should strengthen the content and teaching of science, technology, engineering and mathematics (including digital and data technologies, design, and engineering principles) during upper primary and compulsory secondary schooling to encourage students to pursue university and VET courses in these areas

> Universities and VET institutions, in collaboration with industry, should provide and promote course options that will assist Australia's current and future workforce to develop the skills required to meet the demands of the future transport sector. These may include, but not be limited to, skills in data analysis and modelling, city planning, software development, geospatial technologies, network and data security, logistics, skilled trades, transport data administration and project management

Research priorities

What are the skills requirements to meet future transportation needs, and how do these map on to existing incentives, provision, and accreditation processes? How do any gaps get addressed?
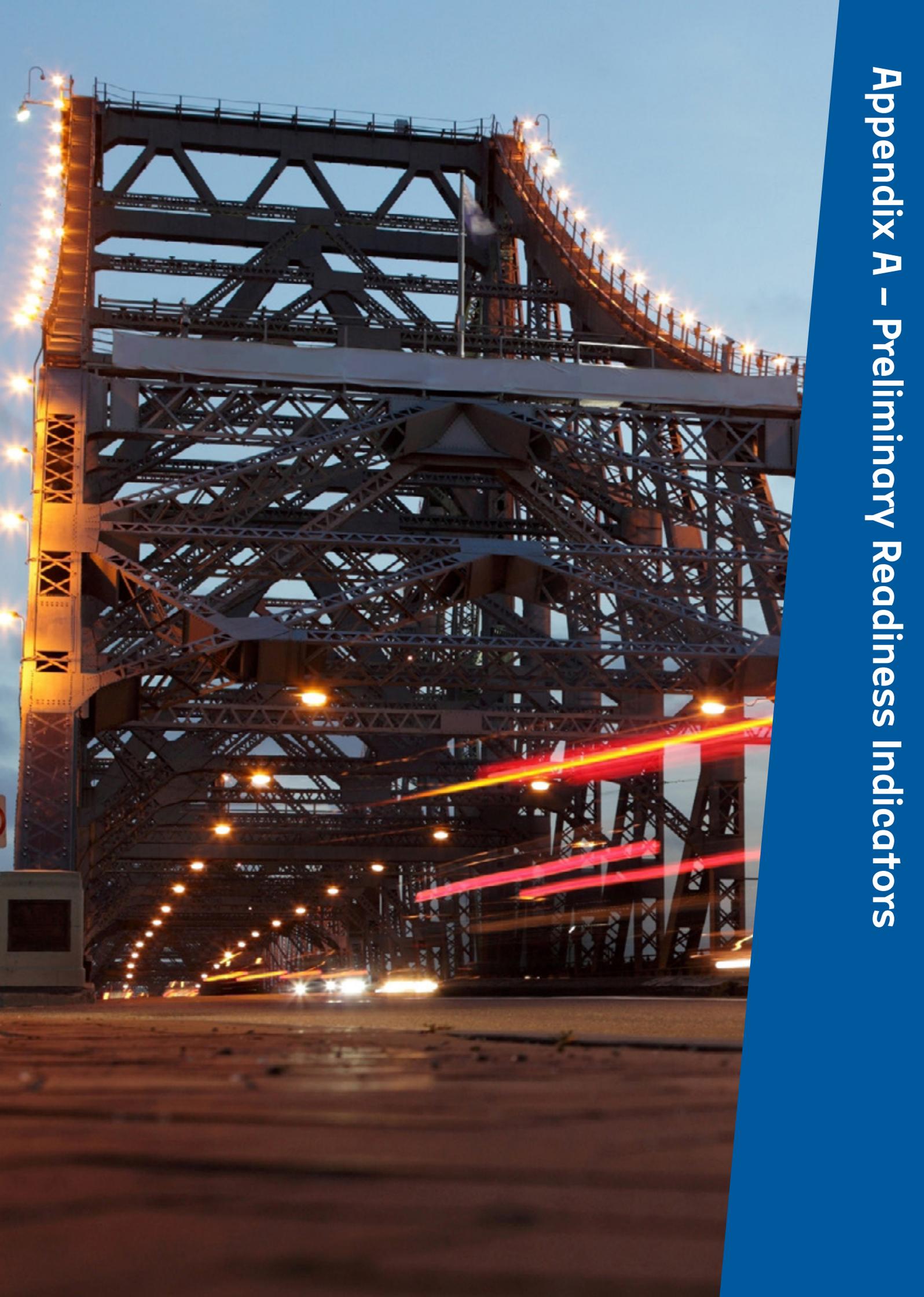
Appendix A – Preliminary Readiness Indicators

A summary of the industry stakeholder insights, readiness metrics and preliminary readiness indicators are provided in **Table 10** for LEVs, **Table 11** for CAVs, **Table 12** for HFMT, and **Table 13** for intelligent transport systems.

