Infrastructure Victoria
Automated and Zero Emission Vehicles
Transport Engineering Advice

ARUP

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Acronyms

AV	Autonomous/Automated Vehicle
CAV	Connected and Autonomous/Automated Vehicle
CBD	Central Business District
DSRC	Dedicated Short-Range Communications
EV	Electric Vehicle
GT4	Austroads 'Guide to Traffic Management Part 4: Network Management'
HPFV	High Performance Freight Vehicle
IV	Infrastructure Victoria
ITS	Intelligent Transport Systems
MaaS	Mobility-as-a-Service
M&P	Movement and Place
MABM	Melbourne Activity Based Model
PBPD	Performance Based Practical Design
PU/DO	Pick-Up/Drop-Off
RASF	Roads and Streets Framework
SRN	Strategic Road Network
TDM	Transport Design Manual
TfV	Transport for Victoria
V2G	Vehicle-to-Grid
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Other-Part-of-the-System
VICA	(Victorian) Infrastructure Capability Assessment
VKT	Vehicle Kilometres Travelled
ZEV	Zero Emission Vehicle

Executive Summary

Roads and streets are the lifeblood of local, regional, state and national economies around the world. They constitute most of the public spaces within our cities, towns and regions, and are utilised everyday: to get to work, school, to shop, to do business and to transfer goods and services. When roads and streets are congested, experience serious crashes or create barriers; they can significantly threaten the function and livelihood of cities, towns and regions. So, planning for the significant changes expected in the future is critical for any highly-functioning and liveable city.

The trend towards Automated Vehicles (AVs) and Zero Emission Vehicles (ZEVs) has been a focus for some time now, and as the prospect draws closer of AVs becoming a mainstream transport mode, it is becoming more widely accepted that they have the potential to completely change the way we live. With the convergence of AVs and ZEVs makes it an area replete with opportunity - what they might offer, what they might achieve.

However, for all the claimed benefits from the wide-scale use of AVs, there remains a great deal of uncertainty that presents immense challenges for the State of Victoria from a transport planning and engineering perspective. Although we are seeing many AV trials taking place globally and here in Australia, there are many questions that simply cannot be definitively answered today. We do not know how rapidly technology will evolve, we do not know the ownership structures that will be adopted, we do not know the future costs of technology, and we do not know if a wide-scale spread of Level 4/5 (i.e. highly automated) vehicles will occur, or indeed exactly what the mix of automated and human driven cars will be.

With regard to light to medium (includes buses) sized ZEVs the winner is likely to be battery electric powertrains, however a lot of uncertainty remains as to how heavy vehicles will be powered particularly over large distances.

With this uncertainty, combined with only partial understanding, evidence and clarity around how AVs and ZEVs might be used and implemented, it becomes very challenging to create or change specific road network infrastructure. However, with global acceptance that AVs will largely operate within the existing road network, governments **can** act **now** to future proof and prepare for this change to enable and encourage the safe and efficient use of AVs and ZEVs on the network.

Setting ourselves up for change is of paramount importance. The introduction of AVs and ZEVs into our transport system brings a unique opportunity to deliver on broader societal outcomes, such as those affecting mobility, the environment and road safety. However, there are real challenges and ramifications for Victoria if AVs and ZEVs are not managed within an overarching framework and coordinated approach.

Project Aims and Method

Infrastructure Victoria (IV) awarded Arup the transport engineering assignment, to help inform the development of advice for the Victorian Government around the capabilities and potential impacts of AVs and ZEVs on Victoria's road users and network. The study was undertaken during May 2018 to understand capabilities and potential impacts, and highlight opportunities/challenges for the possible wide-scale use of AVs and ZEVs in Victoria, from a transport engineering perspective. The study has utilised a combination of sources and methods, including accessing global subject matter experts, academic research, and utilising results and information collected from several AV trials managed by Arup in Australasia and Europe.

Through this study we have aimed to:

- Discuss key changes presented by the evolution of AVs and ZEVs, from a transport engineering perspective
- Understand the risks, opportunities and impacts of AVs and ZEVs for all road users including pedestrians, cyclists and motorcyclists
- Consider the physical infrastructure from a design, build, operation and maintenance perspective – i.e. 'Whole of Lifecycle'
- Explore on-road electric vehicle charging infrastructure which may have a direct impact on the road network – for both light and heavy vehicles
- Assess how movement occurs on the Victorian road network - from an operations planning and traffic management perspective - and how AVs could be considered within this context
- Discuss and analyse the impact of AVs and ZEVs on the design, management and operation of car parking and land use.

Through this study, IV and the Victorian Government will gain a better understanding of some of the potential changes to transport engineering, planning and infrastructure design

It is widely accepted that the future of mobility will look very different to the present, with advances in energy, communications and automated driving technologies instigating major shifts in the industry and for society. Setting ourselves up for the change that is coming, is critical.

Findings, Recommendations and Actions

This study presents a range of findings, recommendations and strategic priority actions for IV and the Victorian Government to consider in planning for the possible wide-scale use of AVs and ZEVs on Victoria's road network.

The following pages (section 1) highlight the key findings and recommendations from each of the study's sections. The findings and recommendations in this report have been workshopped by the project team to develop strategic priority actions that Victoria may like to consider more broadly in preparing and enabling an AV and ZEV future, these are discussed in **section 9 Strategic Priority Actions**.

1 Key Findings, Recommendations and Actions

1.1 Key Findings and Recommendations

This report has put forward several possible responses for each section that Victoria could consider investigating further. In addition to these responses the following key findings and recommendations were highlighted for each section.

1.1.1 Planning for All Users (Section 4)

The purpose of this section was to discuss and assess the risks, opportunities, and impacts of AVs and ZEVs for other road users such as pedestrians, cyclists and motorcyclists. The following key findings and recommendations are discussed:

- A need to actively plan and encourage active travel in an AV future
- Planners and engineers should aim to create consistency and predictability of active travel infrastructure and user behaviour. Investment is likely to be prioritised along strategic cycling corridors and walking networks
- The walkability of neighbourhoods and key activity centres is already considerably impacted by the private car, AVs have the potential to improve or worsen walkability depending on how implementation is planned and managed
- Pedestrians, cyclists and motorcyclists are over represented within accident statistics. Road authorities should support AV technology to considerably improve safety for vulnerable road users
- A need for flexible and adaptable streets into the future.

1.1.2 Physical Road Asset (Section 5)

The purpose of this section is to outline and discuss the impacts AVs and ZEVs could have on the road asset from a design, build, operation and maintenance perspective (‘Whole of Lifecycle’). The following key findings and recommendations are discussed:

- An assessment was undertaken to understand whether the minimum requirements for AVs to operate within an acceptable error rate a summary of the results is shown in **section 5.7.2**
- Due to the rapid and evolving nature of AVs and ZEVs there is a need to build in an ability to easily adapt design standards and performance requirements
- There is a real potential that physical road assets, such as pavement and structures could be impacted by unplanned and uncoordinated AV deployment, there is a need for government to proactively plan and manage AV use

- The Victorian Government in conjunction with other jurisdictions need a clear plan to manage the transition phase to deliver the desired outcome
- There is a significant amount of work being done at a national level through organisations, such as: Austroads and the National Transport Commission, to prepare Australia for an AV future. It is important that Victoria fully participates and contributes to this work, to ensure a consistent and timely approach is taken
- An aspect of AV deployment the Government should begin an active role in monitoring is the use of heavy vehicle platooning. It has the potential to deliver significant benefits but may have impacts on the physical road asset.
- The ownership model of AVs is likely to have significant impact on the provision and design of parking, and Pick-up and Drop-off Facilities (refer to **section 8 Parking and Land Use**).

1.1.3 On-Road Electric Charging Infrastructure (Section 6)

This section discussed key considerations and areas for further investigation relating to electric vehicle charging infrastructure that may have a direct impact on the road network. It is important to highlight that EV charging may be quite different for light and heavy vehicles due to the power requirements and uses. The following key findings and recommendations are discussed:

- To enable and encourage an EV future for Victoria government policies and interventions are needed
- It is expected that light vehicles AVs will mainly be powered by batteries
- There remains a high level of uncertainly around whether heavy vehicles will use hydrogen or battery power
- For Victoria, it is likely electric bus charging will be similar to the light vehicle approach, unless a cost effective ‘very rapid charge’ solution is developed
- With ‘in-motion’ charging still in early development, the near-term response for light vehicle EVs will likely be focused on stationary charging, primarily through plug-in and secondarily through induction charging.

1.1.4 Road Operations and Management (Section 7)

This section highlights how movement occurs on the Victorian road network from an operations planning and traffic management perspective, and how AVs are considered within this context. The following key findings and recommendations are discussed:

- It is widely accepted that a majority of the benefits associated with AV technology will be reliant on the vehicles being ‘connected’
- The operation and management of the road network needs to be outcomes and performance led, to ensure AVs are delivering on broader Government objectives

- Victoria has several ‘control’ centres covering different parts of the transport network. Planning should begin soon to bring these centres under one roof to assist with AV deployment especially during the transition period.

1.1.5 Parking and Land Use (Section 8)

This section outlines analysis of the impact of AVs and ZEVs on the design, management and operation of car parking. It then goes on to explore case studies and the repurposing of car parking land uses. Refer to **section 8.9 Findings** for details.

1.2 Strategic Priority Actions

Reflecting on the study’s findings and recommendations, the project team developed nine strategic priority actions from a transport engineering perspective. The following strategic priority actions have been identified:

Vision

- Responsibility and Governance
- Community and Stakeholder Engagement

Understanding

- Cooperation with Other Jurisdictions
- Readiness and Testing

Clarity

- Movement and Place
- Outcome Led Design

Adaptability

- Real Options Analysis
- Road Standards and Guidelines
- Funding Mechanisms.

2 Background

2.1 Purpose

The purpose of this report is to provide transport engineering advice to Infrastructure Victoria (IV) in respect to the use of Automated Vehicles (AVs) and Zero Emission Vehicles (ZEVs) on Victoria's road network.

This study was carried out under the guise of the Terms of Reference set by the Special Minister of State, who requested IV provide advice regarding the infrastructure requirements for the implementation of AVs and ZEVs in Victoria[1].

2.2 Transport Engineering Advice

Arup's transport engineering advice aims to assist IV in understanding the capabilities and impacts of AVs and ZEVs on Victoria's road network, including the roadside environment and all road users. This study has intended to inform IV's understanding of potential impacts to planning, designing, operating and maintaining Victoria's road network, and the type of responses to address the impacts. To respond to IV's brief and consider the implications of AVs and ZEVs from a transport engineering perspective, the study has been structured as follows (Figure 1):

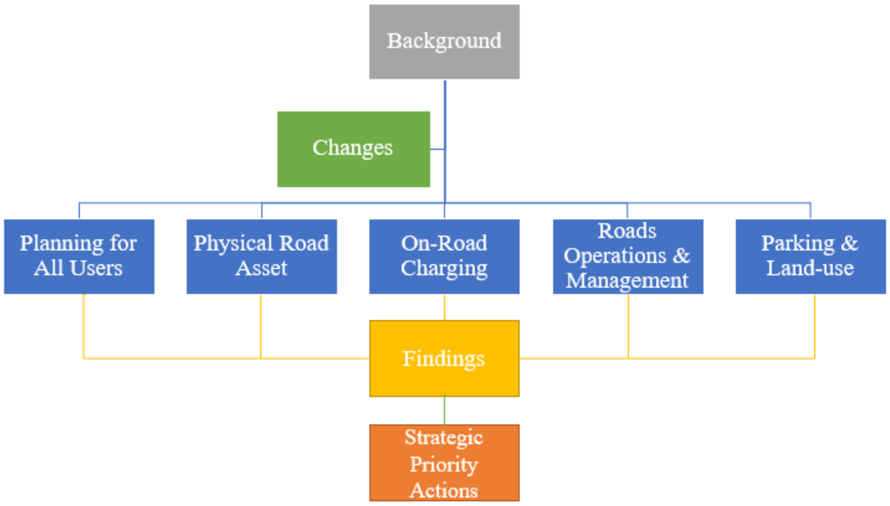

Figure 1: Report Structure

The following highlights each section, shown above:

2. Background: provides context and background to the study.

3. Changes: highlights and discusses some of the potential changes AVs and ZEVs may present into the future.

4. Planning for All Users: explores the impact of AVs and ZEVs on other road users.

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[1] Infrastructure Victoria, 2018, http://www.infrastructurevictoria.com.au/node/104

5. Physical Road Asset: discusses how AVs and ZEVs impact on the road network's physical infrastructure from a whole of life perspective.

6. On-Road Electric Charging Infrastructure: considers and discusses vehicle charging infrastructure that interacts with the road network.

7. Road Operations and Management: focuses on ways movement occurs on the road network and how AVs could be integrated.

8. Parking and Land Use: provides an assessment and discussion on the impact of AVs and ZEVs, from a car parking and land-use planning perspective.

9. Strategic Priority Actions: in reflection of the findings created during this study the project team generated nine strategic actions that could be considered by government.

2.3 What Are AVs and ZEVs?

2.3.1 Automated Vehicles (AVs)

Automated Vehicles (AVs) are those that do not require human input to safely navigate their surroundings[2] and use a variety of sensing technology. Figure 2 highlights how an AV senses the world. They are likely to be cooperative, with connections to other vehicles, infrastructure and the internet[3], this is discussed in more detail in the following section.

The AV term can be used for both passenger and freight however it is important to understand the relative impacts for each will differ considerably based on the use cases for each. For the purposes of this report, individual sections will discuss passenger and freight challenges separately as appropriate.

The Society of Automotive Engineers (SAE) International categorises different levels of autonomy for vehicles between Level 0 and Level 5 (refer to Figure 3).

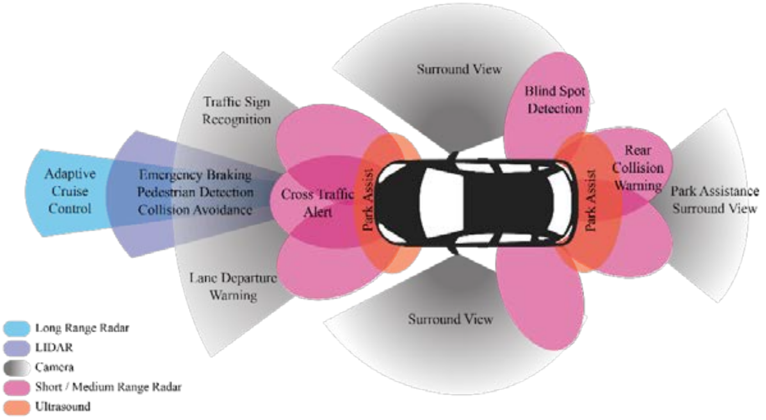

Figure 2: AV Sensors Source: Texas Instruments[4]

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[2] Gehrig. S.K, Stein. F.J, 1999, Institute of Electrical and Electronics Engineers; Dead reckoning and cartography using stereo vision for an autonomous car

[3] Infrastructure Victoria, 2018, http://www.infrastructurevictoria.com.au/AVadvice

[4] Williams. P, 2015, http://www.autos.ca/auto-tech/auto-tech-autonomous-cars-will-change-everything/

2.3.1.1 Levels of Autonomy

Figure 3 summarises the level of autonomy for vehicles from Level 0 to Level 5. This study was primarily concerned with Levels 4 and 5.

Level 2 vehicles are already operating and can be commercially purchased in Australia. Level 3 vehicles are expected to be operating by the end of 2018 on Australian Roads[5] with the release of the Audi A8.

Some analysts, such as industry research firm IHS Markit, suggest commercially available Level 4 vehicles will be deployed in the United States in mobility service fleets around 2021 and will be available in private vehicles closer to 2025[6].

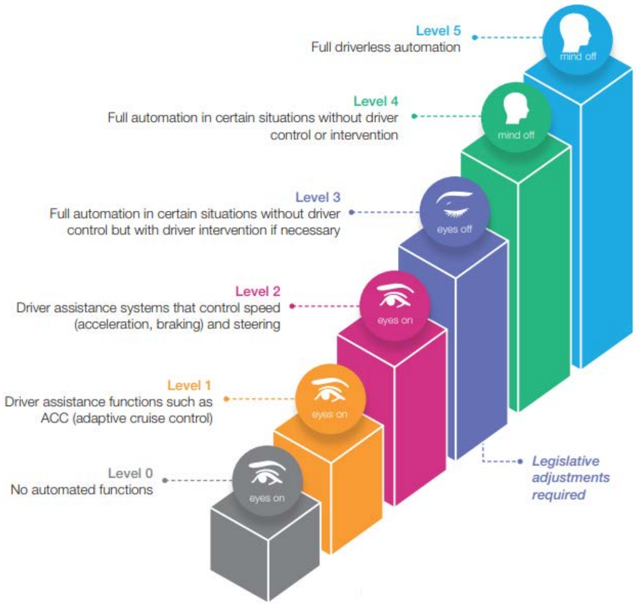

Figure 3: Level of Automation (Source: Arup)

However, many from industry are suggesting timeframes are likely to be shorter. For example, Audi and Nvidia announced they will deploy a Level 4 automated car by 2020[7]. The exact timing of commercially available AVs operating at level 4 and 5 on Victoria's open road network is unknown, however there are a range of companies and institutions investing significant capital into the development of increasingly capable automated systems[8].

It is important to highlight that even with more than one million new vehicles sold annually, Australia is a very small car market comprising less than 1.5% of global

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[5] P. Maric, 2017, https://www.caradvice.com.au/581052/2018-audi-a8-weve-driven-the-worlds-first-level-3-autonomous-vehicle/

[6] Adams. E, Carlson. J, IHS Markit, 2017, http://www.thedrive.com/tech/16768/how-long-really-until-self-driving-cars-hit-the-streets

[7] Ross. P.E, 2017, http://www.thedrive.com/tech/16768/how-long-really-until-self-driving-cars-hit-the-streets

[8] Davies. A, 2018, https://www.wired.com/story/guide-self-driving-cars/

vehicle production[9]. Therefore, if Australia believes that there are benefits to having AVs on its roads, there is a need for Australia to consider how this technology is attracted and easily enabled on the road network.

2.3.1.2 How AVs work

The following diagram outlines the inputs AVs use to operate appropriately[10].

Figure 4: Level of Automation (Source: David Silver, Udacity)

AVs have five core components which work together to create self-driving. Computer vision is the use of cameras to see the road and other elements. This is then integrated with data other sensors, such as radar and LIDAR, in-sensor fusion which builds a comprehensive understanding of the environment the vehicle is operating in. Localisation is then used for the vehicle to locate its position to a high level of accuracy. The vehicle then uses path planning to chart the trajectory of where it is going and it predicts what the other vehicles around it will do so it can manoeuvre safely. Finally, once the trajectory is established, the vehicle needs to control the various vehicular elements, i.e. turn the steering wheel and press the accelerator, in order to follow that trajectory[11].

This explanation refers to automated vehicles with limited connectivity. The next section describes the differences between and features of cooperative / connected and automated vehicles.

2.3.2 Connected and Automated Vehicles (CAV)

It is important to distinguish between a connected or cooperative vehicle, an autonomous vehicle and a connected/cooperative automated vehicle. For the purposes of this report the terms connected and cooperative will be used interchangeably, however cooperative is a sub-set of the connected vehicle.

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[9] Federal Chamber of Automotive Industries, 2017, https://www.accc.gov.au/system/files/Federal%20Chamber%20of%20Automotive%20Industries%20-%20September%202017.pdf

[10] David Silver, 2017, https://medium.com/udacity/how-self-driving-cars-work-f77c49dca47e

[11] David Silver, 2017, https://medium.com/udacity/how-self-driving-cars-work-f77c49dca47e

A connected vehicle communicates with other vehicles, roadside infrastructure and transport management systems (i.e. traffic signals). The driver is in control at all times and receives warnings of changes in traffic conditions as they happen. Connected vehicles can provide drivers with awareness of similarly equipped vehicles and infrastructure and do not depend on line-of-sight communications to operate.

An autonomous, or automated, vehicle (as mentioned in the previous section) uses and relies upon a variety of sensor technologies to operate without the control of a driver to varying levels of autonomy.

A connected automated vehicle utilises the connected systems to communicate with other similarly equipped vehicles and road infrastructure and then automates the responses to associated traffic condition changes[12]. See Figure 5 below for a graphical representation.