Table 10: Preliminary Readiness Indicators for low and zero emissions vehicles

Readiness parameters	Summary of industry stakeholder insights		Summary of readiness metrics		Readiness
	Strengths	Challenges	Strengths	Challenges	
Infrastructure readiness		> Charging time > Connectivity between energy and transport > LEV charging infrastructure network > Hydrogen charging infrastructure > LEV transit lanes	> Gradual increase in number of LEV charging points to meet interest/demand > Government investment in charging infrastructure to support 3 million LEVs by 2030 > $90 million national research centre to support the role hydrogen and biogas fuels will play in supplying Australia's energy needs	> Number of LEV charging points below international average > Number of hydrogen charging points > Energy consumption from grid > Connectivity between LEVs and sustainable energy sources	
Skills availability	> Australian R&D expertise > Strong heavy vehicle manufacturing industry	> Preparation of current and future workforce > Training and education > Manufacturing > Presence of a local workforce	> High numbers of degree completions in general, civil, mechanical, industrial and electrical engineering	> Low number of degree completions in automotive engineering > Low demand for mechanics working with LEVs or hydrogen fuel cells	
Social readiness	> Interest and acceptance > Perception of safety > Public awareness of benefits of LEVs	> Affordability > Range anxiety > Charging time	> Consumer attitudes show positive awareness and interest in buying an LEV[348] > Increasing numbers of car sales	> Concerns around affordability > Range anxiety > Lack of infrastructure	
Economic and commercial feasibility	> Growth of number of LEV models in brand fleets	> Cost of vehicle > Fuel excise > Availability of fast charging technologies for freight vehicles	> Number of LEVs in car brand fleets > Estimated that 10 million LEVs will be on the road by 2037[349]		
Policy and regulatory readiness	> Government fleet policy > Safety standards > Established department addressing LEVs > Government investment in LEVs > Government funded LEV programs > Quality of LEV regulations > Vehicle emissions standards > Incentives/subsidies to purchase, recharge and drive vehicles > Strategies to link LEVs with sustainable energy sources > Fuel excise > Long term national strategic focus	> Clear regulatory and policy framework	> Availability of financial incentives in selected states and territories > LEV public transport trials > Government fleet policy > Government hydrogen refuelling infrastructure projects	> Regulation for vehicle emissions standards > Financial incentives not available in all states and territories	

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348. ClimateWorks Australia. The state of electric vehicles in Australia. Second report: driving momentum in electric mobility. https://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_australia_state_of_electric_vehicles2_june_2018.pdf June 2018.

349. Parkinson, G. AEMO has just doubled its forecast for EV uptake in Australia. *Renew Economy*. https://reneweconomy.com.au/aemo-just-doubled-forecast-ev-uptake-australia-66789/ 19 April 2018.

Table 11: Preliminary Readiness Indicators for connected autonomous vehicles

Readiness parameters	Summary of industry stakeholder insights		Summary of readiness metrics		Readiness
	Strengths	**Challenges**	**Strengths**	**Challenges**	
Infrastructure readiness	> Network coverage (4G) > Road quality	> Network connectivity and accessibility (5G, V2X) > Location services in regional and rural areas > City planning > Designated segments of network, including designated lanes, to reduce congestion > Development of infrastructure in rural, regional, and edge of city areas (including last mile services)	> Network coverage (4G) > Number of CAV trials	> Low number of government funded CAV pilots compared to privately funded pilots > Low number of V2X trials > Sufficient refuelling infrastructure	◑
Skills availability	> Australian R&D expertise > Driving skills	> Current workforce with relevant skills > Training and education > Manufacturing > Presence of a local workforce > Preparation of current and future workforce	> High numbers of degree completions in general, civil, mechanical, industrial and electrical engineering	> Low number of degree completions in automotive engineering	◕
Social readiness	> Productivity and efficiency > Last mile convenience and efficiency > Strong interest > Reduction of car use through mobility as service offerings	> Acceptance > Concern towards level of disruption > Accessibility > Perception of safety > Loss of independent control over vehicle > Security and privacy > Affordability > Public awareness of benefits of CAVs	> Strong desire to use automated vehicle technology	> Low number of Australians with a positive view towards CAVs > Concerns surrounding safety, privacy, increased congestion	◑
Economic and commercial feasibility	> Research and development hubs > Likely decrease in costs associated with vehicle crashes > Improvement in efficiency and productivity > High number of privately funded trials > Benefits of the complementarity of CAVs and LEVs	> No CAV technology headquarters in Australia > Understanding the benefits Shared mobility > Understanding the cost benefits for use in freight vehicles > High cost of vehicle > No local manufacturing > Increase in congestion	> Annual venture-capital investments in non-public mobility-related start-ups > Government funding for driverless vehicle trials in NSW, VIC and SA > Research and development hubs	> Low number of government funded CAV pilots compared to privately funded pilots	◑
Policy and regulatory readiness	> Established government department addressing CAVs	> Government investment in CAVs, including government funded CAV programs and trials > Quality of CAV regulations and standards > Australian Design Rules (ADR)/ compliance of vehicles > Clear regulatory and policy framework > Number of federal and state laws needed to change to allow CAVs > Long term national strategic focus > Liability and insurance schemes to address CAVs > Policies to ensure accessibility and equity > Ethics > Data accessibility and ownership > Privacy and cybersecurity > No legislation surrounding the operation of automated trains in Australia	> Federal Government funding to improve machine learning and developing a new AI ethics framework	> Number of Australian state and federal laws needed to change to allow CAVs	◑