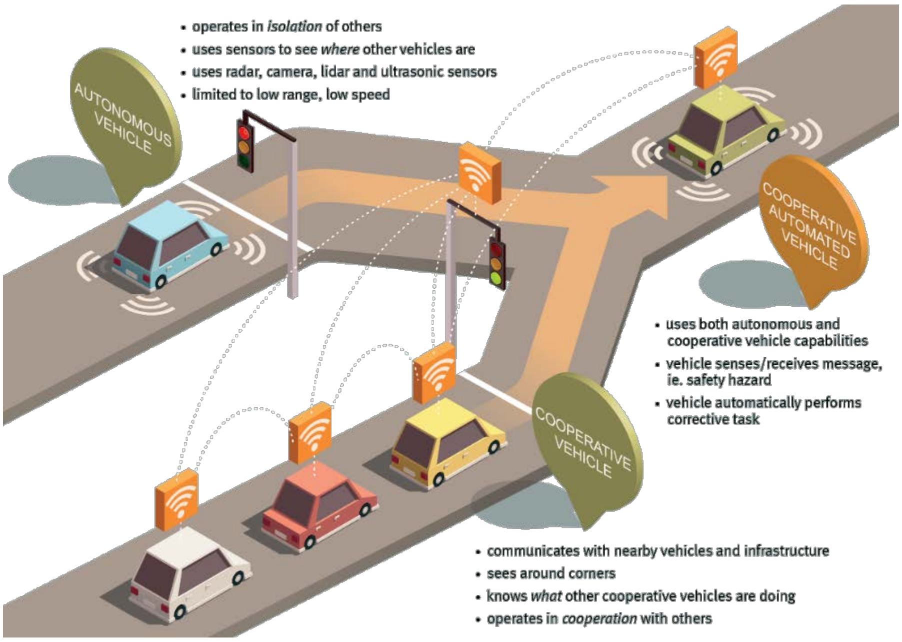

Figure 5: Cooperative Autonomous Vehicles (Source: Queensland Government)

2.3.3 Zero Emission Vehicles (ZEVs)

By definition, a Zero Emission Vehicle (ZEV) utilises a powertrain that emits no exhaust gases[13] , and many also extend this definition to include a fuel source that emits no exhaust gases. Fuel-cell (hydrogen) and electric engines are the most commonly used sources of energy in this growing sector of the transportation industry, with a number of manufacturers investing significant capital in the development and production of such vehicles. The number of vehicles utilising alternative fuel sources is expected to significantly increase from the current 2.1% of vehicles across Australia in 2017[14].

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[12] Queensland Government, 2017, https://www.qld.gov.au/transport/projects/cavi/cooperative-automated-vehicles

[13] California Air Resources Board, 2018, https://ww2.arb.ca.gov/about/glossary

[14] Australian Bureau of Statistics, 2017, http://www.abs.gov.au/ausstats/abs@.nsf/mf/9309.0/

Many electric vehicles currently available employ lithium-ion battery technology, allowing for multiple recharges through residential electrical supplies and/or charging stations. There are also potential economic and environmental benefits associated with the use of electric vehicles, such as the cheaper unit cost of electricity compared with fossil fuels and the lack of greenhouse-gas output. However, there are challenges with the large-scale adoption of electric vehicles regarding the necessary supporting infrastructure, as the lithium-ion batteries in current electric vehicles limit the range of travel to below that of a comparable fossil fuel vehicle, and may require a significantly longer charging/refuelling time. We note that IV have procured a separate study on the financial impacts including budget impacts of ZEVs/AVs and vehicle cost impacts.

Hydrogen is seeing a renaissance as a viable fuel source, after a period where fuel-cell vehicle research was significantly overlooked in favour of battery electric-vehicle efforts[15]. Large amounts of capital are being invested into developing the necessary powertrain and storage/supply technology to support widespread hydrogen powered transportation networks. For example, Royal Dutch Shell has implemented hydrogen refuelling stations across the UK and western USA, working with Honda and Toyota, and are aiming to develop 400 stations in Germany[16]. The benefits of hydrogen are highly attractive, as the range and re-fuel times are already comparable to fossil-fuel powered vehicles. Furthermore, water vapour is the sole emission from a hydrogen powertrain. However, the production (through electrolysis) of hydrogen can be an inefficient process, compared with the power losses associated with the operational cycle of an electric vehicle which are significantly lower. The logistics of safe storage and distribution of large amounts of hydrogen are also more onerous than the transmission of electricity[17].

There are significant incentives associated with reducing transportation emissions at all scales. Policy makers are increasingly sensitive to the negative impacts of climate change on society, and ample evidence exists of the contribution of fossil-fuel use to these impacts. The increase over time of the unit cost of hydrocarbon-based fuels and its volatility are also causal factors to the growing allure of alternative, environmentally-friendly fuel sources[18].

2.4 Infrastructure Victoria's Future Scenarios

Infrastructure Victoria released their 'Future Scenarios' report in April 2018. The aim was to create a set of scenarios which enabled the assessment of a range of uncertainties to help determine the best course of action. The scenarios deliberately test extremes to help isolate the impact of different variables. Importantly, they acknowledge the most probable outcome will be the combination of scenario impacts. This study has utilised these scenarios in assessing impacts and responses. Figure 6 below provides a snapshot of the

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[15] Walk. M.L, 2009, https://www.nytimes.com/2009/05/08/science/earth/08energy.html

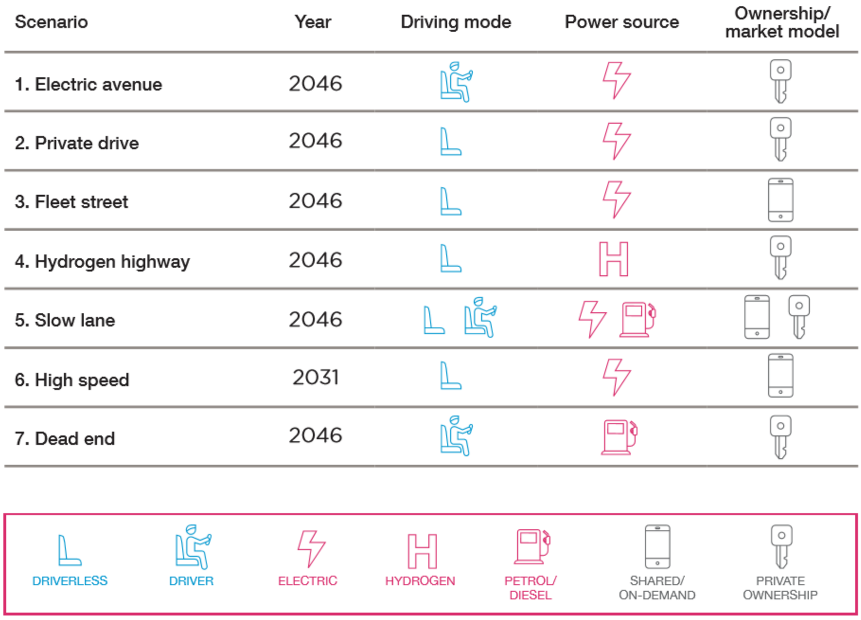
[16] Shell Australia, https://www.shell.com.au/energy-and-innovation/make-the-future/on-top-of-the-world/could-a-cars-only-emission-be-water.html

[17] RE new Economy, 2018, https://reneweconomy.com.au/toyota-vs-tesla-can-hydrogen-fuel-cell-cars-compete-with-evs-11540/

[18] Energy Education, 2015, http://energyeducation.ca/encyclopedia/Hydrocarbon_resource

scenarios, please refer to IV’s Scenario report for further information and background: http://infrastructurevictoria.com.au/AVadvice.

It is highlighted that when this study discusses a fully AV future, this includes scenarios 2, 3, 4 and 6, and a full future includes scenarios 1, 2, 3, 4 and 6.



Scenario	Year	Driving mode	Power source	Ownership/ market model
1. Electric avenue	2046	🧑	⚡	🔑
2. Private drive	2046	💺	⚡	🔑
3. Fleet street	2046	💺	⚡	📱
4. Hydrogen highway	2046	💺	H	🔑
5. Slow lane	2046	💺 🧑	⚡ ⛽	📱 🔑
6. High speed	2031	💺	⚡	📱
7. Dead end	2046	🧑	⛽	🔑

💺 DRIVERLESS
🧑 DRIVER
⚡ ELECTRIC
H HYDROGEN
⛽ PETROL/ DIESEL
📱 SHARED/ ON-DEMAND
🔑 PRIVATE OWNERSHIP

Figure 6: Infrastructure Victoria AV ZEV Scenario (Source: Infrastructure Victoria)

2.5 Context: Australian Approach to AV Readiness

There is currently significant work occurring at a national level in the space of AV readiness, therefore it is imperative that Victoria participates with other jurisdictions across Australia to have a unified approach to regulation, policy and standards in order to create an efficient and safe transport system. Taking this approach will provide a solid foundation for accessible, liveable and sustainable cities and regions.

The Commonwealth Department of Infrastructure, Regional Development and Cities (DIRDC) is currently heading up the national transport technology strategy which includes addressing cybersecurity, as well as keeping Australia’s vehicle design rules, relating to automated vehicles, relevant and up-to-date with international standards. Australia’s transport ministers (through the Council of Australian Governments Transport and Infrastructure Council) have agreed to a program of work on a national level, which is being implemented collaboratively across all levels of government and through intergovernmental organisations such as the National Transport Commission and Austroads.

The National Transport Commission (NTC) - as a national transport reform agency - has the mission of championing and facilitating changes that improve productivity, safety and environmental outcomes. In November 2016, the Transport Minister approved the recommendations outlined in NTC’s policy paper ‘Regulatory Reforms for Automated Road Vehicles’. The release of the policy paper concluded a one-year project to research the regulatory barriers and develop recommendations to support future reform and further created a series of actions to develop the reform. The release of the discussion paper 'National Guidelines for Automated Vehicle Trial' then signified the start of phase one of NTC's Roadmap of Reform which includes a number of completed and upcoming projects[19].

Austroads is working with key government and industry stakeholders to establish supporting frameworks for the use of connected and automated vehicles with particular focus on impacts on traffic operations such as road infrastructure. To this end, Austroads' Connected and Automated Vehicle (CAV) program is currently underway and includes a number of projects either being led by Austroads themselves or in close collaboration with other government and industry stakeholders. The Austroads Strategic Plan 2016-2020 outlines their priorities and focus for research and investigation[20]. The current Austroads CAV program includes researching the following[21] and it is expected some of these will be published by the third quarter of 2018:

- Cooperative ITS
- Automated Vehicles – Framework for Road Operations
- Automated Vehicles – Framework for Registration and Licensing
- Cooperative ITS – Operational Framework
- Implications of In-Vehicle Sign Recognition on Road Operators
- Directions to C-ITS Deployment
- Strategic Direction for Security in C-ITS.

Austroads and NTC's work complements other government work which is preparing for Australia's automated vehicle future. It is commonly accepted that all levels of government both at a state and national level must work together, in order to create an end-to-end regulatory system which allows for the safe, commercial deployment of AVs in Australia from 2021. Other than DIRDC, NTC and Austroads, a number of other key stakeholders will play an important role, including but, not limited to: Australian Communication and Media Authority (ACMA); Geoscience Australia and the National Positioning Infrastructure Advisory Board; National Heavy Vehicle Regulator; Transport Certification Australia; respective state and national level vehicle standards and regulation authorities; and, equivalent road authorities in other states and territories.

Set against this context of activity, broadly, Australian governments and industry recognise the need to evolve legislation, regulatory frameworks, industry standards and codes of practice for AV technology. It is flagged that a critical part of this should be on-road and off-road trials – which will help support the

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[19] National Transport Commission, 2018, http://www.ntc.gov.au/roads/technology/automated-vehicles-in-australia/#Current

[20] Austroads, 2018, http://www.austroads.com.au/about-austroads/strategic-planning

[21] Austroads, 2018, http://www.austroads.com.au/drivers-vehicles/connected-and-automated-vehicles/projects

development and introduction of safe and efficient AV technology on Australia’s road network.

2.5.1 AV Capability and Certification

Whilst the defined levels of automation (refer to **section 2.3.1**) indicate the overall varying capabilities of AVs across levels, it is evident that specific capabilities at any particular level could vary depending on the type and quality of vehicle technology implemented by different manufacturers and equipment suppliers. Also, the capability is likely to evolve and improve over time. Issues of variable performance of automated functions and how AVs interact with existing road infrastructure is evident from trials of existing AVs undertaken in Victoria and elsewhere (refer to **section 2.6.2**). A ramification of this in relation to issues addressed in this study is that requirements for infrastructure design and maintenance are closely tied to AV functionality.

A key AV performance consideration is in relation to safety. The NTC is considering the issues that need to be addressed to ensure the safe commercial deployment of AVs in Australia[22] and the options to address the key problem risks. The approaches under consideration would regulate the requirements for AVs to meet certain criteria to assure an acceptable level of safe operation, specifically in relation to the automated driving system (ADS). The approaches include a certification process for the ADS. Amongst the safety risks that the proposed ADS certification would need to address are these issues most directly related to interaction with infrastructure and road operations:

- Compliance with relevant road traffic laws
- Minimal risk condition
- On-road behavioural competency
- Testing for the Australian road environment.

An issue falling under the consideration of this IV engineering study is the degree to which the road environment may need to be altered from existing conditions to accommodate AVs and/or the extent to which AVs should or could be designed to operate within an unaltered road environment. In either case there will need to be some consideration of what are the:

- Minimum conditions required for operation – likely to be aligned to measures primarily focussed on safety
- Optimal conditions – which may be a higher level of AV capability and/or infrastructure provision to assist meeting objectives such as efficiency of road operations.

These issues are addressed in later sections of this report.

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[22] NTC, 2018, Safety assurance for automated driving systems consultation regulation impact statement. http://www.ntc.gov.au/Media/Reports/(C07CE648-0FE8-5EA2-56DF-11520D103320).pdf

In the same way that AVs could be certified, an approach to road design for AVs could be to apply a road certification system that identifies a road meets a certain set of criteria that enables AVs (of a specified level) to operate on that road. The need for or benefit of such certification approach is unclear at this stage. This report has not adopted a position on this issue, rather we have identified certain infrastructure requirements and issues associated with operation of AVs. The most appropriate way for such requirements to be operationalised and (if needs be) regulated or certified requires further consideration.

2.5.2 State Example: Queensland's Cooperative and Automated Vehicle Initiative

Queensland's Department of Transport and Main Roads is currently undertaking the Cooperative and Automated Vehicle Initiative (CAVI) to help prepare for the arrival of new vehicle technologies related to safety, mobility and sustainability benefits[23]. The CAVI program includes four components:

- Cooperative Intelligent Transport Systems (C-ITS) pilot
- Cooperative and Highly Automated Driving (CHAD) pilot
- Vulnerable road user pilot
- Change management.

The timeline of CAVI is 2017 – 2021, with early procurement and planning having occurred in 2016.

The purpose of CAVI, according to the Queensland Government, is to lay the technical foundation for the next generation of smart transport infrastructure that is coming and in some cases, is already here and available. The Queensland Government acknowledges that they are responsible for getting ready for connected and automated vehicles and other emerging transport technologies[24].

CAVI's focus is on:

- Developing policy
- Supporting regulation, legislation, licensing and possible certification and testing
- Managing infrastructure, data and system integration
- Conducting pilots and feasibility studies
- Ensuring that cooperative and automated vehicles can operate safely and legally on our roads
- Ensuring data produced by automated vehicles is not misused and is secure from hacking
- Considering consumer issues including insurance and liability

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[23] Queensland Government, 2017, https://www.qld.gov.au/transport/projects/cavi/cavi-project
[24] As above 23

- The needs of all Australians, and the impacts that the introduction of automated vehicles will have on our workforce and future skills needs.

All the above points are highly relevant and applicable to the Victorian Government moving forward.

The largest component of the CAVI program is the C-ITS Pilot, which will take place on public roads in and around the City of Ipswich from 2019 for up to one year.

Figure 7 below displays the timeline of the C-ITS Pilot (current as at April 2018).

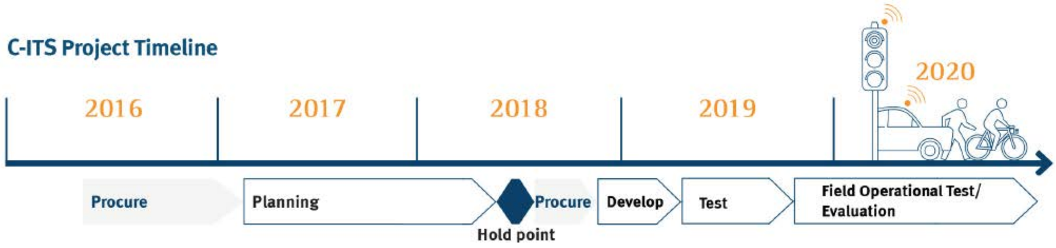

Figure 7: C-ITS Pilot Timeline (Source: Queensland Government)

A number of C-ITS safety use-cases including Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) applications will be tested as part of this trial. The pilot will involve around 500 public and fleet vehicles retro-fitted with C-ITS devices, and roadside units also installed on selected arterial roads and motorways. This pilot will include a security management system component, which will endeavour to exchange authentic and trustworthy information and data, as announced by the Queensland Minister of Transport and Main Roads in a media statement on 8 June 2018[25].

The CHAD pilot will involve a small number of connected/cooperative and automated vehicles being tested on public and private roads using trained and public participants. Currently detailed timeframes are unknown however the pilot will occur between now and 2021.The pilot will assess:

- Asset readiness – assessing the capability of automated vehicles to read existing signs and lines
- Driver behaviour – exploring the interface relationship between the human and machine
- Vehicle performance – how the cooperative automated vehicles function compared with the purely automated vehicles[26].

The elements above are all key aspects to understanding the effects on infrastructure requirements of the road network and relevant for IV and the Victorian Government.

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[25] Queensland Government, 2018, http://statements.qld.gov.au/Statement/2018/6/8/smart-state-supports-smart-vehicles

[26] Queensland Government, 2017, https://www.qld.gov.au/transport/projects/cavi/cavi-project

IV and the Victorian Government would significantly benefit from staying abreast of the CAVI program, checking in on the progress as per the timeline, in order to continuously gain understanding and learnings from the progress of these works.

2.6 Study to be Read in Conjunction

It is highlighted that alongside this study IV commissioned LEK and Arup to undertake an international market scan of AV and ZEV development. It is expected this will be released in conjunction with this study and the two will be read together.

In addition to the market scan, the project team has identified three documents in particular that should be read in conjunction with this study, which builds upon these reports and provides more Victorian context. Again, we have taken the approach that this study will be read in conjunction with the following three reports:

1. **(Victorian) Infrastructure Capability Assessment**[27]

   Has assessed infrastructure capability for nine different sectors including the road network. In particular, it identified the future challenges and opportunities associated with the road network.

2. **Victorian Connected and Automated Vehicle Trials**[28]

   The outcomes and learnings from these trials has the potential to directly affect the infrastructure requirements moving forward, as the technology and trends are still emerging. With this high level of uncertainty, it is imperative to keep up-to-date with the on-road trials and pilots as they will provide IV and the Victorian Government with real data and relevant practical information relating to the capability of connected and automated vehicles.

3. **Assessment of Key Road Operator Actions to Support Automated Vehicles**[29]

   This report, commissioned by Austroads, is an international and local review of the emerging requirements for AVs to operate on the road network. A key objective for the investigation was to provide guidance on an effective and consistent approach to the design, maintenance and operation of road networks which support the deployment and use of AVs. It is important that the findings from this report are considered by IV and the Victorian Government to aid in achieving a consistent, national approach moving forward.

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[27] Infrastructure Victoria, 2016, http://www.infrastructurevictoria.com.au/sites/default/files/files/160229%20-%20Executive%20Summary%20-%20Final.pdf

[28] Transurban, 2018, https://cAVs.transurban.com/content/dam/cAVs/documents/victorian-trials-report.pdf

[29] Austroads, 2017, https://www.onlinepublications.austroads.com.au/items/AP-R543-17

2.6.1 (Victorian) Infrastructure Capability Assessment

The (Victorian) Infrastructure Capability Assessment (VICA) was commissioned by IV to assist in developing objectives and identifying needs for Victoria's 30-year infrastructure strategy.

With regards to the road network, VICA:

- Identified Victoria's major road assets and provided the wider context in which road assets operate, including the interconnections between assets, identification of key stakeholders and current industry trends
- Provided a base of quantitative data as a foundation from which IV developed their strategy in relation to road asset value, historical and forecast investment, infrastructure performance and current/future capacity
- Identified the future challenges and opportunities associated with the road network, specifically related to how existing road infrastructure can be used to accommodate future demand.

There are three key highlights from VICA which are important in relation to this study: Freight Demand, Transport Integration Act (2010) - Integrated Transport Planning, and Challenges and Opportunities**.**

Freight Demand

One of the biggest factors in the degradation of the road asset is the volume and weight of freight vehicles. It is therefore important to first understand the actual demand for freight into the future, as this provides insight into the freight task that needs to be meet, regardless of what scenario eventuates. Please refer to **section 3.4** for discussion on the implications of travel and freight demands for Victoria.

Transport Integration Act (2010) - Integrated Transport Planning

It is important to recognise that any transport engineering considerations need to take place under the broader guise of state legislation and policy, in particular the Transport Integration Act (2010). The VICA highlights that for Victoria to provide accessible, mobile and efficient linkages throughout the transport network, it is important that there is an integrated approach to network planning in order to:

- Assess the real impact of transport projects on the users and local community
- Define government agency delivery responsibilities
- Maximise ancillary benefits beyond the transport requirement
- Ensure transport solutions are sustainable for today and the future
- Incorporate other planning schemes into the approach such as urban, land and travel demand management
- Provide flexibility for the future.

These points are particularly relevant to the types of considerations which need to be given to AVs and ZEVs, to ensure their role in delivering an integrated transport system for Victoria.

Challenges and Opportunities

In reviewing the impact of AVs and ZEVs in this report, we have given particular attention to the challenges and opportunities raised by VICA for Victoria's road network, and how these vehicles could form one part of a toolbox of measures to either meet the challenge or take up the opportunity. Table 1 and Table 2 outline the opportunities and challenges identified respectively.

Table 1: Identified Future Opportunities for Victoria's Road Network (Source: Infrastructure Victoria)

Opportunities
Improvement in road safety to get to 'zero deaths'
Addressing congestion at peak times and at bottlenecks
Managing the environmental impact of road use while catering for increasing demand
Planning of road maintenance and improvements
Ensuring efficient and safe use of shared roads (automobiles, trams, bicycles)
Increased access for heavy vehicles on road network (metro and regional)
Access to key gateway infrastructure (Port of Melbourne, Melbourne Airport)
Access to new growth areas
Provision for high productivity freight vehicles which require strengthened bridges and in some cases, pavement widening
Declining road conditions to meet user needs

Table 2: Identified Challenges for Victoria's Road Network (Source: Infrastructure Victoria)

Challenges
Coordinate road developments with city shaping initiatives
Manage demand to improve utilisation of existing assets (roads) during off peak periods
Control traffic movements by leveraging new technologies (such as co-ordinated traffic management systems and real-time information for users)
Ensure road planning complements other modes of transport (e.g. integration with intermodal hubs for both people and freight)
Facilitate more effective road sharing systems for alternative users (e.g. dedicated lanes for trams, cars, bicycles and access for pedestrians)
Road space allocation from parking to vehicle use

2.6.2 Victorian Connected and Automated Vehicle Trials

Transurban in conjunction with VicRoads, RACV and the State Government of Victoria has recently released the findings from phase one of the Victorian Connected and Automated Vehicle (CAV) trials initiative. Arup worked alongside Transurban to develop the program and assisted with project management of the trials.

The Victorian CAV Trial Phase 1 report highlights key findings and recommendations made for parts of the Victorian road network. Although this study is focused on a future state and transitional issues, it is important to reflect on what is required in the near-term to support the safe and efficient operation of partially automated vehicles (Level 1-3) onto Victorian roads.

In parallel with the vehicle trials, the Victorian CAV initiative undertook a customer engagement study to understand people's perceptions and views. Their market research found 84% of people were very keen to have partial automation features in their next vehicle. At the same time, 9% of people were hesitant to change and 7% were neutral. Among the group that identified as 'very hesitant', five key barriers to adoptions emerged:

- **Fear of new technology**: many do not trust a computer to be better than a human
- **Potential impact on driving skills and behaviours:** fear of irreversible social change, decrease or loss in driving skills
- **Overconfidence in one's ability:** feel there is no current need to use driver-assistance due to trust in own ability
- **The enjoyment of driving:** driving is more than just getting from 'A' to 'B'
- **Price/value**: want to buy most affordable car available, not interested in frills or special features.

These findings should be taken into consideration when planning for the roll out of AVs in Victoria. While these conclusions offer no ramifications to road engineering directly they may impact the roll out of AVs which in turn will affect road engineering.

2.6.3 Assessment of Key Road Operator Actions to Support Automated Vehicles

The Assessment of Key Road Operator Actions to Support Automated Vehicles report was commissioned by Austroads (released May 2017) to undertake an international and local review regarding the emerging requirements for AVs to operate on public and private road networks, including urban and rural areas.

A key objective for the investigation was to provide guidance in order to facilitate the effective and consistent approach to designing, maintaining and operating road networks which support the deployment and use of AVs on Australian and New Zealand roads. It is highlighted that certain members of the project have extensive experience with planning and operating Victoria's road network, including the managed motorway system.

The report captured key issues under the following three broad categories:

- Physical Infrastructure
- Digital Infrastructure
- Road Operations.

Key findings relative to this study are summarised below.

Physical Infrastructure

The report put forward that physical infrastructure requirements of Australian and New Zealand roads will vary for different AVs, and for different use cases, and that AVs will be designed to operate on road networks as they currently stand. It also identified that in order to best support a wide range of AVs, physical infrastructure design and maintenance elements may need to change.

Digital Infrastructure

The digital requirements, in a similar manner to physical infrastructure, will vary depending on the type of AV and the use case being supported. The key issues identified as the most pressing were data management, positioning services, mapping, cellular coverage and communication technologies.

Road Operations

The management and operation of the road network needs to evolve to support new use cases which come with the introduction of AVs, and to optimise the potential transport outcomes across a road network. In particular, a focus on new management approaches such as ‘Movement and Place’, updating standards and guidelines to ensure regional and global consistency, and addressing road works and temporary road layout changes.

Lastly, the report concluded: *‘There is an obvious challenge in providing practical guidance to transport agencies in a still evolving and changing environment.’*

3 Changes

3.1 Purpose

This section documents and discusses some of the potential key changes identified during the development of this study. The potential changes have a direct relation to transport engineering implications for Victoria. They are covered under the following headings:

- Vehicles and Users
- Road Operations
- Travel and Freight Demands.

The potential key changes have helped the project team explore the impacts of change and what possible infrastructure responses might be available. It is important to acknowledge the changes are evolving and new developments are occurring nearly daily, therefore certain changes anticipated at the time of writing this study may no longer apply tomorrow. Readers should use this section as a starting point in discussions and consideration.

To further illustrate change and how to prepare for it, a case study on an overseas equivalent to VicRoads - Highways England - has been included at the end of this section (refer to **3.5 Case Study: Preparing for Change – Highways England** and **Appendix A**).

3.2 Vehicles and Users

3.2.1 Vehicle Types

The physical characteristics of the vehicle fleet are essential to consider in the design and maintenance of road infrastructure. For example, vehicle weights have an impact on pavement design and maintenance, and the outside dimensions influence the geometric design of roads and lane widths.

An important trend occurring is the increased variability in the appearance and dimensions of passenger and freight vehicles. The term ‘right-sizing’ is now used to highlight the concept that people, generally under shared scenarios, will likely start to use a vehicle that is better sized to match the requirements of a particular trip or use case. For example, the UK Autodrive trials[30] are testing both connected ‘mainstream’ vehicles (Figure 8) for high speed and local roads, and new personalised automated pods (Figure 9). In the Milton Keynes (UK) test bed, one use case sees mainstream vehicles locate a parking building with available spaces, then a personalised pod is summoned to a selected drop-off/pick-up (DO/PU) point, and utilises the pod for the last part of their journey. The pod can travel through pedestrian areas or on streets closed to other vehicles.

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[30] UK Auto Drive, 2018, http://www.ukautodrive.com/

Figure 8: UK Autodrive Mainstream Connected Vehicle

Figure 9: UK Autodrive Personalised Pods[31]

Vehicle manufacturers are increasingly focussing on developing products to match various use cases. However, the full benefits of the ‘right-sizing’ concept would only be realised with the concurrent adoption of a shared ownership model. This is due to the fact that fleet based operators will have the economies of scale to invest in numerous vehicle types to match individual customer journey needs, whereas private owners are generally unlikely to own numerous vehicles for each type of journey.

Each different vehicle type may be supported by different energy sources. Figure 10 illustrates Toyota’s current view on probable energy sources for different vehicle types and requirements.

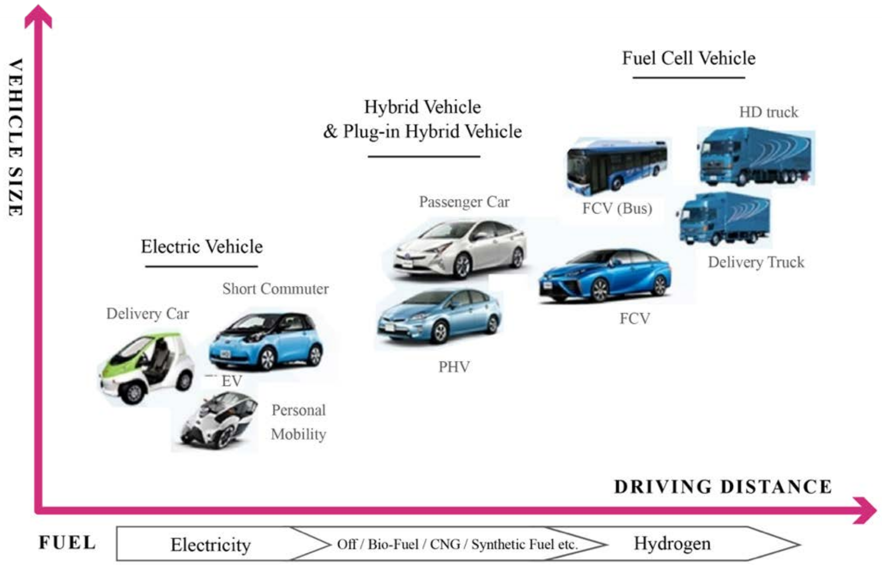

Figure 10: ZEV Energy Sources[32]

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[31] Production Engineering Solutions Media, 2018, https://www.pesmedia.com/uks-first-driverless-pods-arrive-milton-keynes/

[32] Toyota Innovation, 2018, http://www.toyota-global.com/innovation/

One possible outcome from the ‘right sizing’ trend is that AVs may not need to be able to operate in all environments. If people can utilise the right vehicle for the task, the need for the same vehicle to operate on multiple road types - unsealed roads, high speed rural highways, and inner city shared zones - becomes a minor issue. For example, Toyota’s personal mobility vehicle highlighted in Figure 10 may only operate on streets with a speed limit of less than 50 km/h.

With regards to infrastructure, the changing vehicle types and their use are a key consideration in understanding how the road asset may perform into the future. The design, operation and maintenance of road assets - such as pavement and structures - are strongly influenced by expected maximum axle weights and the configurations of heavy freight vehicles.

With the information available, it is unlikely AVs or ZEVs will in themselves require heavy vehicles to increase their weight allowance more than the levels currently permitted on Victorian roads. It is acknowledged that an AV future could impact certain factors which drive demand for freight.

3.2.2 Fleet Configuration and Lifecycle

In it anticipated that the pace of innovation in AVs could continue to accelerate for decades to come. The predicted end outcome of full automation post 2045 is clearer than the scenarios for 2030, when human-steered, partially automated and fully automated vehicles could all be in operation on Victoria’s roads. Figure 11 illustrates an important insight from research undertaken by the Bloomberg Aspen initiative[33] - highlighting that the transition phase could last at least 25 years. The report suggests that in the next few years, approximately a thousand AVs will give the world its first glimpse of an automated future, however in less than ten years, over a million are expected to be in use worldwide. Therefore, in considering a possible fully AV outcome there is a need to also understand the implications of the transition phase, where human drivers will interact with partially and fully automated vehicles.

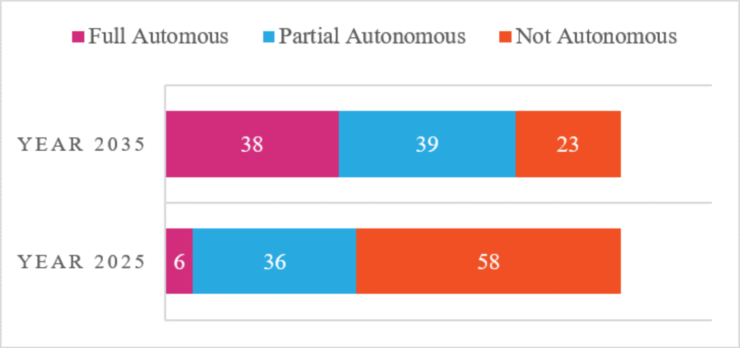

Figure 11: Who is Driving? (Vehicles in Service, Worldwide %)

To understand the possible future of the AV fleet, we must reflect on the current lifecycle of the Australian and Victorian light vehicle fleet. Figure 12 illustrates the breakdown of registration year for passenger vehicles. Although the current

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[33] Blomberg Philanthropies, 2018, https://www.bloomberg.org/program/government-innovation/bloomberg-aspen-initiative-cities-autonomous-vehicles/

average age of a car in Victoria is 9.7 years (Australia Average is 9.8 years), at least 40% are over 10 years old. It is important to consider this within potential infrastructure responses. For example, if a vehicle purchased in 2021 relies on a camera based system to detect line marking and position itself, even though a newer model in 2025 may rely solely on digital infrastructure (e.g. 3D mapping), it is quite reasonable to assume that good quality line marking for the older vehicle would still need to be maintained to the required standard until at least 2035, to allow the older vehicle to continue operating on the road network.

The same is true for vehicles requiring back up from a human driver. While there are vehicles currently sold in Australia which would be classed as low Levels 1 and 2 autonomous, there is no information as to when vehicle manufacturers would or should stop selling Level 1 and Level 2 vehicles. Based on the current fleet age it could be assumed that Level 1 and Level 2 vehicles would still be operating on the road for 15 years or more. With this in mind, if the last Level 1 or Level 2 vehicle was sold in 2025 - without any intervention or retro fitting - that vehicle could still be on Victorian roads in 2040 and beyond. This example highlights that although it is important to focus forward, if we are to enable AVs to operate on the network, road planners and designers will need to ensure the oldest technology or a human driver can still operate, or intervene in some way. This will include physical infrastructure such as line marking and signage.

It also raises the question of whether minimum capability requirements, age limits or vehicle scrappage schemes may need to be considered in the long-term, if a decision is made to no longer rely on a fundamental piece of physical infrastructure such as line marking. Currently, this infrastructure will need to be maintained at least until 2040 based on conservative estimates.

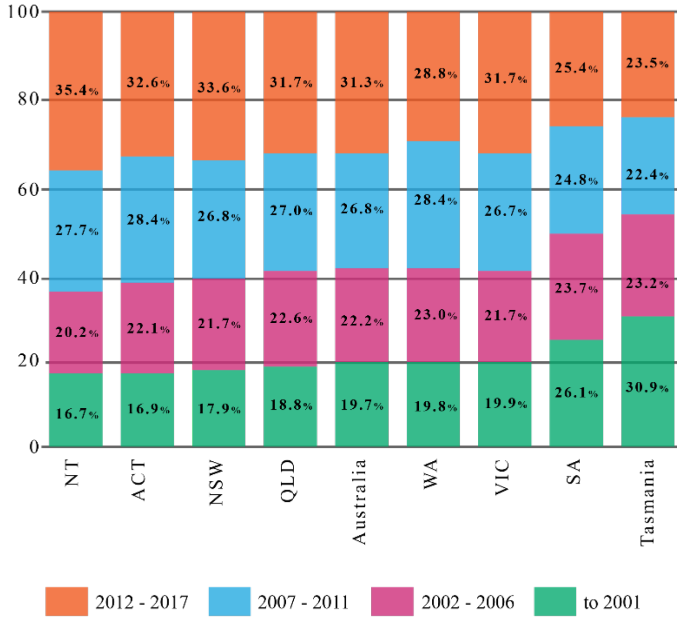

Figure 12: Break Down of Registration Year Passenger Cars[34]

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[34] Jericho, G, 2017, https://www.theguardian.com/australia-news/grogonomics/2017/aug/01/australians-still-love-buying-new-cars-even-when-wage-growth-is-low

3.2.3 Energy

At the time of this study, there is uncertainty as to when battery powered vehicles will be cheaper than conventional internal combustion engines (ICE). However, with battery costs falling by 73% in the past seven years[35], several studies are predicting that battery powered vehicles will reach price parity with ICEs within five years.

The global electric car fleet reached two million vehicles in 2016, after reaching one million vehicles in 2015[36]. It is estimated that global sales were 1.2 million in 2017 and will be 1.6 million in 2018 and 2 million in 2019[37]. By 2050 electric vehicles could grow to 1.7 billion (69% of the market), while conventional vehicles would make up just 12% [38]. It is also important to highlight that beyond light vehicles there is a significant change occurring globally for buses. For example, China's City of Shenzhen, in just five years, has converted its 16,000 vehicle bus fleet to full electric plug-in charging (Figure 13).

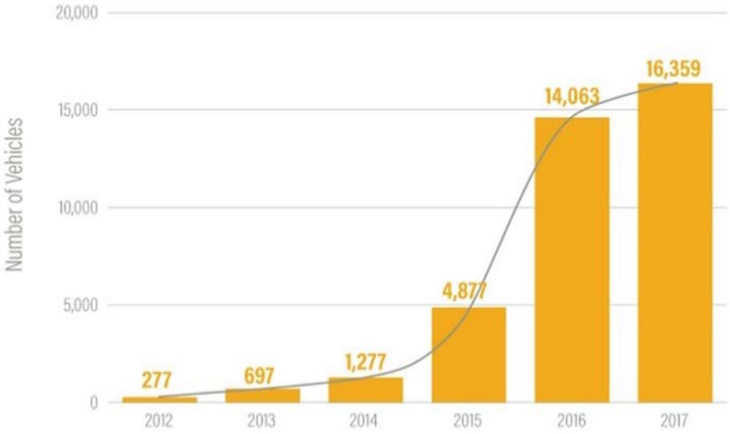

Figure 13: Electric Bus Adoption Shenzhen China[39]

Figure 14 displays modelling which demonstrates how the global car fleet could be powered from 2020 through to 2050[40]. It shows a significant shift to battery powered vehicles with fuel cell (hydrogen) vehicles playing a niche role within the fleet. It is important to note that they believe these results are conservative and several factors may accelerate this process.

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[35] U.S Department of Energy, 2017, https://www.energy.gov/sites/prod/files/2017/02/f34/67089%20EERE%20LIB%20cost%20vs%20price%20metrics%20r9.pdf

[36] International Energy Agency, 2017 https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

[37] Frost and Sullivan, 2018, https://ww2.frost.com/frost-perspectives/global-electric-vehicle-market-looks-fire-all-motors-2018/

[38] Imperial College London, 2017, https://www.imperial.ac.uk/news/177334/coal-demand-peak-2020-according-report/

[39] Modern Architectural Journal, 2018, https://www.modernarchitecturaljournal.com/how-a-chinese-city-turned-all-its-16000-buses-electric/

[40] Imperial College London, 2017, Carbon Tracker Initiative- Expect the Unexpected

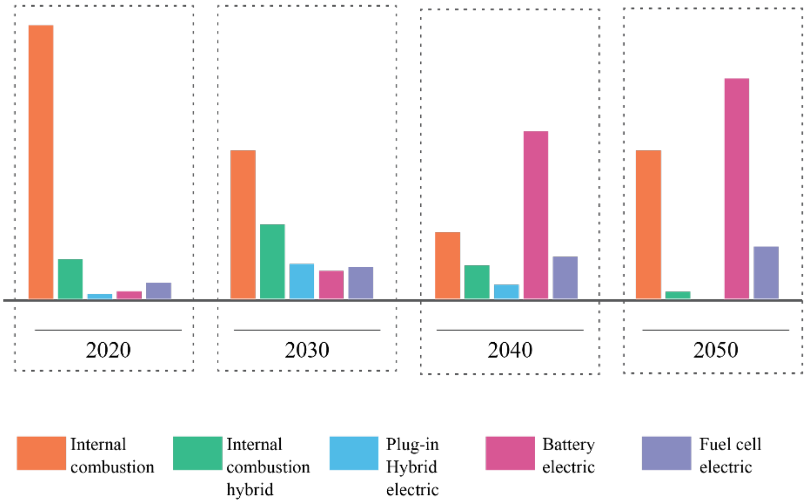

Figure 14: Energy Composition of the Fleet – Battery Only Technology Takes Hold in the Long-Term

Within the context of ZEVs, it is important to note the potential contribution to Victoria's climate change goals. The Victorian Government has committed to reducing Victoria's greenhouse gas emissions by 15-20% below 2005 levels by 2020, with net zero greenhouse emissions by 2050[41]. The Australian Climate Council (ACC) highlights that road transport contributes to 15% of Australia's total emissions. By 2035 on the current trajectory, Australia's emissions will be double 1990 levels[42]. The ACC highlights that Australia is among a small minority of countries without mandatory emissions standards in place, which creates the risk that Australia could see inefficient, relatively high polluting petrol and diesel vehicles being 'dumped' here.