Table 12: Preliminary Readiness Indicators for high frequency mass transit

Readiness parameters	Summary of industry stakeholder insights		Summary of readiness metrics		Readiness
	Strengths	Challenges	Strengths	Challenges	
Infrastructure readiness	> Infrastructure for driverless freight > Network connectivity (4G)	> Infrastructure for driverless passenger trains (platforms) > Infrastructure for driverless passenger buses (stations) > Infrastructure for freight > City planning > Network connectivity and accessibility (5G, V2X) > Location services > Development of infrastructure to support rural, regional, and edge of city areas > Designated segments of network, including designated lanes	> Driverless metro passenger trains in Sydney anticipated to begin service in mid-2019[350] > Platform screen doors installed along driverless train corridor > Track temperature monitoring in VIC > Track security monitoring systems > Driverless freight trains operating in WA > Driverless passenger bus trials on public roads in WA, NT and SA	> Cost	◔
Skills availability	> Australian R&D expertise	> Preparation of current and future workforce > Training and education > Manufacturing > Presence of local workforce > Ownership of data	> High numbers of degree completions in general, civil, mechanical, industrial and electrical engineering	> Low number of degree completions in automotive engineering	◔
Social readiness	> Reduction of car use through mobility as service offerings > Interest and acceptance > Decrease in congestion and commute times > Productivity and efficiency > Last mile convenience and efficiency	> Affordability > Accessibility > Perception of safety > Security and privacy	> 70 per cent of the population would prefer that governments prioritise public transport infrastructure over road infrastructure[351] > Train travel is the most common method of public transport[352]	> Majority of people prefer private vehicles over public transport[353] > Driving is the dominant method of travel to work in Australia[354] > 31 per cent of the population prefer public transport over cars[355] > 39 per cent of Sydney train users who support or strongly support driverless trains[356] > 50 per cent of people would be concerned about safety of driverless trains[357] > 64 per cent of people believe the driver cab should still be included on driverless trains[358]	◕
Economic and commercial feasibility	> Efficiency and productivity > Shared mobility > Privately funded trials	> Research and development hubs > Cost of vehicles > Cost of retrofitting transport network > Manufacturing	> Australia has one freight (Rio Tinto), and one passenger train line (Metro Northwest in Sydney, set to open in 2019)		◑

350. O'Sullivan, M. Driverless train runs full length of new Syndey line ahead of opening. *Sydney Morning Herald.* https://www.smh.com.au/national/nsw/driverless-train-runs-full-length-of-new-sydney-line-ahead-of-opening-20190114-p50raq.html 14 January 2019.

351. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

352. Australian Bureau of Statistics. More than two in three drive to work, Census reveals. Media release. http://www.abs.gov.au/ausstats/abs@.nsf/mediareleasesbyReleaseDate/7DD5DC715B608612CA2581BF001F8404?OpenDocument 23 October 2017.

353. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

354. Australian Bureau of Statistics. More than two in three drive to work, Census reveals. Media release. http://www.abs.gov.au/ausstats/abs@.nsf/mediareleasesbyReleaseDate/7DD5DC715B608612CA2581BF001F8404?OpenDocument 23 October 2017.

355. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

356. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

357. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

358. Tourism and Transport Forum Australia (2017). The Future of Mobility. http://www.ttf.org.au/wp-content/uploads/2017/08/TTF-The-Future-of-Mobility-August-2017.pdf August 2017.