Subject matter experts suggest the convergence of AV and ZEVs is not a matter of *if* but *when*[43]. There is significant potential for AVs to have a positive impact on energy demand, however, it will be important to consider the varying energy efficiency and travel impacts resulting from different levels of automation. It is possible the automation of vehicles in the early stages will result in tangible energy savings which outweigh the possible induced travel activity. In the long-term, it is conceivable the benefits of automation will bring substantially higher increases in travel activity, to a degree that could surpass the current total energy demands across the road network[44]. However, this will be concurrent with a significant decrease in greenhouse-gas emissions due to the uptake of alternative fuels and drivetrains[45]. The magnitude of change, in energy usage as a result of

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[41] Victoria State Government, 2017, https://www.climatechange.vic.gov.au/victorias-climate-change-framework

[42] Climate Council, 2017, https://www.climatecouncil.org.au/transport-fact-sheet

[43] Arup, 2018, https://www.arup.com/publications/research/section/autonomous-connected-electric-and-shared-vehicles

[44] Leiby. L, MacKenzie. D, Wadud. Z, 2016, https://www.sciencedirect.com/science/article/pii/S0965856415002694

[45] Fagnant. D.J, Kockelman. M.K, 2014 https://www.sciencedirect.com/science/article/pii/S0968090X13002581

increased use AVs, remains uncertain due to numerous variable factors that influence the operation of road network in the future.[46]

3.2.4 Connected Vehicles

> *"There is an assumption that all AVs will be connected. Technically they don't need to be for autonomy to function, however most of the well-publicised benefits are associated with this connectivity."*
>
> - Tim Gammons, UK Intelligent Mobility Lead, Arup 2018.

It is important to highlight the key relationship between connectivity and physical infrastructure. In a highly autonomous future, it is likely certain parts of the road network's physical infrastructure could become redundant such as speed signs and protective barriers. However, subject matter experts believe that good connectivity needs to be both between vehicles and with road infrastructure. Currently several global AV trials are underway, to better understand the benefits and application of 5G and Dedicated Short-Range Communications (DSRC) networks. Toyota announced in April 2018, that it will launch vehicles equipped with DSRC systems in 2021, with the goal for all Toyota vehicles in production deploying DSRC by mid-2020s[47].

A good example of a trial being developed is the proposed A2/M2 Connected Corridor[48] by the UK's Department of Transport, which is setting out to create a connected road link that will provide the following services to vehicles:

- Road works information
- Road works warning data
- In-vehicle signing
- Probe vehicle data
- Signal phasing information
- Freight services.

A key element for the A2/M2 trial is testing the capability and capacity of the 5.9 GHz band. In Australia, it is currently a key priority as the 5.9 GHz band (radio frequency) has been allocated for use by cooperative Intelligent Transport Systems (C -ITS) by the Australian Communications and Media Authority (ACMA).

In Victoria, it is unlikely that all road corridors will require connectivity, or have the same levels of connectivity. At present, Victoria targets significant investment in its managed motorway system towards particular corridors, and to apply the same amount of management to Victoria's entire road network would be

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[46] Babiak. H, Iglinkski. H, 2017, https://www.sciencedirect.com/science/article/pii/S1877705817326073

[47] New Atlas, 2018, https://newatlas.com/toyota-connected-vehicle-dsrc/54283/

[48] Department for Transport, 2016, http://www.codecs-project.eu/fileadmin/user_upload/pdfs/Workshop_C-ITS_Deployment_underway_II/Hanson_InterCor_UK.pdf

prohibitively expensive. Instead, different degrees of management are deployed based on needs and benefits.

Underpinning effective connectivity is clear and well-informed planning. It is accepted that AVs make decisions based on a best assessment of their surroundings, however when accounting for variables such as potholes, unclear signs and lines, and poor cellular coverage, the operation of AVs could be hindered greatly. Therefore, it is imperative that in the immediate-term, governments start planning and understanding their role related to the provision of digital infrastructure which will be required to enable the deployment of AVs on the road network to their full potential.

3.2.5 Road Safety and Community Acceptance

One of the key societal benefits often raised from the deployment of AV technology is the considerable reduction in people killed or seriously maimed on the road network. It is estimated that 94%[49] of all traffic collisions are caused by human error; these events can have a catastrophic impact not just on the individuals involved and their families, but also on the wider community.

It is expected that in the 30-year period since 1989, over 50,000 Australians will have been killed on the road network[50]. The ‘toll’ that is *accepted* by society for its mobility needs means the road network is the biggest killer of children under 15, and the second biggest killer of Australians aged between 15 to 24[51]. It is estimated that road trauma costs the Australian economy $27billion a year and $3-$4billion[52] per year for the Victorian economy. When considering the number of people killed in the last 30 years is similar to the population of Shepparton, there is a huge incentive to eliminate the errors leading to these events. According to the TAC, in 2015 more than half (54%) of all lives lost on Victorian roads occurred in regional Victoria, however only 25% of the Victorian population live outside of Melbourne. Against this context, it is understandable why there is so much interest from government in the early adoption of AV technology, as they strive to save people from death and injury.

It is important to acknowledge that AVs alone are unlikely to get us towards zero deaths and fatalities; achieving that goal will require a holistic approach to road safety which takes into account the user, vehicle design, and the operation of the road network. It is assumed that human drivers generally accept a high degree of error when using the road system, reflected by the high toll the community pays in people’s lives, in order to enable fast and easy mobility. The same driver, however, has minimal acceptance for human error when using a passenger plane or train - in fact, an almost zero tolerance for safety failings that result in death and injury. It is suggested that in order to achieve the same safety rate for AVs as

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[49] Stanford Law School: The Centre for Internet and Society, 2013, http://cyberlaw.stanford.edu/blog/2013/12/human-error-cause-vehicle-crashes

[50] Doman. M, Lui. R, Palmer. A, Scott. N, Ting. I, http://www.abc.net.au/news/2018-01-25/every-road-death-in-australia-since-1989/9353794

[51] See note 45 as above

[52] Oriti. T, 2017, http://www.abc.net.au/news/2017-01-02/road-crashes-costing-australian-economy-billions/8143886

with planes or trains, the cost of the vehicle may significantly increase, or may only operate in an access restricted environment e.g. a freeway (no direct access).

In late 2016 the UK Autodrive program engaged with 2,850 members of the community. 33% of respondents expressed opposition to the idea of using a driverless vehicle (Figure 15), while in response to questions about what levels of control they would like to retain, 74% wanted to retain an option to drive manually.

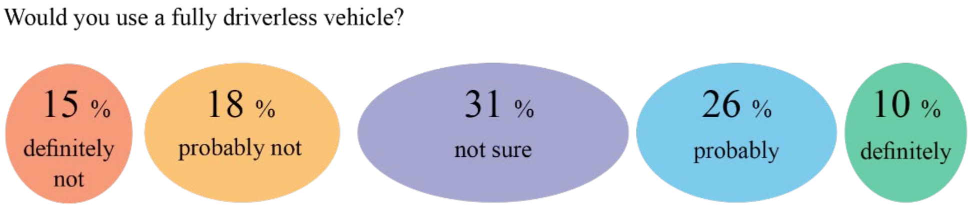

Figure 15: UK Autodrive Community Engagement[53]

Despite the general open mindedness towards driverless vehicles, the engagement found there are issues around trust which need to be addressed. When questioned about which types of user would benefit most from the widespread availability of AVs, 80% responded by suggesting people with disabilities, 42% suggested parents or older loved ones, 36% suggested 'people of my own age/lifestyle', and 18% suggested children (school run). The implication is 'everyone else except me', a response which suggests an element of uncertainty, or lack of trust, in the new technology.

This may suggest that the use of Level 4 and Level 5 AVs on our roads may need to be a soft launch, where they are restricted to operating in particular road environments before progressively being allowed into other environments, as the community better understands their benefits.

One common argument often raised is that if AVs could achieve a near zero crash rate, then systems in place to reduce the impact of crashes such as crumple zones and air bags would no longer be required. It is suggested this argument would become more certain when we better understand community acceptance and also how it might apply to different future vehicle types. For example, personalised pods may have lower safety standards compared to an AV operating within a freeway environment.

3.3 Road Operations

3.3.1 Density

AV technology, as well as improvements in connectivity, are likely to enable vehicles to travel with shorter headways. An AV will be able to sense and react much quicker than a human to external prompts. Traffic models which take this into account generally exhibit significantly higher effective capacities on a road

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[53] UK Autodrive, 2017, http://www.ukautodrive.com/wp-content/uploads/2017/08/Executive-Summary-FINAL.pdf

network. A mesoscopic study that considered a 75% reduction in headway due to automated capabilities, reported that the effective capacity of a network could be tripled if there is full market penetration of automated vehicles[54]. Another study considering varying levels of automated vehicle market penetration found increases in capacity ranging from 5% to 89%[55].

There are significant productivity drivers behind increased vehicle density for the movement of freight. The ability to achieve greater efficiencies by increasing the density of freight movements is highly appealing for operators. It is highlighted that vehicles closely following each other can achieve fuel economy benefits due to the reduction in aerodynamic drag (refer to **3.3.2 Heavy Vehicle Platooning** for more detail).

Need for Connectivity?

With regards to congested roads and vehicle platooning VicRoads highlights within its managed motorway framework:

> ‘*Although it has been demonstrated that it is theoretically possible for AVs without Vehicle-to-Vehicle (V2V) communications to operate in a way that… reduced headways, research with a broader focus highlights that this is unlikely and that cooperative V2V communications are likely to be required to achieve capacity increases*[56]’.

A recent paper was presented on the *‘Impact of Automated Vehicles on Capacity of the German Freeway Network’*[57] which contained a number of diagrams highlighting different headways based on the technology in use (Figure 16 and Figure 17). Of particular interest is the increase in headways for a mixed fleet situation with lack of communication between vehicles.

Figure 16 illustrates that un-connected AVs are likely to be more conservative in their following distances compared to human drivers. It puts forward that headways could be halved in a fully AV connected scenario.

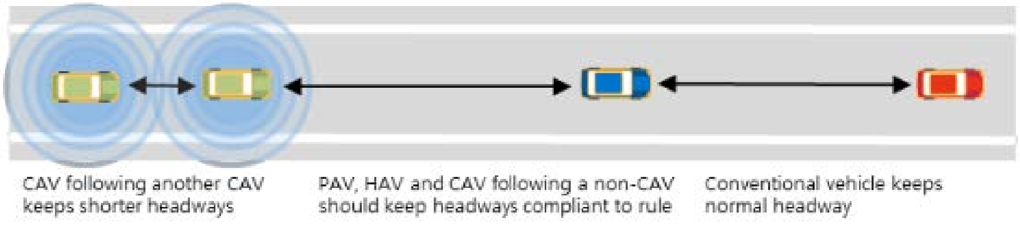

Figure 16: Following Distances - Differing Levels of Technology

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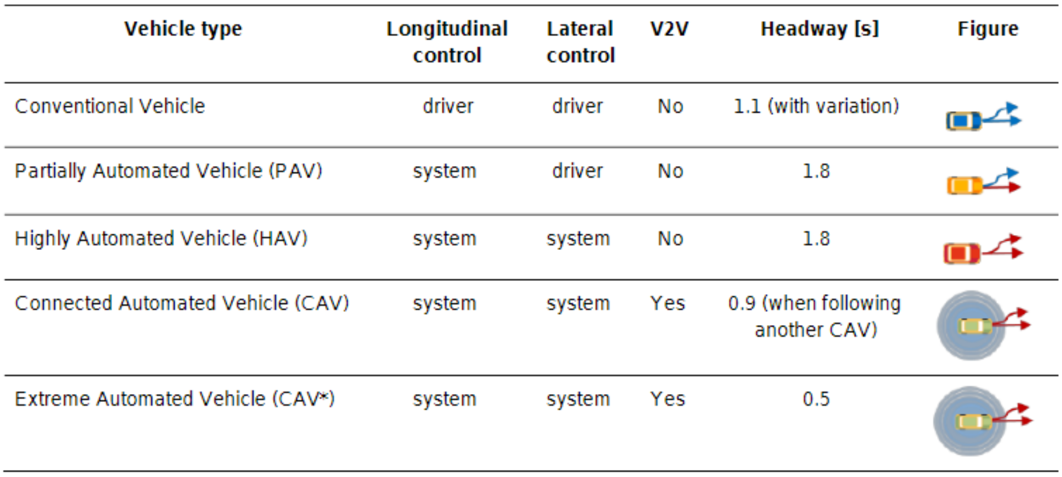
[54] 16th Swiss Transport Research Conference, 2016, http://www.strc.ch/2016/Ambuehl_EtAl.pdf
[55] The national academies of Sciences, Engineering, Medicines, 2014 https://trrjournalonline.trb.org/doi/abs/10.3141/2324-08
[56] VicRoads, 2017, https://www.vicroads.vic.gov.au/~/media/files/technical-documents-new/freeway-ramp-signals-handbook/managed-motorways-framework-march-2017.pdf
[57] Hartmann, Martin & Motamedidehkordi, Nassim & Krause, Sabine & Hoffmann, Silja & Vortisch, Peter & Busch, Fritz, 2017, https://www.researchgate.net/publication/320868890_Impact_of_Automated_Vehicles_on_Capacity_of_the_German_Freeway_Network



Vehicle type	Longitudinal control	Lateral control	V2V	Headway [s]	Figure
Conventional Vehicle	driver	driver	No	1.1 (with variation)	
Partially Automated Vehicle (PAV)	system	driver	No	1.8	
Highly Automated Vehicle (HAV)	system	system	No	1.8	
Connected Automated Vehicle (CAV)	system	system	Yes	0.9 (when following another CAV)	
Extreme Automated Vehicle (CAV*)	system	system	Yes	0.5	

Figure 17: Overview of Vehicle Types and Characteristics

‘Real World’ Situation – Monash Freeway

The US Highway Capacity Manual[58] suggests a capacity value for ‘basic motorway segments’ on a 100 km/h (60 mph) motorway as 2,300 passenger cars per hour per lane (pc/h/lane). However, the NSW State Road Authority highlights: *‘Historically, values in this order of magnitude have been used for lane capacity in design and strategic modelling. However, recent research and design practice has shown that this is inappropriate because hourly flows at this level are rarely achieved in practice and when they do occur over short periods, cannot be sustained for a full hour’.*[59]

Figure 18 for a four lane section of the Monash Freeway highlights the variability in vehicle capacity throughput on a day by day basis from 1,750 pc/h/lane to 2,150 pc/h/lane. At 2,150 pc/h/lane this equates to a headway of 1.67 seconds[60], which is already lower than what was put forward in the research for the German Road Network for Highly Automated Vehicles (HAV). This may suggest that there could actually be some drops in capacity/efficiency of the road network especially in a scenario where the fleet is mixed and relatively ‘unconnected’, such as IV’s Slow Lane Scenario.

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[58] Transportation Research Board, 2018, http://www.trb.org/Main/Blurbs/175169.aspx

[59] NSW Government, Transport Roads and Maritime Services, 2017 http://www.rms.nsw.gov.au/business-industry/partners-suppliers/documents/motorway-design/motorway-design-guide-capacity-flow-analysis.pdf

[60] VicRoads, 2017, https://www.vicroads.vic.gov.au/~/media/files/technical-documents-new/miscellaneous-guidelines/motorway-design-volume-guide-10-accessible.pdf

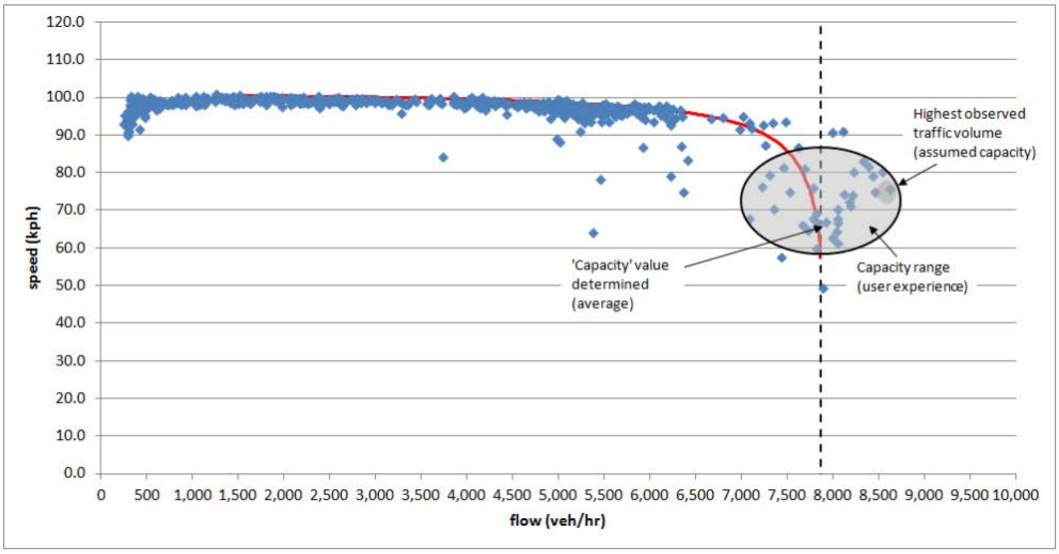

Figure 18: 'Highest Observed Traffic Volume' Versus 'Capacity Value Determined' (Source:[57])

3.3.2 Heavy Vehicle Platooning

The concept of 'platooning' is already quite common in transport engineering. For example, when designing and operating traffic signals, they are often linked to facilitate vehicle platoons. Platoons significantly improve the efficiency of the road by maximising the number of vehicles which pass through green light phases. In the future, it is proposed that platoons can be created through vehicles communicating with one another (V2V) to effectively operate as a single unit.

It is suggested that heavy vehicle platooning is set to be one of the first applications of AVs to reach commercial use[61] and there is a lot of interest in the benefits and impacts of trucks travelling in close formation. The European Automobile Manufacturers Association suggests the benefits are:

- Lower fuel consumption, as the trucks drive closer together at a constant speed, with less braking and accelerating
- Potential to reduce CO2 emissions by up to 10%
- Significantly improve road safety, with connected driving, as braking is automatic with virtually zero reaction time compared to human breaking
- Optimises transport by using roads more effectively, reducing traffic jams
- Potential to make the logistics process more efficient and optimise the labour market.

The Austroads guide for Road Design for Heavy Vehicles[62] highlights the significance of heavy vehicles on the life span of road pavement and structures.

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[61] Grant. L, 2018, http://www.ttnews.com/articles/can-bridges-handle-weight-platooning-trucks-engineering-firm-wants-know

[62] Austroads, 2015, http://www.austroads.com.au/news-events/item/242-road-design-for-heavy-vehicles

The concept of heavy vehicles platooning in the near future, presents a serious concern for the management of Victoria's road assets.[63]

The concern is that trucks will need to follow each other at a relatively close distance to maintain the platoon, resulting in a greater amount of weight being concentrated on smaller than usual portions of the road. Of particular concern for Victoria is the traffic loading on long span bridges – such as the West Gate and Bolte Bridges. Design requirements and assumptions for these types of structures would not have accounted for automated heavy vehicle platooning which may potentially invalidate the original design and current maintenance. It was recently reported that more than two-thirds of bridges managed by VicRoads are currently rated as being in 'poor condition', while nearly half have not been inspected within the road authority's own recommended timeframe[64]. In the same article a Monash University Civil Engineering expert Colin Caprani stated:

'In spite of the mitigating factors on these numbers, there is clearly a case that more resources are required to properly manage Victoria's ageing bridge stock," and he noted that bridges in Victoria will likely face greater stresses in the future, such as heavy convoys of self-driving trucks.'

Will it Impact the Road Network?

It is important to acknowledge there is a lot of uncertainty in this area, with many differing opinions on the potential impacts of platooning. A recent workshop with bridge engineers, conducted as part of this study, saw some argue that platooning would not have a significant bearing on structures - as heavy vehicle platooning is already experienced to some degree during high levels of congestion in Melbourne. Figure 19 demonstrates a common occurrence of trucks following each other closely on Melbourne's West Gate Bridge. In contrast, other bridge engineers put forward calculations that would need to change in order to accommodate platooning within structure design and maintenance. If platooning resulted in more trucks overall using a road corridor, then it follows that the maintenance regime could need to be reviewed also.

Continued research and testing will be required to fully understand the impact of heavy vehicle platooning on Australia's roads, this is expected to be coordinated through bodies such as Austroads potentially working in collaboration with international organisations and vehicle manufacturers.

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[63] Grant. L, 2018, http://www.ttnews.com/articles/can-bridges-handle-weight-platooning-trucks-engineering-firm-wants-know

[64] The Age, 2018, https://www.theage.com.au/national/victoria/state-of-disrepair-figures-reveal-victoria-s-creaking-bridges-20180303-p4z2ok.html

Figure 19: West Gate Bridge (Source: The Age[65])

Technology Solution?

If we assumed freight platooning could be a potential issue for road infrastructure, it is possible that it could be addressed through a technology solution. For example:

- AV trucks could result in better control of axle loads and less risk of overloading and heavy braking
- Through a Vehicle-to-Infrastructure (V2I) solution, vehicles could be instructed to uncouple from the platoon, increase headway or travel in a different lane
- Where an issue on the network is detected, vehicles could be instructed to detour or change driving behaviour
- A major component of highway loading is the dynamic load allowance. AVs are expected to manage this better.

Will it Be Widely Used in the Long-Term?

Current and proposed platooning trials are aiming to solve operational issues with platooning such as: how to join and leave a platoon, which lane the platoon should travel in, how other road users interact with the platoon, who should lead the platoon and how cost savings are shared between different companies within a platoon.

It is questioned whether the current case for heavy vehicle platooning is still the same under fully automated zero emissions future. For example, if a heavy vehicle had a relatively cheap power source, zero emissions, no human driver on-board and could communicate with other vehicles to ensure optimal and safe road operations – what benefits remain for a vehicle operator to invest in heavy vehicle platooning?

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[65] Carey. A, 2016, https://www.theage.com.au/national/victoria/biggest-trucks-banned-from-ageing-west-gate-bridge-20161020-gs6vi4.html

In addition, communities are likely to remain sensitive to heavy freight vehicles on local roads. Even though they may be ZEVs platoons of trucks are unlikely to get wide support to operate outside major freeways and highways.

To date the discussion of heavy vehicle platooning has mostly been based on coordinated platoons of connected vehicles. However, as discussed above, platooning is already experienced on some parts of Victoria's network, this 'uncoordinated' platooning is not expected to change. Rather as AV technology develops, platoons will find it safer to travel with closer headways, which has been identified as the biggest impact to road infrastructure. For the purposes of this study the term platooning implies both coordinated and uncoordinated platoons, essentially trucks following each other with very small headways usually on high speed roads (assumes no congestion).

As discussed, under **section 3.2.1 Vehicle Types** , there is a trend towards 'right sizing'. The logistics industry is changing considerably, and it is possible new types of vehicles will be developed. For example, today's B-double may no longer be required; instead, vehicles could be designed based on the cargo unit requirements. Figure 20 illustrates automated container trucks which are a common sight in several port and freight hubs globally; it is not unreasonable to consider these vehicles operating on public roads in the future.

Figure 20: Automated Freight Trucks[66]

In addition, from a societal and environmental perspective, there is a consideration of whether on-road platoons compete with heavy rail lines, and if so, what are the impacts on the community and environment?

While there is uncertainty as to the long-term case for heavy vehicle platooning, it is acknowledged that under a Slow Lane scenario/transitional period, heavy vehicle platoons could achieve noticeable benefits. A potential for the technology would be along connected corridors with high volumes of trucks and no rail connection, such as between Webb Dock and the intermodal freight terminal in Melbourne's West.

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[66] Kilcarr. S, 2014, http://www.fleetowner.com/blog/aiming-self-driving-freight

3.3.3 Lane Positioning

AV technology makes it possible to precisely position the vehicle on the carriageway and within its lane. Currently, laser scanners in vehicles offer a range accuracy between 0.02 metres and 0.5 metres[67]. As shown in Figure 21 there are several technologies being developed and explored to improve the positioning of vehicles. The positioning accuracy is likely to significantly improve as new vehicles are released. TOF refers to Time-Of-Flight or 3D cameras which are used for pedestrian recognition or pre-crash detection. As opposed to laser scanners, TOF cameras capture their surrounds with one single light pulse.

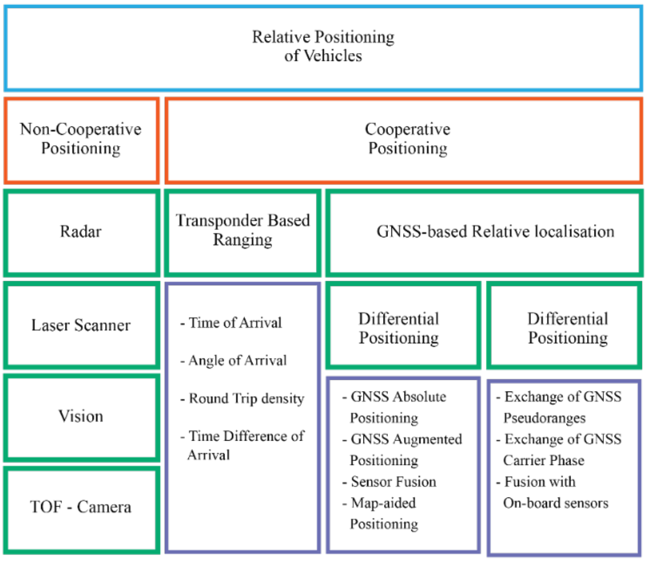

Figure 21: Vehicle Positioning Technologies (Source: [67])

Where positioning accuracy improves significantly, to within millimetre accuracy, and lane positioning algorithms become uniform, there is the potential that all vehicles will track along the same precise section of road. This will present both opportunities and challenges, for road design and maintenance, particularly as load repetition on specific sections of pavement will increase but will decrease for other areas.

The Austroads Guide to Pavement Technology Part 2 Pavement Structural Design informs the design of flexible and rigid pavements in Australia[68]. The design process only accounts for heavy vehicles. The volume of forecast heavy vehicles per day is extrapolated over the design life to determine the total fatigue loading, the inherent uncertainty in such forecasts contributing to variability in actual performance of the design. The current assumption is that all heavy vehicles traverse along the same exact location. Therefore, the current design approach is considered appropriate for an automated vehicle future. It should be noted that the current non-uniform routing does provide an added layer of conservatism which would be removed. However, the main factor of interest for design remains the proportion of heavy vehicles, not the lane positioning.

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[67] Jimenez. F, 2017, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5335929/

[68] Austroads, 2017, Guide to Pavement Technology Part 2, Pavement Structural Design

Where confidence is provided on the wheel path location (through AVs), road agencies should consider how to leverage this information to extend the life of pavement assets by adopting appropriate asset management models. For example, line marking can be moved by +/- 0.3 metres to change the location of loading, such that any distress the pavement is subjected to can be evenly distributed. In reality this means more of the pavement built could be used (shoulder to shoulder). This approach could be further enabled by the reduced clear zone or buffer requirements between vehicles, allowing the line marking to be moved across the pavement.

3.3.4 Noise Pollution

ZEVs are known to contribute significantly less noise pollution than ICEs, due to the differences in how propulsion is generated inside the engine and the fewer moving parts present[69].

These vehicles are considered too quiet for hearing-impaired pedestrians. In response to this, the European Union is mandating that ZEVs be fitted with acoustic alerting systems; a contentious subject as it diminishes the benefits realised with quieter transport activity[70].

However, it should be noted that powertrain noise is only one of the parameters contributing to the acoustic pollution generated by vehicles. The A-Weighted Sound Pressure Levels generated by tyres on pavement is higher than that generated by powertrains at all travel speeds[71]. It is expected the other IV studies commissioned alongside this one will consider the environmental and health benefits from reduced noise pollution.

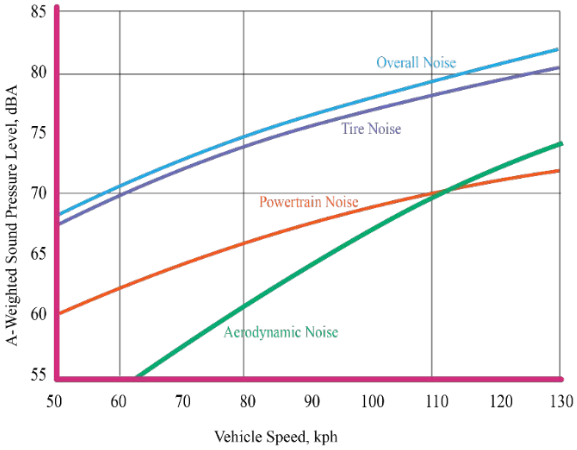

Figure 22: Contributions of Various Sub-Sources of Highway Noise (Source: University of Central Florida[72])

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[69] University of Waikato, 2015, https://www.waikato.ac.nz/__data/assets/pdf_file/0007/278080/Electric-Vehicle-Policy-New-Zealand-in-a-Comparative-Context.pdf

[70] Acoustical Society of America, 2017, https://www.sciencedaily.com/releases/2017/12/171205091534.htm

[71] See 64 as above

[72] Donovan. P.R, *Vehicle Exterior Noise: Handbook of Noise and Vibration Control*

3.3.5 Speed

The reduction of human influence over the control of a vehicle results in greater predictability in its movements, as factors such as reaction times and attention are no longer limiting factors in determining safe speeds[73]. This will potentially enable the ability for certain roads and freeways to operate at a higher speed limit, which would have potential positive impacts on the capacity of the road network as well as delivering benefits to vehicle occupants, and fleet operators (freight, public transport or shared AV fleet), through travel time savings, reduced fleet sizes and/or logistical efficiencies.

Within transport engineering, there are currently three ways speed is considered in road design and planning:

- **Posted speed:** the road speed limit that will be sign posted
- **Design speed:** the vehicle speed that is used as the input into the road design, for example VicRoads designs freeways 10 km/h above the posted speed
- **Operating speed:** a selected percentile (usually 95th) at which a driver is expected to travel on a given road under favourable weather conditions and under prevailing traffic conditions.

Due to the advanced driving capabilities of AVs, the three speed concepts could become blurred. For example, the 10 km/h uplift from the posted speed to the design speed provides conservatism that principally allows for existing non-compliance or human behaviour. AVs will likely operate at a maximum prescribed speed, the posted speed. This would present opportunities for road authorities.

For existing assets, either the posted speed could remain unchanged, increasing conservatism in the system, or posted speeds could be increased to design speeds given full compliance by vehicles on the network. For any new infrastructure, the design speed could be reduced to the desired posted speed which could potentially allow for tighter radius horizontal and vertical curves, reduced lane widths and tighter spacing of intersections. These design changes may allow for some reductions in the impacts of new construction projects, such as on properties, environmentally and culturally sensitive areas, as the roads could ‘fit’ into tighter corridors.

3.3.6 Signage and Wayfinding

The uptake of Google Maps or other route planning services for private trips and the use of ride share services such as Uber and Lyft have already led to an increasing percentage of navigation decisions being made by predetermined algorithms. AVs will likely navigate almost entirely through predetermined algorithms, although stakeholder engagement from the UK Autodrive program suggests a segment of the population would like to have the ability to control this

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[73] Leiby. P, MacKenzie. D, Wadud. Z, 2016, https://www.sciencedirect.com/science/article/pii/S0965856415002694

function[74]. As discussed in section **7 Road Operations and Management**, this has implications for the network capacity and management.

3.4 Travel and Freight Demands

Characteristics of AVs could lead to changes in private and freight related road travel demand arising from a combination of factors. References cited below have identified possible impacts. Demand changes in scale, timing and location, have direct flow on implications for the supply of road infrastructure to meet desired operating conditions. However, in isolation from changes associated with other AV characteristics, demand changes alone would not alter typical engineering planning and design approaches used for accommodating changes in conventional vehicle demand.

Commissioned work by IV for this study[75] provided insight into potential demand changes within the Victorian context, based on modelling of IV's AV Scenarios undertaken using the Melbourne Activity Based Model (MABM). These findings are generally consistent with impacts identified in literature. As this work has not addressed impacts for road freight, these issues are considered in a separate subsection below.

3.4.1 Ownership Versus Shared

Increased uptake of AV car sharing and ride sharing models, may reduce total vehicle ownership. A number of private car sharing endeavours already operate in the State of Victoria, such as GoGet and Flexicar along with multiple taxi alternative services at varying levels of penetration, such as Uber and Go Catch. Models have also shown that the replacement of trips made by conventional private vehicles to AVs can lead to significant reductions in vehicle ownership[76].

Demand Management - 'Mobility as a Service' (MaaS)

As highlighted within IV's Scenarios there is significant potential for Victorians to move away from an ownership model of vehicles to a services model for mobility. The concept of MaaS is of particular interest to road operators and governments globally, as it has significant potential to better manage how and when people use infrastructure. MaaS brings every kind of transport together into a single source, to enable people to make the best choice for their trip.

It seamlessly combines transport options from different providers, handling everything from travel planning to payments[77]. MaaS is likely to play a key role in encouraging the shared ownership model of AVs, by helping people get used to no longer owning a car, but having the ability to travel when they need to.

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[74] UKAutodrive, 2017, http://www.ukautodrive.com/wp-content/uploads/2017/08/Executive-Summary-FINAL.pdf

[75] KPMG, 2018 (Unpublished)

[76] Guhathakurta. S; Khalil. E, Zhang. W, 2018, https://www.researchgate.net/publication/323866541_The_Impact_of_Private_Autonomous_Vehicles_on_Vehicle_Ownership_and_Unoccupied_VMT

[77] Mobility as a Service, 2018, http://maasaustralia.com/

3.4.2 Vehicle Kilometres Travelled

With AVs, the total Vehicle Kilometres Travelled (VKT) are likely to increase significantly for private travel[78]. Furthermore, induced travel may also increase VKT as it becomes cost-effective and comfortable to travel further distances and make more discretionary trips. This has the potential to affect land use development, as the increased speeds, reduced costs and greater comfort while travelling could promote longer commutes[79]. Further, increased VKT of heavy vehicles, because of reduced costs for freight movements, will likely increase the maintenance requirements of pavements.

An increase in private vehicle modal share is also possible, as the option of travelling in an automated private vehicle becomes more attractive than using alternative public transport or walking/cycling options[80]. These impacts are explored further in the transport modelling, and population and land use work streams. The extent of the impact will vary for each of the seven IV ‘Future Scenarios’.

3.4.3 Freight Demand

Like private travel, freight vehicle movement is a derived demand. Freight demand relates and responds to changes in higher level economic production and distribution systems. The complexity of the freight logistics system makes forecasting of such impacts uncertain and highly case specific.

In general, AVs are not expected to fundamentally change the overall level of commodity movement, as road freight is only an element of the logistics chain that contributes to the overall cost of moving goods. However, the implications of AVs could vary significantly by commodity sector, depending on the specifics of the market being served and potential competition from other markets and freight modes.

The potential for a change in the cost of road freight being sufficient to cause significant changes in mode choice, could vary substantially, with contrasting examples being:

- Trade exposed industries, where marginal cost changes could lead to significant change or restructure of supply sources at a regional or global scale, with flow on effects to local economies and freight demand
- Where modal competition has potential to occur, such as between road and rail on medium to long haul inter-regional routes, which could be sensitive to cost changes. This could include containerised and bulk commodity movements
- Freight movement associated with distribution functions within regions, such as within Melbourne, where the market is already dominated by truck travel.

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[78] Guhanthakurta. S, Khalil. E.B, Zhang. W, 2018, https://www.sciencedirect.com/science/article/pii/S0968090X18303188
[79] Transportation Research Board 2018, http://www.trb.org/Energy/Blurbs/177565.aspx
[80] Kroger. L, Kuhnimof. T, Trommer. S, 2018, https://www.sciencedirect.com/science/article/pii/S0965856417301180

Here, access to the ultimate pick-up or delivery destination is vital, so roads will likely remain critical.

In addition to the above structural changes, a reduction in costs and/or relaxation of constraints may lead to 'induced' demand where marginal cost reductions increase consumer demand for goods.

Potential ways in which AVs could alter road freight costs include:

- Reduced direct costs due to removal of driver costs for AV trucks. The extent to which this occurs may vary considerably depending on the requirements for human involvement in delivery functions at trip ends
- Reduced costs due to higher vehicle utilisation – 24-hour operation is likely to be more feasible for AV truck operations, with the removal of driving hours and driver scheduling constraints being a significant factor. Improved information systems may also assist in improving scheduling and reducing adverse impacts of network unreliability, although such improvements are also likely to be pursued with conventional vehicles
- Better 'self-regulation' capabilities enabling more flexible network access regimes for HPFV's contributing to higher productivity
- Reduced (or increased) costs due to indirect factors such as changes in road congestion levels driven by private AV travel.

Freight ZEVs may also give rise to cost changes, such as through reduced energy costs or the ability to operate vehicles with lower amenity impacts contributing to alternative access regimes or operating hours in sensitive areas.

While not fully translatable to the Victorian context, estimates of how AVs may reduce the total cost of ownership of freight vehicles in the UK[81] suggest annualised cost reductions of approximately 15%. In the competitive freight industry, such cost reductions are likely to flow onto reducing freight costs for consignors.

The extent of the above changes, will also be affected by the regulatory and policy settings under which freight operations occur.

It is noted that while the focus here is on impacts of AVs, automated operations also have the possibility to change other aspects of freight operations. Port systems for container handling are already highly automated, and with more widespread use, automated operations could potentially lower the current cost penalties associated with double handling of containers where road to rail transfers occur, contributing to improved competitiveness of road/rail intermodal operations.

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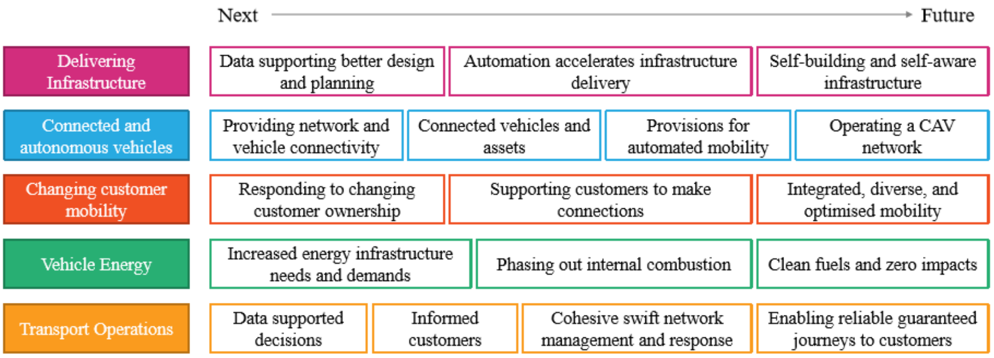
[81] Wadud, 2017, http://www.demand.ac.uk/wp-content/uploads/2017/09/Commission-Zia.pdf

3.5 Case Study: Preparing for Change – Highways England

In December 2017, Highways England released their: '*Connecting the Country - Planning for the long-term*'[82] document. This future transport strategy builds upon their long-term network development plan.

The document sets out what they believe the future could hold and how their Strategic Road Network (SRN) may evolve. It has identified trends which will shape their SRN and influence the operation of the road system over the next 30 years and beyond. With a number of similarities between the operation of road networks in the United Kingdom and Victoria, this document is of particular relevance. Figure 23 highlights the five key themes which were identified in the Highways England document, where they will focus next and where they believe the 'future' focus will need to be.



Next → Future

Delivering Infrastructure	Data supporting better design and planning	Automation accelerates infrastructure delivery	Self-building and self-aware infrastructure	
Connected and autonomous vehicles	Providing network and vehicle connectivity	Connected vehicles and assets	Provisions for automated mobility	Operating a CAV network
Changing customer mobility	Responding to changing customer ownership	Supporting customers to make connections	Integrated, diverse, and optimised mobility	
Vehicle Energy	Increased energy infrastructure needs and demands	Phasing out internal combustion	Clean fuels and zero impacts	
Transport Operations	Data supported decisions	Informed customers	Cohesive swift network management and response	Enabling reliable guaranteed journeys to customers

Figure 23: Five Key Themes, Current Focus, and Future Focus

Figure 24 highlights some of the key ideas and concepts associated with the theme of connected and automated vehicles. Note the focus *now* is on the design and testing of connected corridors which will enable new road designs for autonomy *next*. The review of existing capital projects to assess the implications of AVs is at the front of mind.

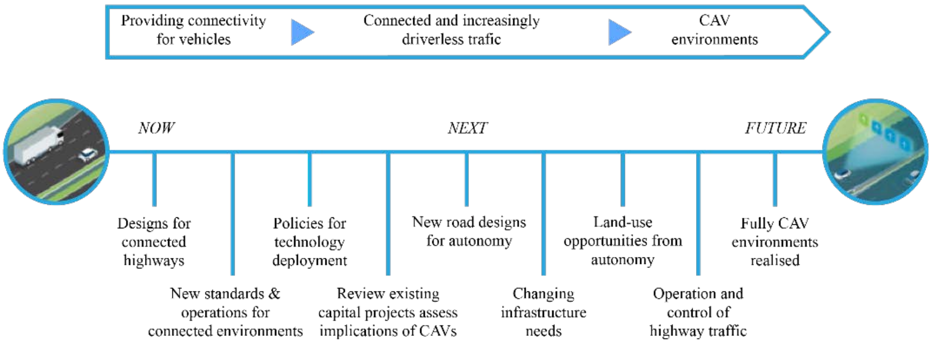


Figure 24: Connected and Automated Vehicles Now, Next and Future

Refer to **Appendix A** for further discussion.