Table 12: Preliminary Readiness Indicators for high frequency mass transit (continued)

Readiness parameters	Summary of industry stakeholder insights		Summary of readiness metrics		Readiness
	Strengths	**Challenges**	**Strengths**	**Challenges**	
Policy and regulatory readiness	> Established department addressing high frequency mass transit > Governments investment in mass transit > Government funded mass transit programs and trials > Quality of mass transit regulations and standards > Clear regulatory and policy framework > Long term national strategic focus > Liability and insurance schemes	> Policies to ensure accessibility and equity > Data accessibility and ownership > Privacy and cybersecurity	> NSW State Government is planning/investing in driverless train technology (including control and monitoring systems, and platform infrastructure)		◑

Table 13: Preliminary Readiness Indicators for intelligent transport systems

Readiness parameters	Summary of industry stakeholder insights		Summary of readiness metrics		Readiness
	Strengths	**Challenges**	**Strengths**	**Challenges**	
Infrastructure readiness	> Network coverage (4G) > Traffic signal controls	> Network connectivity and accessibility (5G, V2X) > Location services > City planning > Designated segments of network, including designated lanes > Development of infrastructure in rural, regional, and edge of city areas (including last mile services)	> Network coverage (4G) > Completion of successful V2X technology trials (roadside sensors for vehicle-to-infrastructure, vehicle-to-vehicle and vehicle-to-pedestrian communications)[359–361] > Regulations introduced by the Australian Communications and Media Authority (ACMA) allow the 5.9 GHz band to be used for ITS in Australia, making the local guidelines consistent with ITS arrangements in the US and the European Union[362] > Deployments of dynamic speed zones and active lane management, ramp metering, traveller information systems, e-tolling and other well-established systems[363] > Australia world leader in design of Advanced Traffic Management Systems (Sydney Coordinated Adaptive Traffic System (SCATS)) > Development and implementation of intra-city motorways with interoperable tolling and ITS to improve traffic flow > Leader in smart motorway technologies with the ITS platform, STREAMs (coordinated on-ramp metering, automatic incident detection, dynamic variable speed limits and lane use management)[364]	> Network connectivity and accessibility (5G, V2X) > Location services	◔

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Table 12: Preliminary Readiness Indicators for high frequency mass transit (continued)

Readiness parameters	Summary of industry stakeholder insights		Summary of readiness metrics		Readiness
	Strengths	Challenges	Strengths	Challenges	
Skills availability	> Australian R&D expertise	> Training and education > Ownership of data > Preparation of current and future workforce	> High numbers of degree completions in general, civil, mechanical, industrial and electrical engineering	> Low number of degree completions in automotive engineering	◑
Social readiness	> Interest and acceptance > Productivity and efficiency > Reduction of car use through mobility as service offerings	> Loss of independent control over vehicle > Accessibility > Perception of safety > Security and privacy > Public awareness of benefits of ITS	> Customer communication, such as the use of AI to predict, plan and respond to events, and inform passengers/freight customers, will significantly optimise transport efficiency	> High proportion of Australians are concerned about data privacy in transport[365]	◕
Economic and commercial feasibility	> Shared mobility > Decrease of costs associated with vehicle crashes > Improvement in efficiency and productivity > Privately funded trials	> ITS technology headquarters in Australia > Research and development hubs > Freight vehicles > Cost of vehicle > Manufacturing	> R&D projects undertaken through iMove CRC are creating new technologies and solutions to address congestion, road trauma and end-to-end freight movement[366] > Australian industry is utilising Data61 simulation in the transport sector to model ramp signalling on motorways[367] > ITS Australia, Transport for Victoria, Transport for NSW, TransLink, Department of Transport WA, Royal Automobile Association SA, and iMove CRC are working towards increasing the understanding of the impact of Mobility as a Service (MaaS)[368] > Australian companies, Intelematics and MTData, are working directly with government and industry to implement telematics technologies[369]		◑
Policy and regulatory readiness	> Established department addressing ITS > Government funded ITS programs and trials > Quality of ITS regulations > Rail and aviation safety policies and regulation	> ADR/compliance of vehicles > Clear regulatory and policy framework > Number of federal and state road rules/laws needed to change to allow CAVs > Long term national strategic focus > Liability and insurance schemes to address ITS > Policies to ensure accessibility and equity > Ethics > Data accessibility and ownership > Data standardisation > Privacy and cybersecurity	> Regulations introduced by the Australian Communications and Media Authority (ACMA) allow the 5.9 GHz band to be used for ITS in Australia, making the local guidelines consistent with ITS arrangements in the US and the European Union[370] > Australia's National Transport Commission is reviewing the use of telematics for regulatory purposes across the transport sector[371]	> Key C-ITS issues affecting regulatory policy include: human factors; mix of old and new technology in the transport system and mixing different road users; data accuracy; security and anonymity; and, whether C-ITS applications operate as warning systems or trigger automated interventions[372]	◑

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