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[82] Highways England, 2017, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/666876/Connecting_the_country_Planning_for_the_long_term.pdf

4 Planning for All Users

4.1 Purpose

The purpose of this section is to discuss and assess the risk and opportunities, and impacts of AVs and ZEVs for other road users such as pedestrians, cyclists and motorcyclists.

In identifying risks and opportunities this section has also considered how potentially changing infrastructure and operations to enable and encourage AVs and ZEVs may impact on other road users.

The section outlines:

- Key concepts and approaches to network planning, street form, and human behaviour
- Identified risks/opportunities, impacts and responses
- Response options further explored
- Conclusion and recommendations.

4.2 Context

Streets and roads across Melbourne and Victoria have many different functions, forms and uses. They move people, vehicles and goods, and they are public places, typically connected to adjacent buildings, which provide access for people within communities to connect.

Infrastructure requirements respond to the environment in which the road or street exists. For instance, infrastructure and operational requirements of a regional arterial differ greatly when compared to a local street in suburban or inner-city Melbourne.

4.2.1 SmartRoads/Movement and Place

The key attributes, which shape road or street infrastructure and operational requirements, can be categorised into two main areas:

- **Movement:** roads and streets as a movement conduit for people and goods to get from point A to point B, including private vehicles, on-road public transport (bus and tram), trucks, cyclists, motorcycles and pedestrians
- **Place:** streets as destinations in their own right, where activities occur on or adjacent to the street such as shopping, working, eating, talking, waiting and resting.

Figure 25 below from VicRoads illustrates the high-level concept of framework.

Movement objective:
Decrease travel time

Place objective:
Increase (people) dwell time

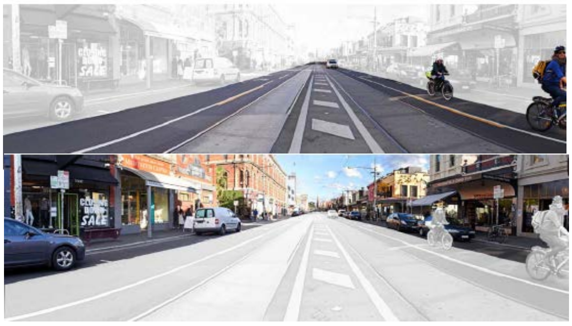

Figure 25: Movement and Place Concept (Source: VicRoads)

In Victoria, there is recognition of the importance of considering ‘Movement and Place’ functionality in delivering a consistent approach to network planning. It is understood TfV is currently developing a framework to enable Movement and Place (M&P) classifications for every road and street in Victoria, which builds upon the Network Operations Planning framework ‘SmartRoads’, previously developed by VicRoads[83]. It is thought that the M&P classifications will ultimately inform a street typography to facilitate and enable the desired functionality. Figure 26 below is an example from a similar framework in New Zealand which highlights outcomes and performance measures for a particular street type ‘mixed arterial’.

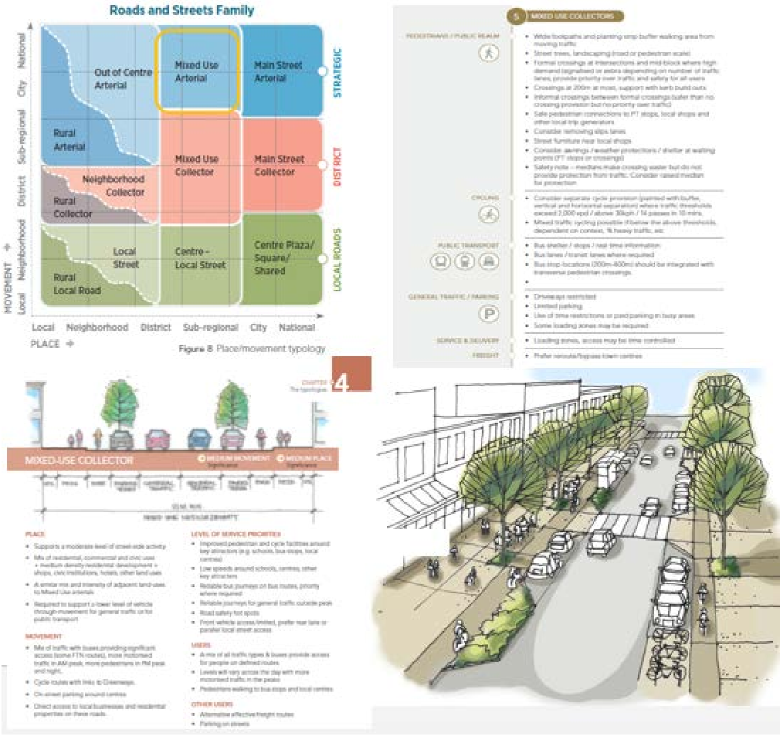

Figure 26: Auckland Transport - Street Typology Example[84]

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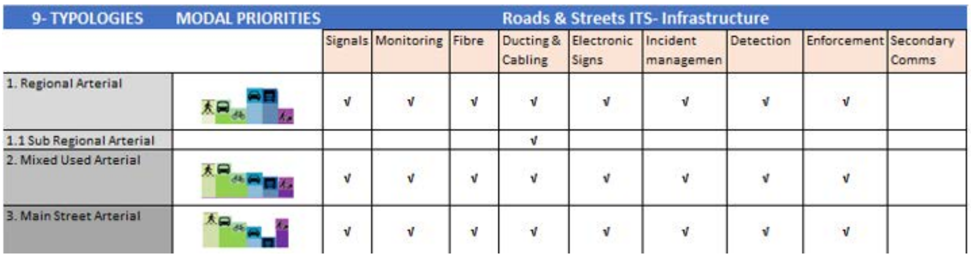
[83] VicRoads, 2016, https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/smartroads

[84] Auckland Transport, 2018, https://at.govt.nz/about-us/manuals-guidelines/roads-and-streets-framework-and-the-transport-design-manual/

The broad principles of M&P are explored in the Austroads 'Guide to Traffic Management Part 4: Network Management'. It recognises the M&P framework as best practice, as it reflects a more integrated approach to the operation and planning of transport systems. Importantly, these frameworks can be developed in a way that considers future mobility and technology needs, and helps target investment. Using the example above, this can then be used for future proofing ITS infrastructure (Figure 27).



9- TYPOLOGIES	MODAL PRIORITIES	Roads & Streets ITS- Infrastructure								
		Signals	Monitoring	Fibre	Ducting & Cabling	Electronic Signs	Incident managemen	Detection	Enforcement	Secondary Comms
1. Regional Arterial		√	√	√	√	√	√	√	√	
1.1 Sub Regional Arterial					√					
2. Mixed Used Arterial		√	√	√	√	√	√	√	√	
3. Main Street Arterial		√	√	√	√	√	√	√	√	

Figure 27: Auckland Transport Future Proofing Street Types

Auckland Transport also has a Toolkit (Figure 28) used to address the challenges of M&P and future proofing. A similar concept should be considered when planning for all users and associated infrastructure requirements and interventions.

Figure 28: Auckland Transport Toolkit to Address Challenges

4.2.2 The Human Element

The road design standards which govern current road layouts are based on a number of operating parameters relating to both the vehicles which use them, as well as the physical ability of the road users. Human abilities which influence infrastructure responses and road safety measures include:

- **Human driver reaction time**: used to determine stopping distances when driving and visibility requirements
- **Human walking speed:** used to determine minimum signal green times for pedestrian crossings
- **Biological response to impact:** pedestrians have been shown to have a 90% chance of survival when struck by a car travelling at 30 km/h or below, but

less than 50% chance of surviving an impact at 45 km/h. Pedestrians have almost no chance of surviving an impact at 80 km/h[85].

- **Impairments in human ability** to see and hear, requiring responses such as the use of tactile pavers.

The human element is fundamental to Victoria's Safe Systems approach to road safety. The Safe System approach is built on the premise that people make mistakes which can lead to crashes, and that there is a limit to the human body's tolerance to crash forces. Accordingly, the road transport system needs to be designed and managed to cater for human failure.

By applying the Safe System philosophy, the long-term vision is to eliminate fatal and serious injuries arising from crashes. The achievement of a Safe System is a shared responsibility and it requires the following four interconnected cornerstones of safe travel to be working effectively together: safer people, safer vehicles, safer roads and safer speeds.

Road safety depends on the integrated and complex relationship between various components: the driver's psychology, traffic conditions, the vehicle, the environment and the road infrastructure. Not all roads and streets are controlled through the use of traffic signals or segregated facilities. The majority of our streets rely on private vehicles, cyclists and pedestrians to follow the road rules and to make safe decisions when interacting.

A key element of successful and safe interaction is the ability for road users to make eye contact with each other at lower speeds. Hamilton-Baillie, a UK street design specialist, notes that the use of social and physical context as a means to adapt traffic behaviour is critically dependent on speed and eye contact86. In many streets and low speed environments, in particular shared zones, road user behaviour is controlled by interpersonal behaviour between street users, including non-verbal negotiation and social interaction. As such, eye contact results in a layer of social cues in the operation of our transport system that cannot be controlled or predicted through infrastructure alone.

Figure 29: Eye Contact Is Key (Source: www.psychologicalscience.org)

Recent research from France identified that if pedestrians at uncontrolled pedestrian crossings make direct eye contact with oncoming drivers, they are more likely to stop[87].

"People tend to be less inclined to kill you if they have looked you in the eye"- Richard Simmons, Commission for Architecture and the Built Environment (CABE).

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[85] World Health Organisation, 2009, http://apps.who.int/iris/bitstream/handle/10665/44122/9789241563840_eng.pdf;jsessionid=E2C58945BCE16E3B44AFC17EB05D9C9A?sequence=1 Accessed: 10 May 2018

[86] Hamilton-Baillie associates, 2018, http://hamilton-baillie.co.uk/villages-and-rural-traffic/

[87] Eyssartier. C, Gueguen. N, Meineri. S, 2016, https://www.sciencedirect.com/science/article/pii/S0022437515001097

4.2.3 Walkability

Walking is universally the most convenient and healthiest mode of transport for humans, it links people with surrounds without any dependency on vehicles. Maintaining pedestrian prioritisation in the face of AVs is essential to ensuring healthy lifestyle habits remain, and modal integration functions smoothly between the movement choices. Walkability is recognised by planners and policy makers as an essential component to liveable cities with a focus in recent years towards high quality infrastructure supporting active transport, lifting physical and mental health of residents through use.[88] AVs have the strong ability to connect people through enabling a greater breadth of mobility, but with this comes the heightened responsibility to focus on walkability, its associated infrastructure, its benefits and to not deprioritise walking to a second rate option.

Retaining walkability of our streets and roads is a key consideration in planning for the introduction of AVs. With the prospect of fences, footbridges, grade separation and EV charging stations being installed to prevent pedestrians disrupting AVs, street framework and design guides need to be developed which achieve a positive outcome for other road users, and continues to provide them with walkability, easy connections to places and the ability to lead active lifestyles.

While AVs present exciting opportunities for the future, they also bring a raft of questions and issues which need addressing. While they could provide the opportunity to create an exciting city life for people and multi-modal road networks, they also may create a situation where people do not want to walk as it is perceived to be difficult, not attractive and unsafe.

We are now at a stage where it is possible to shape the future of Melbourne and Victoria, with regards to the introduction of AVs and ZEVs. This is an opportunity which requires thorough planning, processes, discussion, investigation and investment in high quality roads and streets for people.

4.3 Risk/Opportunity, Impact and Response

Through a workshop process, key issues were identified where AVs and ZEVs may impact other users, specific examples are highlighted below in **section 4.3.1.**

The issues were used to help understand what possible risks or opportunities could eventuate, the positive or negative impacts and suggested responses. This is detailed in **section 4.3.2 Roads and Streets Assessment**.

4.3.1 Key Issues Identified

Figure 30 is not an exhaustive list but rather has been created to highlight specific examples where planners and engineers may need to reconsider how they design and operate streets in the future.

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[88] Arup, 2018, https://www.arup.com/perspectives/themes/transport/what-does-the-autonomous-vehicle-revolution-mean-for-our-health-and-wellbeing

Will a pedestrian and AV both think they have priority?

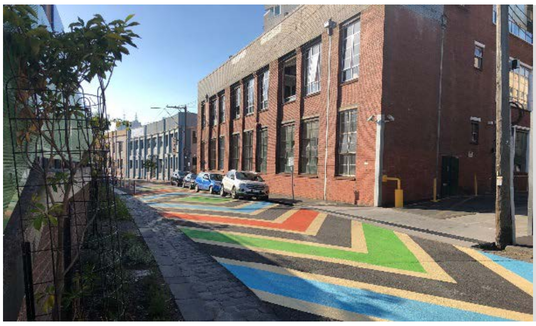
Source: Arup

Will an AV know pedestrians may walk out of the tram and onto the easy access tram stop?

Source: Arup

How will charging infrastructure be incorporated into the street environment?

Source: Arup

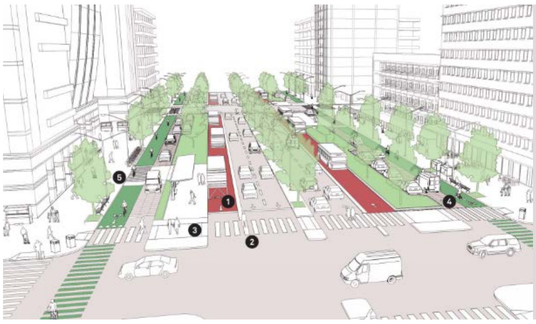


Blurred priority. Who will think they have priority, the pedestrian or the AV?

Source: Arup

Will AVs make it more difficult to cross the street?

Source: Arup



Will AVs provide the opportunity to improve accessibility and multi-modal streets?

Source: Global Street Design Guide, NACTO.

Figure 30: Instances Where AVs and ZEVs May Create Issues for Other Road Users

4.3.2 Roads and Streets Assessment

Roads and streets have evolved naturally in response to human needs, and they will continue to do so when AVs and ZEVs come to fruition. AVs and ZEVs are likely to provide various issues and opportunities for other transport modes such as pedestrians, cyclists and motorcycles. Table 3 below summarises the outcomes of the assessment workshop that looked at:

- What are the potential risk or opportunities?
- When could the risk or opportunity become a reality (trigger points)?
- How and where will the risk or opportunity impact on the network?
- Possible responses / options to consider

This is not an exhaustive assessment but rather a starting point for further discussion and planning.

To understand how and where the risk or opportunity will impact the assessment categorised the road network into four broad groups:

- **Multi-lane arterials:** this includes roads equal to or larger than dual lane carriageways. They generally have a moderate to large movement function with low to moderate place function. Examples within Melbourne include Nepean Highway, Punt Road and Bell Street.
- **High streets:** this includes main street arterials and collector roads, mixed use collector and streets through areas of high activity. They generally have a low to moderate movement function with moderate to high place function. Examples within Melbourne include Chapel Street, Flinders Lane and Malvern Road.
- **Local streets:** this includes neighbourhood collector, local and access streets, and streets through light industrial and residential areas. They generally have a low to moderate movement function with low to moderate place function. Examples within Melbourne include Drummond Street in Carlton, Salmon Street in Port Melbourne and typical residential streets.
- **Regional roads:** this includes two-lane single carriageway roads that connect regional centres and areas. The generally have a moderate to high movement function and low place function. Examples include the Geelong-Ballan Road, Tylden-Woodend Road and Three Chain Road from Carlsruhe.

Table 3: Planning for All Users - Assessment Risk, Impact and Response

The assessment table below summaries the:

- **Risk or Opportunity**: a potential issue/situation that may occur without intervention
- **Trigger Point**: when the potential issue/situation may become a reality
- **Impacts**: how and where will the risk or opportunity impact on the network
- **Response**: possible responses/options to consider

Workshop held: 07 May 2018

Impact Levels

🔴 Major negative impact
🟠 Negative impact
🟡 Minimal/negligible impact or not applicable
🟢 Positive impact
🟢 Major positive impact

Risk & Opportunities, and Trigger Points (TP)	**Impacts**				**Possible Responses**
	Multi-Lane Arterial	**High Street**	**Local Street**	**Regional Road**	
Effective footpath width reduced due to widespread ad-hoc installation of charging stations on side of road where on street parking is permitted. TP: moderate uptake of EVs.	🟠	🔴	🟠	🟡	Develop design standards to guide the design and placement of EV charging stations when located in the public road reserve. Charging stations should be designed to ensure pedestrians are not impacted and footway capacity is retained. Refer to **section 4.4.1 Re-Charge Parklets (Concept)**. Consideration should be made to future proofing EV Charging points to enable them to become wireless in an AV future.
Potential safety issues for pedestrians with silent electric cars, trucks and buses. TP: minor to moderate uptake of EVs.	🔴	🔴	🔴	🟡	Educating public on awareness prior to uptake. Work with national organisations like ANCAP and NTC to develop consistent vehicle requirements e.g. vehicle ‘noise’ requirement
Reduced pedestrian/cyclist to human driver eye contact with fully automated vehicles, leads to uncertainty of next manoeuvre. TP: minor uptake of Level 4 and above AVs.	🟠	🟠	🟠	🟠	Street design to clearly reflect ‘Movement and Place’ functionality. Lower vehicle speeds adopted in highly pedestrianized areas. Consider changes to road planning and design, at a national level, for pedestrian and cycling infrastructure e.g. signalisation of slip lanes over non-signalised. Further investigation of ‘light’ on AVs to indicate pedestrian has been identified. This would need to be developed at a national level working in partnership with car manufacturers.

Risk & Opportunities, and Trigger Points (TP)	**Impacts**				**Possible Responses**
	Multi-Lane Arterial	**High Street**	**Local Street**	**Regional Road**	
Automated vehicles follow road rules whereas human drivers in some instances do not (e.g. right turn giving way to pedestrians at local t-intersection). Leads to uncertainty of next manoeuvre. TP: minor uptake of Level 4 and above AVs.	🟠	🟠	🟠	🟠	Road infrastructure to clearly articulate pedestrian right of way (e.g. zebra crossings at local T-intersections, raised intersections).
Level 3 and above AV technology not able to see/predict pedestrians/cyclists due to either limitations from the technology or poor visibility/sight lines (trees and structures, etc.) TP: moderate uptake of Level 3 and above AVs.	🔴	🔴	🔴	🟠	Significant testing required by car manufactures and government to test if the AV is fit for use on public roads. At a national level review (Austroads), and if required update road design standards for sightlines. At a minimum, advise planners and engineers on how AVs work and what are some key considerations that should be made in design and planning. It is suggested that due to the rapid change Austroads Guides and associated VicRoads supplements may need to be online only, and be structured the same way as ‘Wikipedia’
Ethical dilemma of hitting pedestrians or another vehicle injuring motor occupants. TP: minor uptake of Level 4 and above AVs.	🔴	🔴	🔴	🔴	Consistent rules should be in place based on human values and should consider the vulnerability of pedestrians and safe system principles. This is an ongoing discussion globally with vehicle manufacturers, Victoria will need to work through the NTC to understand and gain agreement on the appropriate rules vehicles will use in Australia.
AVs likely to have better perception, and reaction/stopping times than current non-automated vehicles. TP: high uptake of Level 4 and above AVs, no human drivers.	🟢	🟢	🟢	🟡	Potential for pedestrian infrastructure and/or priority to be implemented in conditions currently considered unsuitable due to human driver capabilities, such as a zebra crossing on a multi-lane arterial road.
AVs fail to give way to pedestrians when alighting/boarding tram at non-DDA compliant tram stops and easy access tram stops. TP: significant uptake of Level 3 and above AVs.	🟡	🔴	🟡	🟡	Convert 100% tram stops to DDA compliant tram stops by 2022 as set out in the Disability Standards for Accessible Public Transport 2002. Testing of AVs at easy access tram stops. Noting this is a complicated treatment that may not be suitable for AVs.

Risk & Opportunities, and Trigger Points (TP)	**Impacts**				**Possible Responses**
	Multi-Lane Arterial	**High Street**	**Local Street**	**Regional Road**	
Pedestrians and cyclists make mistakes at locations with no formal crossings potentially leading to crashes with AVs. TP: significant uptake of Level 3 and above AVs.	🔴	🔴	🔴	🟠	Due to efficiency gains of AVs across the network, this may allow for speed limit reductions – Ideally, posted speed limits should be equal to or less than existing on roads other than freeways and major arterials (with no place conflicts). This will reduce the impact if a crash occurs and may give the vehicle additional time to react. AVs potentially provide the opportunity to provide low cost treatments for pedestrian and bicycle crossings where previously they were not feasible. 'Connected corridors' along key movement roads would possibly be able to detect and advise AVs of pedestrian/cyclist. Pedestrians and cyclists may use a smart phone app, as a fail-safe to inform AVs of their location.
AVs may be more 'confident' and travel at posted speeds in local streets, when a human driver may travel at a slower speed e.g. child on bike, child getting out of a parked car. TP: moderate uptake of Level 3 and above AVs.	🟡	🟡	🔴	🟡	Operating speed limit for AVs to be reviewed on local streets. Ideally speed limits should be less than 50 km/hr on local streets. Work with vehicle manufacturers to have rules around children present and other potential conflicts.
Potential for fences or guardrails to be installed at edge of kerb to prevent pedestrians disrupting AVs. TP: moderate uptake of Level 4 and above AVs.	🟠	🔴	🔴	🟡	Generally, a poor outcome for pedestrians and amenity. Street framework and design guides to be developed. In some circumstances AVs will have better driving capabilities, and may negate the need for pedestrian barriers.
All cyclists require GPS positioning systems so they are connected to vehicles. TP: significant uptake of connected vehicles.	🔴	🔴	🔴	🔴	Connected AVs need to detect all forms of cyclists with or without GPS systems. Any system that cyclists could wear or install – would need to be used only as a back-up.
AV trucks platooning in on local streets and activity centres impacting amenity e.g. Somerville Road, Yarraville. TP: significant uptake of connected trucks choosing to platoon.	🟠	🔴	🔴	🟡	Truck platooning to be banned in certain areas. AVs and ZEVs will make it possible for all heavy vehicles to be substantially detoured from sensitive areas.

Risk & Opportunities, and Trigger Points (TP)	**Impacts**				**Possible Responses**
	Multi-Lane Arterial	**High Street**	**Local Street**	**Regional Road**	
Majority private AV ownership model, increasing vehicle volumes impacting amenity. TP: significant uptake of Level 4 and 5 AVs.	🟡	🔴	🔴	🟡	Posted speed limit reviewed, greater physical or virtual traffic calming (LATM) solutions, this may include potential truncation or closures of streets to through traffic.
Pedestrians walking across road knowing AVs will yield. TP: moderate uptake of Level 4 and above AVs.	🟡	🟢	🟢	🟡	While we want to improve walkable streets and active lifestyles, we need to be careful not to disrupt AVs on streets with moderate to high movement functions such as multi-lane arterials. Unless pedestrians have a high level of service, there is a risk they will walk across the street due to frustration in waiting, causing traffic flow disruption. Signal timings need to be reviewed to reduce pedestrian waiting times and to provide more formalised crossing locations. The increased lane capacity with AVs should be sufficient to provide proportionally more time to pedestrians crossing the road.
Pedestrian or bicycle crash with an AV during transition phase. TP: minor uptake of Level 3 and above AVs which may not identify vulnerable road users.	🔴	🔴	🔴	🟠	Formal trialling and approval protocols should seek to prevent such occurrences; however, the following responses may be required if an incident does occur. AVs potentially banned from using the street until the crash has been reviewed (may become unfeasible on freeways and major movement corridors). If the AV was at fault, the ban could remain in place until the technology improves. The ban may only be applied to the car manufacturer. If other AV manufacturers have different technology, they may be exempt. Victoria to begin developing a process and responsibilities for investigating AV crashes. A segregated cycling network might be required to improve safety and efficiency along the principal bicycle network.
Sensing capability and situational awareness of AVs should enable advanced warning of approaching cyclists to be provided to passengers in a stationary vehicle. This could potentially reduce the risk of cyclists being doored by parked cars. TP: significant uptake of Level 3 and above AVs.	🟢	🟢	🟢	🟢	On a national level, work with vehicle manufacturers to utilise the vehicle's technology to detect and warn of approaching cyclist. Possible opportunity for future app developments. Testing AVs to ensure situational awareness of cyclists and warning passengers of approaching cyclist.

Risk & Opportunities, and Trigger Points (TP)	**Impacts**				**Possible Responses**
	Multi-Lane Arterial	**High Street**	**Local Street**	**Regional Road**	
Reduced cyclist conflict/crashes with left turning AVs and cyclists travelling through. TP: significant uptake of Level 4 and above AVs.	🟩	🟩	🟡	🟡	While this may prove a challenging driving task, there is a big opportunity to reduce crashes compared to human drivers. Testing and verification of AVs on Australian roads will need to demonstrate the AV understands when to yield to cyclists and when it is safe to undertake the left turn.
Greater sensing capability of AVs reduces road safety risk associated with filtered right turns and hook turns at signalised intersections in conflict with pedestrian, cyclists, trams and other through vehicles. TP: minor uptake of Level 4 and above AVs.	🟩	🟩	🟡	🟡	While this may prove challenging, there is an opportunity to reduce crashes relative to human drivers. Road authorities are generally not supportive of permitting uncontrolled non-priority movements at signalised intersections due to safety reasons. However, if the safety issues are mitigated through AV uptake, there is an opportunity to reinstate and/or increase filtered right turn phases and hook turns, and potentially improving traffic flow and tram priority outside of the CBD. AV vehicle testing to understand when it is safe to undertake these movements.
Camera and radar technology at intersections used to provide position of pedestrians/cyclists which is fed back through to connected AVs. TP: significant uptake of connected vehicles.	🟢	🟢	🟢	🟩	Practical given it does not require any GPS system on pedestrian and cyclists. Government to investigate the feasibility of this type of treatment, potentially with an intersection pilot prior to an uptake of CAVs.
AVs could be directed away from residential, urban areas and areas of high pedestrian activity. TP: moderate uptake of Level 4 and above AVs.	🟩	🟢	🟢	🟩	The road network could be categorised based on the M&P framework. Concept of Operations may need to be developed (refer to **section 7.2.1**).
Considerable change in road operations from AV driving patterns e.g. smaller headways and average network travel speeds leads to crashes for human driven motorcycles. TP: minor uptake of level 4 and above AVs.	🔴	🟠	🟡	🟠	Posted speed limits should be reviewed to ensure continued safe operation for motorcycles and non-AVs in locations where speeds or risk substantially increase as a result of AV uptake. Consider 'connected' motorcycles that talk to AVs, to provide more room for manoeuvring. Review motorcyclist training and licencing regime – 'Riding with AVs'.
Greater situational awareness and traffic management compliance of AVs should substantially improve road	🟢	🟢	🟢	🟢	Testing and certification of AVs will ensure that motorcycles are accounted for within the driving system.

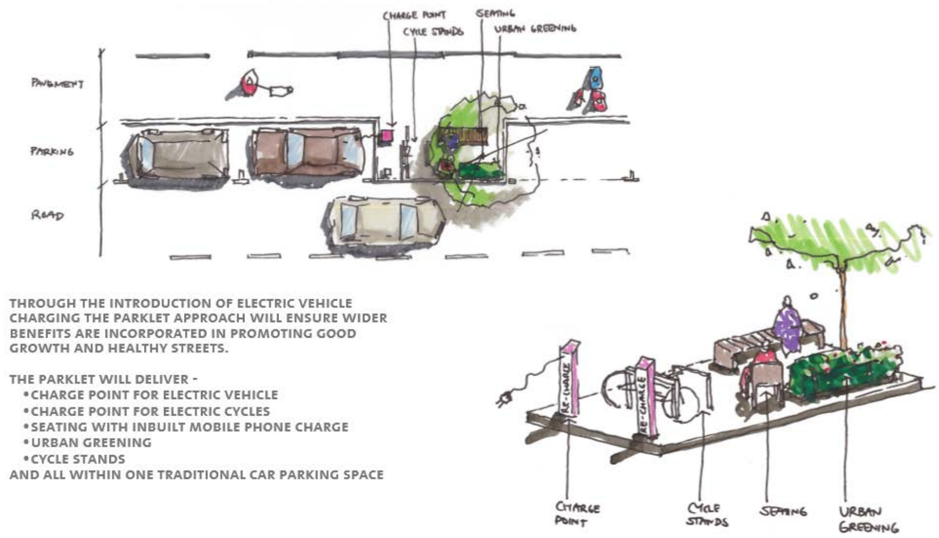
Risk & Opportunities, and Trigger Points (TP)	**Impacts**				**Possible Responses**
	Multi-Lane Arterial	**High Street**	**Local Street**	**Regional Road**	
safety for motorcyclists as a high speed vulnerable road user by reducing or eliminating common crash types involving motorcycles. TP: moderate uptake of Level 4 and above AVs.					Consider 'connected' motorcycles that talk to AVs, to provide more room for manoeuvring. AVs to record and share data on motorcyclists on the network with road authority. Especially, if there is a crash.
Removing traffic lights in a fully connected and automated world would mean pedestrians, cyclists and motorcyclists could create perceived issues with crossing the road/intersection. TP: Full uptake of Level 4 and above AVs.	🔴	🔴	🔴	🟡	All road users and amenity need to be considered at intersections. Traffic signals could be retained as a redundancy system and to provide pedestrians and cyclists comfort that they are able to cross. Signalised intersections to be upgraded with pedestrian and cyclist detection technology and fitted with DSRC to enable connected vehicles to receive advanced information on how to behave. It will be important to future new traffic signal installations to allow for easily upgrading with DSRC in the future. Street framework and design guides to be developed that which could consider different intersection treatments that give pedestrians priority but do not involve traffic signals.
Grade separation of key movement corridors to separate out conflicts between AVs, and pedestrians and cyclists significantly hinders walkability and attractiveness of cycling TP: moderate uptake of Level 3 and above AVs.	🔴	🟡	🟡	🟡	While grade separations can provide considerable efficiency and safety benefits – pedestrian bridges and underpasses quite often divide communities significantly affecting pedestrians and amenity. Where grade separation is deemed required, pedestrians and cyclists should be left at grade and AVs taken below.
In a primarily private rather than shared AV ownership model, increased congestion may lead to more people walking and cycling. TP: significant uptake of Level 4 and above AVs.	🟢	🟢	🟢	🟢	Studies to be undertaken on how modal shift to walking and cycling impacts congestion. State and Federal Government to invest in improved walking and cycling infrastructure.
With road space occupying up to 30% of public use space, there is an opportunity to adapt streets over time to reallocate space to other uses than movement. TP: opportunities to start adapting from today	🟡	🟡	🟡	🟡	Planners and engineers could consider how to make streets adaptable over time. Rather than one substantial change, incremental changes over time (refer to **section 4.4.3).**

4.4 Possible Response Options

The response options listed in Table 3 above have been explored further in this section.

4.4.1 Re-Charge Parklets (Concept)

As highlighted in the potential risks, there is an issue around charging infrastructure and its impact on footpaths. One possible idea put forward by Arup is the opportunity to convert parking spaces to ‘Re-Charge Parklets’ (Figure 31) to accommodate charging infrastructure and more space for pedestrian amenity and bicycle parking. Parklets may also need to be considered in the future where there is a high number AVs picking up and dropping off, and pedestrian movements along the footpath becomes an issue. Design of parking spaces is further explored in section **8.5 Delivery of Parking**.



THROUGH THE INTRODUCTION OF ELECTRIC VEHICLE CHARGING THE PARKLET APPROACH WILL ENSURE WIDER BENEFITS ARE INCORPORATED IN PROMOTING GOOD GROWTH AND HEALTHY STREETS.

THE PARKLET WILL DELIVER -
- CHARGE POINT FOR ELECTRIC VEHICLE
- CHARGE POINT FOR ELECTRIC CYCLES
- SEATING WITH INBUILT MOBILE PHONE CHARGE
- URBAN GREENING
- CYCLE STANDS

AND ALL WITHIN ONE TRADITIONAL CAR PARKING SPACE

Figure 31: Re-Charge Parklet (Source: © Arup)

Building on this concept, there are several proposals for kerb outstand tram stops in Melbourne similar to High Street, Northcote (Figure 32). There could be opportunities to future proof or to install electric car chargers at the same time of installation.

Figure 32: High St, Northcote - Tram Stop

4.4.2 FlexKerbs

A key element of designing and operating streets of the future will be the management and operation of the kerbside lane – a concept being developed by Arup is further explored in **section 7.4.2**.

4.4.3 Adaptable Streets

For discussion purposes, Arup has created a concept based on an inner Melbourne street, which represents what an adaptable street could look like over time – this is presented in **Appendix C**.

4.5 Conclusion, Findings and Recommendations

4.5.1 Conclusion

The purpose of this section was to discuss and assess the risk, opportunities, and impacts of AVs and ZEVs for other road users such as pedestrians, cyclists and motorcyclists. It also addressed how changing infrastructure and operations to enable and encourage AVs and ZEVs may impact on other road users.

There are inherent uncertainties with tailoring roads and road infrastructure for AVs while maintaining a safe and suitable level of non-AV compatibility. While there are significant benefits in the optimisation of roads to suit AVs, the human factor and the intrinsic variability in how road users interact with the environment around them, means that non-AV travel on a corridor attuned to AV travel has risks which need to be considered.

Road infrastructure is currently designed so human road-users are able to safely and accurately react. However, road highway standards will require more consistency nationally and globally in roadway design and operations to inform the AV sensing system. It is also possible that the onset of AVs could lead to a reduction in roadside infrastructure, such as signage, due to the fact that vehicles will have the ability to connect to infrastructure directly instead of relying on visual sensors.

There are additional risks present in optimising roads to better cater for AVs, as guidelines ensuring industry standard practices concerning AVs do not exist. AVs hold many promises for cities and road safety, but the potential benefits are not guaranteed. It is acknowledged that planning needs to proactively guide the technology towards the desired outcomes.

4.5.2 Key Findings and Recommendations

Plan and Encourage Active Travel in an AV Future

Although there are potentially significant road safety benefits for pedestrians and cyclists from an AV future, there is also a real risk that removing the human element (driver eye to pedestrian eye) could create confusion and stress. We already know that pedestrians and cyclists are sensitive to stresses from cars, discouraging them from active travel which has significant implications for health and wellbeing. As AVs become a mode of transport with noticeable mode share, they will need to be operated in a manner that aligns with the road priority based on time of day and place value. AVs provide the opportunity to direct 'traffic' away from streets with sensitivities to traffic, such as: high streets and residential areas. It is important that Victoria considers a Movement and Place framework that guides the appropriate movement function, and incorporates a street design manual which informs planners on how to take up the opportunities presented by AVs, preserving other attributes of desirable street functionality, while also future proofing for possible wide-scale AV use e.g. pick-up and drop-off zones.

Consistency and Predictability of Active Travel Infrastructure

Although wholesale changes to the physical road infrastructure are not expected to be required to enable AVs to operate, consistency of behaviour and infrastructure would assist. AVs are likely to make it considerably safer for pedestrians and cyclists, however inconsistencies in how they behave can create both road safety and operational issues, especially if AVs become very cautious. As AVs Level 3 and above become used, issues may arise. It is suggested, there may be a need for a targeted investment program to improve the AV interface with pedestrians/cyclists, helping to make their behaviour more predictable for AVs. This could include separated bicycle lanes on strategic cycling corridors and signalisation of crossings and slip lanes along key pedestrian routes. This would be a long-term program that starts in the short-term, to incrementally improve consistency of both user behaviour and infrastructure. However, investment in infrastructure should be done under the guidance of Austroads guidelines. Victoria should collaborate with Austroads, and partner jurisdictions to understand and update guidelines to include considerations of AVs in the design and implementation of pedestrian and cycling infrastructure.

Support AV Technology to Improve Safety for Vulnerable Road Users

Additional risks to pedestrians, cyclists and motorcyclists may be posed by a significant mix of AV operating Levels from 0 to 4, without appropriate regulation and management. This is a risk manufactures have already perceived, with some publicly stating they do not intend to release vehicles with partial automated capability (Level 3) due to the difficulty of safely managing the handoff process between vehicle and human control when required[89]. It is important that Victoria works collaboratively with other jurisdictions through the NTC to draft and implement national driving laws to allow automated driving systems to operate on the road network safely. This will ensure a nationally consistent law is in place so authorities can know who is in control of a motor vehicle at any point in time – see NTC's work on changing driving laws to support automated vehicles[90]. In addition to working with the NTC, Victoria will need to work with Austroads and partner jurisdictions to address potential safety issues for pedestrians and cyclists including:

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[89] Davies. A, 2017, https://www.wired.com/2017/01/human-problem-blocking-path-self-driving-cars/

[90] National Transport Commission, 2018, https://www.ntc.gov.au/current-projects/changing-driving-laws-to-support-automated-vehicles/

- Electric cars, trucks and buses make little to no noise
- Reduced eye contact between pedestrians/cyclists with a human driver
- AVs potentially travelling at the sign posted speed limit significantly faster than human drivers might do in certain circumstances.

One avenue to address the issues noted above is to update the Safe Systems planning and assessment approach, to include consideration of AVs in the process. Refer to **section 7.4.3 Refining the Safe Systems Approach**.

Walkability of Neighbourhoods and Activity Centres

There is a direct correlation between the rates of people walking and obesity, and the associated diseases linked to obesity[91]. Walkability of a neighbourhood is measured through its attractiveness and ease of getting around on foot. It can be impacted by several factors, one of which is barriers created by high volume, high speed roads. AVs - if managed and operated to support walkability - could have significant health, environmental and economic benefits, alternatively widespread use of AVs could see considerable negative outcomes. With the prospect of infrastructure being installed to support the operation of AVs and ZEVs, such measures may not be the preferred response for walkers, for example:

- Footpath width could be reduced for charging station stations or drop-off/pick-up areas
- Roundabouts are selected over traffic signals, potentially causing difficulties for pedestrians and cyclists to cross
- Increased separation such as pedestrian fencing and grade separations.

Victoria could consider developing street typologies and associated street design guides that enhance walkability, which are regularly updated as more certainty is gained around the uses and needs of AVs and ZEVs. It is important that the design and operation of streets is performance and outcome led rather than through application of designated templates. Doing so will ensure key stakeholders are part of the process.

A Need for Flexible and Adaptable Streets into the Future

AVs present a unique opportunity to re-imagine our cities and spaces by making our streets more adaptable and flexible over time. Without deliberate and coordinated planning AVs may have significant impacts on amenity and place values. Victoria needs to begin setting road and street objectives and appropriate urban design standards for its street typologies accounting for future mobility options. This does not need to wait for wide-scale deployment of AVs but can begin today.

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[91] Tsai. C, 2018 https://www.active.com/articles/slow-walking-may-be-best-prescription-for-obese

5 Physical Road Asset

5.1 Purpose

The purpose of this section is to outline and discuss the impacts AVs and ZEVs could have on the physical road asset from a design, build, operation and maintenance perspective (‘Whole of Lifecycle’).

The section outlines:

- The context of Victoria’s physical road asset
- Key road assets identified and risks assessed against the transition phase/Slow Lane scenario and a full AV scenario
- Using the key road assets identified above an assessment of whether the minimum requirements have been meet for acceptable AV operation in Victoria
- General discussion on impacts and potential responses for existing and future road infrastructure
- Conclusion and recommendations.

5.2 Context

5.2.1 Existing Road Network

The existing Victorian road network is divided into six classes of roads with a mix of ownership. The detailed classification and ownership structure of roads in Victoria is outlined within the (Victorian) Infrastructure Capability Assessment commissioned previously by IV[92].

There are approximately 150,000 km of roads across Victoria that are open for general traffic, with a further 50,000 km of minor roads and tracks in state parks[93]. Only 23,000 km of the total Victorian road network are ‘*declared*’ roads, defined in the Road Management Act (2004) to include freeways and arterial roads managed by the state road authority VicRoads. A map of all the declared roads in Victoria can be seen in Figure 33. The majority of roads in Victoria are owned and maintained by many municipal councils. Currently there are 79 municipal councils in Victoria with 31 located in the metropolitan area and 48 in rural and regional areas[94].

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[92] Infrastructure Victoria, 2016, http://www.infrastructurevictoria.com.au/sites/default/files/images/Deloitte%20Aurecon%20-%20Options%20Assessment%201%20Report%20-%20FINAL.pdf.PDF

[93] VicRoads, 2018, https://www.vicroads.vic.gov.au/traffic-and-road-use/road-network-and-performance/types-of-roads

[94] Municipal Association of Victoria, 2017, http://www.mav.asn.au/vic-councils/about-local-government

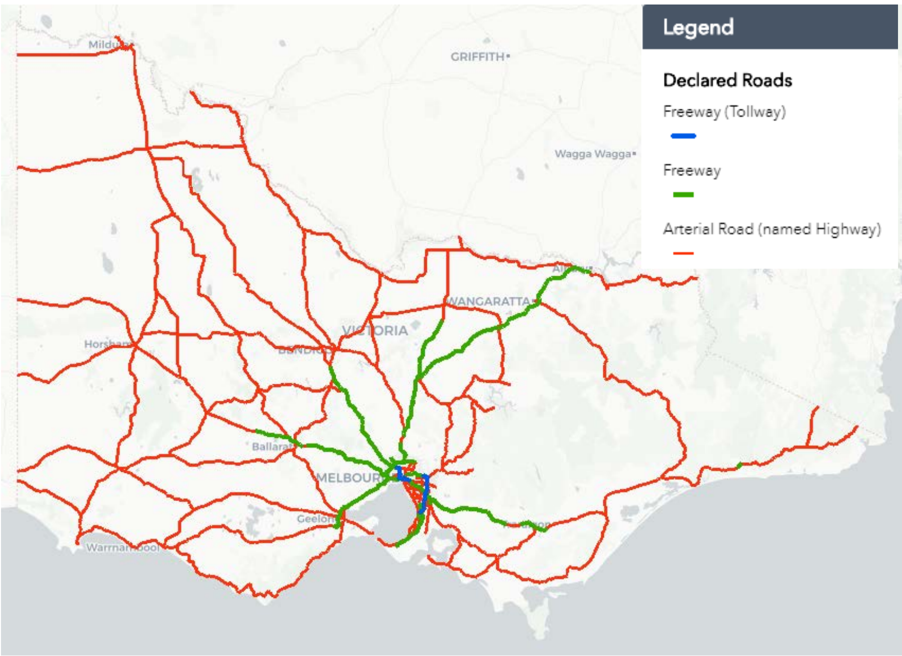

Figure 33: Map of Declared Roads in Victoria (Source: VicRoads, 2018)

5.2.2 Heavy Vehicle – Mass Limits

Figure 34 and Figure 35 highlight the differences in roads which are approved for B-double use (62.5 tonne vehicles) and those approved for A-double High Productivity Freight Vehicles (HPFV) which operate at weights between 68.5 and 85.5 tonnes. Please note: Green: no permit, Yellow: permit required, Red: No access. These images clearly reveal the very small portion of the road network which allows for vehicles heavier than 68.5 tonnes.

Figure 34: B-Double Approved Routes (Source: VicRoads)

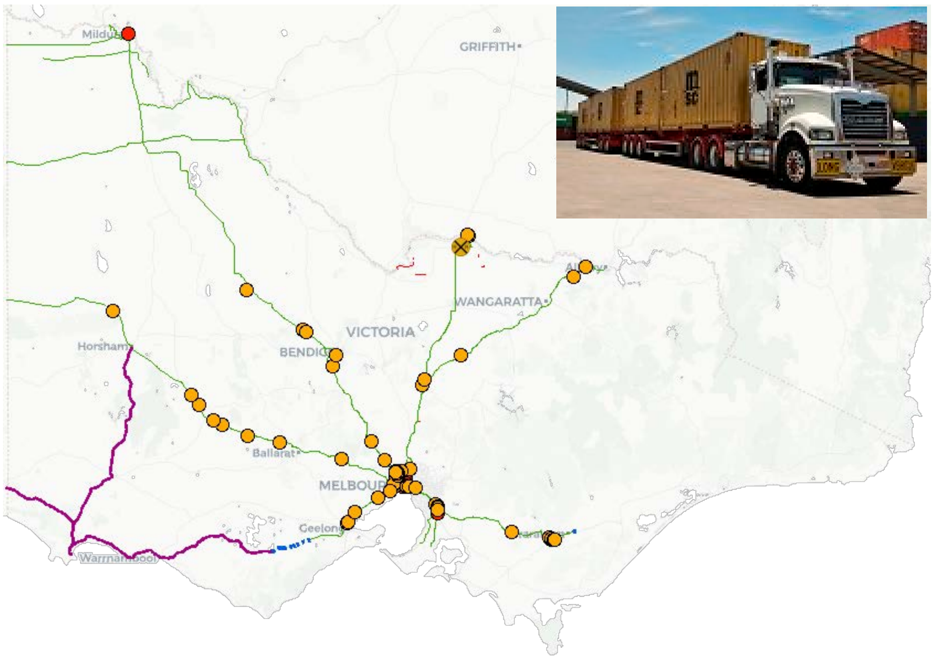

Figure 35: High Performance Freight Vehicle Approved Routes (Source: VicRoads)

5.2.3 Maintenance of Existing Infrastructure

VicRoads currently has the responsibility of managing the majority of declared roads, except for toll roads. This includes inspecting and maintaining the traffic lanes, signals, signage, barriers and the operation and coordination of the road. Funding for maintenance and upgrading of these roads is derived largely by the Victorian Government. In the 2016/17 financial year, VicRoads spent approximately $3.5 billion on the Victorian road network[95].

Municipal councils are individually responsible for the inspection, maintenance and upgrading of roads that are not state or privately owned. Funding for councils is mostly derived from local rates, charges and grants from the State and Federal Governments. Each Council's proportion of funding from different sources varies - with rural councils relying more heavily on government grants and metropolitan councils relying more on local rates and charges[96]. For example, Maribyrnong City Council's constituency is made up of nearly 90,000 people within 30 square kilometres and contains 430 km of road[97]. Over 80% of these roads are council owned and funded. For the 2018/19 period, Maribyrnong City Council has budgeted $14.6 million to spend on roads which represents approximately 10% of the council's total income for the year[98]. This example illustrates how sensitive local governments are to any significant costs to their road infrastructure.

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[95] VicRoads, 2017, https://www.vicroads.vic.gov.au/about-vicroads/corporate-responsibility/vicroads-annual-report

[96] VicRoads, 2017, https://www.vicroads.vic.gov.au/about-vicroads/corporate-responsibility/vicroads-annual-report See 91 as above

[97] Maribyrnong City Council, 2018, https://www.maribyrnong.vic.gov.au/Home

[98] Maribyrnong City Council, 2018, https://www.maribyrnong.vic.gov.au/About-us/Our-plans-and-performance/Annual-budget

The current condition and strategy for the direction of road infrastructure in Victoria is important to determine the impact AVs and ZEVs might have on physical infrastructure in the future. IV's commissioned Infrastructure Capability Assessment (2016) made the following key findings:

- Urban freeways in good condition generally, with sound but not extensive ICT networks
- The condition of urban arterials is considered to vary greatly but the ICT networks are providing a good availability of information
- Rural and regional arterials have limited information regarding condition however customer surveys have shown people are less satisfied with these roads than the State average.

5.2.4 Future and Planned Maintenance Budgets

The Auditor General's report highlighted that Victoria's road infrastructure has deteriorated and a more strategic approach is required to address this. The impact of this is even more prudent with regards to the introduction of AVs and ZEVs to ensure the pavement condition meets the minimal operational requirements. The road network will require constant and accurate monitoring, coupled with regulatory control, to ensure the pavement condition does not create unsafe conditions[99]. The impact on budget is not yet clear however, it is clear that efficiency in processes will be key in supporting the future network for all road users.

5.2.5 Proposed and Committed New Infrastructure and Upgrades

With a significant investment in new and upgraded road infrastructure, it is becoming more pressing to consider how AVs and ZEVs may impact on the design and operational requirements. Note that the difference in project budgets versus local road maintenance budgets is vast. The North East Link project budget is $14-16 billion, whereas the Maribyrnong City Council has a total annual budget approximately a 1000 times less for roads. If AVs and ZEVs are to form part of an integrated transport network, local roads are likely to become an important consideration, especially the aspect of where funding will come from if upgrades or changes are required.

5.2.6 Victorian CAV Trial Program

As highlighted in **section 2.6.2**, Transurban in partnership with the Victorian Government, VicRoads and the Royal Automobile Club of Victoria, have recently completed the first phase of a three phase trial program that investigates how Connected and Automated Vehicles (CAVs) interact with motorway infrastructure. This first phase looked at how partially automated vehicles (Level 1 and 2) react to the motorway environment, which included: speed signs, toll

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[99] Victorian Auditor-General's Office. 2017. https://www.audit.vic.gov.au/report/maintaining-state-controlled-roadways

points, line markings, motorway artwork and architecture, entry and exit ramps, objects on the road, merging vehicles, varied light and weather conditions, peak-hour congestion and road works. The second and third phases will focus on vehicles with higher levels of connectivity and automation. The summary of the key findings is as follows:

- Electronic speed signs and signs on tunnel walls were challenging for some vehicles
- Flashing signs were read more reliably than other electronic signs
- Sign types, locations and position changed the level of readability
- Static speed limit signs on adjacent exit ramps were incorrectly read by vehicles travelling on main motorway on occasion
- Yellow lines were generally read well however white lines near yellow lines disrupted lane keeping
- Stopped/merging vehicles were not always detected
- CityLink’s sound tube disrupted lane keeping and a vehicle’s ability to determine speed limits
- Lane keeping was disengaged by gaps in line marking under toll points and when line marking changed on occasion
- Exit ramp line markings were incorrectly followed by some vehicles
- Stationary vehicles at the end of exit ramps were not always detected.

“Cars that can steer themselves, recognise speed limits and manage their speed are already driving on Australia’s roads. However, much of our 50,000 kilometres of motorways was built decades ago and may not provide the best conditions for these new vehicles let alone be ready for the highly automated vehicles that are to come.”[100]

This summary of key findings and the statement above both signify the need for further trials and investigation in order to understand and address the physical and digital infrastructure requirements.

5.3 Risk Assessment

Section 3 of this report discusses key potential changes which could be likely from the use of AVs and ZEVs on the road network. This section outlines the outputs from a risk workshop that considered specific types of physical road infrastructure for the transition phase/Slow Lane scenario, and full AV fleet scenario. The risk assessment was then then used to understand whether minimum requirements have been meet to enable the safe and efficient operation of AVs on Victoria’s road network refer to **section 5.4 Minimum Requirements Assessment**.

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[100] https://cAVs.transurban.com/trials/victoria/partial-automation

5.3.1 Key Risks Items Identified

The key risk items include: signage, lane widths, line marking, pavement, bridge structures, barriers, road geometry and intersections, and other infrastructure. Each of the key risk items has been assessed for the risk level and possible responses for each. The responses by government and/or road owners and operators, has the potential to be as varied as the possible scenarios for deployment. The high level of uncertainty around how vehicle technology will evolve has required the project team to make several assumptions, in order to outline how each type of physical infrastructure could be impacted.

5.3.2 Risk Assessment Summary

Below is a summary of the risk assessment for each key item. The full assessment is discussed in **section 5.4**.

Table 4: Road Asset - Risk Assessment

The assessment table below summaries the:

- **Risk Item:** Physical infrastructure that is a risk
- **Scenario Risk Level:** Likelihood of risk on infrastructure for different scenarios, and
- **Actions**: Possible actions/mitigation to consider.

Workshop held: 08 May 2018

Risk Levels
● High Risk
● Medium Risk
● Low Risk
● Minimal/Negligible risk or not applicable

Risk Item	**Scenario Risk Level**		**Possible Actions**
	Transition Phase/Slow Lane Scenario	**Full 'Connected' AV Fleet Scenario**	
Physical Signage	● High risk as both camera-based systems and humans will need to read and understand physical signage.	● Connected AVs will obtain signage/advice from digital infrastructure not signage therefore physical signage requirements will significantly reduce.	A review of signage design guidelines and standards to allow for rationalisation of sign face design. This review should focus on elimination of text heavy designs and investigate the integration of symbols from Vienna convention based signs set. Review of maintenance regimes to ensure that signage is kept to a high standard – reflectivity and readability. New signage roll out to prioritise signage causing an adverse effect on AVs safety over those that are not read at all. Pre-road opening inspections before AVs are permitted access. Application of machine readable codes being embedded into current road signs to be considered. Incorporating a camera based drive by audit into maintenance inspections would allow road authorities to determine whether a signs current location is acceptable for TSR systems.
Lane Widths	● Low risk likely to stay the same.	● Likely to reduce lane width requirements and land can be reallocated.	No infrastructure response regarding lane width is considered necessary to facilitate the introduction of a fully AV fleet. Reallocation of road space away from vehicle use through the implementation of narrow lanes, should be considered and prioritised through 'Movement and Place' classification and assessment frameworks. During the transition phase, road design could begin adopting desirable minimum lane widths under current standards. Road geometry guidelines around lane widths should continue to be reviewed and updated to reflect the enhanced sensing and control capabilities of a fully AV fleet.

Risk Item	**Scenario Risk Level**		**Possible Actions**
	Transition Phase/Slow Lane Scenario	**Full ‘Connected’ AV Fleet Scenario**	
Line Marking	🔴 High risk due to safety concerns of poor/ inconsistent line marking for camera-based systems and humans.	🔵 Line marking unlikely to be required for fully connected AV.	Line marking to be maintained as the default lane use control for the foreseeable future. It is likely that human drivers and camera-based driving systems will need to be removed from the road system before line marking is made redundant for AV operations. It is recommended the Victorian Government review its approach and standard for line marking to better understand the safety benefits of enhanced line marking for both humans and AVs.
Pavement	🟡 Medium impact as pavement must be maintained for both connected AV and human drivers.	🟡 Medium impact as pavement requirements may change.	It is reasonable to expect that a technology/connected solution would be pursued and developed to maximise the asset life of an existing or future road pavement over an infrastructure solution to upgrade the asset. This technology may include lane positioning of a connected fleet such that vehicle tracking is altered over time to ensure uniform wearing of the pavement and maximise the design life of the existing asset. For infrastructure yet to be built, or in the planning phase, there is an opportunity to consider concentrated vehicle loads in the design and construction of the new pavements. It could become possible in the future to restrict AV heavy vehicles to particular lanes on the freeway. These lanes could then be designed with increased strength to cater for high volumes of heavy vehicles and closer headways. It is suggested that Victorian transport authorities keep abreast of road material technologies to ensure performance specifications consider new types of materials. The Victorian Government already holds significant GIS data on pavement and structures. This data could be used to inform vehicles of which lane to travel in or avoid, resulting in prolonging the life of the pavement.
Bridge Structure	🔴 High risk as bridge structures must be maintained for both connected AV and human drivers with differing loading.	🔴 High risk as loading may significantly change.	Changes to existing infrastructure could be an increased number and change in location of traffic lanes and loading of the structure for which it had not been designed (such as platooning). This may mean additional structures adjacent to existing ones or the strengthening of existing. This type of investment is typically required when a clear need is identified for the works. This is expected to be the case for existing infrastructure in the future. For infrastructure yet to be built or in the planning phase, there is an opportunity to consider how the potential might impact on the structure and how the current design can consider or respond to the potential future requirements. The design could consider what type of strengthening works could be easily undertaken in the future, how that would be designed and constructed, and when it would be required within the design life of the asset.

Risk Item	**Scenario Risk Level**		**Possible Actions**
	Transition Phase/Slow Lane Scenario	**Full 'Connected' AV Fleet Scenario**	
			A connected vehicle solution (V2I) could be developed to inform vehicles to avoid certain structures/sections of pavement or change their driving pattern e.g. longer headways.
Barriers	🟠 Medium risk as must be maintained for both connected AV and human drivers.	🟡 Low risk as it is likely the number of barriers will reduce significantly.	As a potential response for existing infrastructure, the need to install and maintain barriers is likely to remain until a point where the probability of errant vehicles is very low and human drivers are no longer involved in the driving task. The easy removal of those barriers in the future is something that could be considered in the design of future infrastructure. That is, design should consider decommissioning the barriers, the opportunities for the entire road corridor once those barriers are removed, and how the design of the current road corridor could consider those changes.
Road Geometry and Intersections	🔴 High risk due to challenging interactions between low level automated vehicles, human driver and road geometry.	🟡 Low risk as connectivity allows vehicles to communicate and navigate the situation.	Response for existing infrastructure alignment of existing infrastructure may limit the use of Level 1 and Level 2 AVs, due to their inability to fully interpret road geometry and adjust their paths and speeds accordingly. However, large scale modifications to accommodate these vehicles is not recommended. Level 1 and Level 2 AVs and non-AV vehicles will need to rely on human intervention, while highly automated vehicles (Level 4+) should be able to navigate such road geometry independently. Response for future infrastructure design guidelines will need to evolve in line with uptake and development of AV capabilities. If a full AV scenario is realised, guidelines will need to be amended to ensure the maximum benefits around land use are achieved.
Other Infrastructure (public transport priority, drainage, noise attenuation emergency stopping bays)	🔴 High risk due to challenging interactions between varying parties and infrastructure.	🟡 Low risk as connectivity allows vehicles to communicate and navigate situations.	Reallocation of road space away from vehicle use through the implementation of narrow lanes, should be considered and prioritised through existing 'Movement and Place' classification and assessment frameworks. For infrastructure yet to be built or in the planning phase, there is an opportunity to consider how the potential might impact on the structure and how the current design can consider or respond to the potential future requirements. Response for future infrastructure design guidelines will need to evolve in line with uptake and development of AV capabilities. If a full AV scenario is realised, guidelines will need to be amended to ensure the maximum benefits around land use are achieved. If AVs are used on high speed roads in Victoria, road authorities may need to be proactive in instructing vehicles on what to do in minimum risk condition mode and/or understanding what provisions may need to be designed into the road network.

5.4 Minimum Requirements Assessment

The objective of doing this assessment is to assist informing possible future actions in order to enable AVs on Victoria's road network.

Using outputs from the **Risk Assessment** in **section 5.3**, and the information collected during this high-level study, an assessment was undertaken as to whether minimum requirements have been reached for different levels of autonomy to effectively operate on Victoria's road network.

To determine whether minimum requirements are present, the assessment has attempted to understand: '*Whether each of the prescribed levels of automation is ready to operate on Victoria's road network based on an accepted rate of errors*'. To create the accepted error rate, the following criteria and assumptions were made to assess the appetite for risk (error), while also accounting for who is ultimately responsible for that risk.

5.4.1 Criteria and Assumptions

Firstly, this assessment has been approached from the perspective of today, while acknowledging the fact that as technology continues to develop, the acceptance of errors may decrease. Secondly, an error is not an accident but rather the driving system potentially going into fall-back mode or seeking external intervention to assist with the correct decision (e.g. contacting a central traffic management centre).

Higher performance expectations are set for corridors with stronger movement functions and less conflicts. For this high-level assessment, the four road and street types selected were:

1. **Motorway:** any road in Victoria classified 'M' (i.e. motorway)
2. **Arterial Roads:** declared state arterials with minimal conflicts, and local council roads that would be classified as having an arterial function
3. **Streets with Conflicts:** streets that have high place and/or accessibility functions. This would include declared roads such as Bridge Road, Richmond
4. **Unsealed Roads:** includes roads that do not have pavement.

The following criteria were used to inform the assessment for each level of autonomy:

1. Level 1/2 AVs are designated as driver assisted technology, i.e. the driver remains in full control and can easily overcome any errors that occur from the driving system
2. Level 3 AVs involve computer controlled driving, with a human driver monitoring the system and intervening where required, therefore for safety reasons a limited error rate should only be accepted
3. Level 4 AVs should never within fail geo-fenced areas – some small errors could be expected on non-movement corridors or in complex/unexpected situations
4. Level 5 is expected to work all the time, except in rare cases.

The result of applying the criteria to each of the roads and streets outlined above is shown in Table 5:

Table 5: Acceptance of Error

AV Level	**Motorway**	**Arterial Roads**	**Streets with Conflicts**	**Unsealed Road**
L1 / L2	Every once in a while	Sometimes	Often	Frequently
L3	Rarely	Every once in a while	Sometimes	Often
L4	Never	Rarely	Every once in a while	Sometimes
L5	Never	Never	Rarely	Every once in a while

The following scoring was used by the assessment to indicate whether the minimum requirement has been met:

Table 6: Minimum Requirement Scoring

🟢	Meet
🔴	Not Meet
🔵	Not Applicable

Table 7: Assessment of Minimum Requirements

Physical asset item	**Road / Street type**	**Meets Min?**	**Commentary & Gap**	**Possible Actions**
Physical signage	**Level 1/2**			
	Motorway	●	Through the Transurban led Victorian CAV Trials[101] and the Arup led Austroads study into Implications of In-Vehicle Traffic Sign Recognition[102] (TSR) it has become apparent that Level 2 AV technology varies significantly between vehicles. The technologies performed differently under several use cases and a number of vehicles have limitations on what the technology can and cannot do. This suggests the technology has a way to go in terms of development. The results from the trials indicate a currently high error rate. Watch relevant Victorian CAV Trial videos at the links below: https://www.youtube.com/watch?v=qG8daDe_WjE https://www.youtube.com/watch?v=QWvszVx6qZI Currently, TSR is mainly limited to speed signs providing a driver assistance aid. Due to the infancy of the technology it is difficult to ascertain what the minimum requirements are, therefore the current standards for design and reflectivity still apply i.e. it assumed if existing standards are followed then the technology will work. Findings from the Austroads study raised several issues, including: time based signage like school speed zones as TSR cannot read text; and modern electronic signs 'flickering' where the camera could not detect the signage. It is possible that improvements to in-vehicle camera technology and variable signage may be required in the future. It is suggested VicRoads alongside other Australasian road authorities need to understand this issue better and determine whether infrastructure changes are required, especially to managed motorways.	1. Currently, Victoria does not hold an accurate data set of every location and quality of sign. It is understood that Queensland have fitted TSR to selected vehicles to detect and log where signs are; this could be considered by Victoria to build up a database. 2. Work through Austroads and Standards Australia to have a consistent approach to traffic signs in Australia. 3. Test and record data for Victoria's motorway system and key arterials, and make changes to unreadable signage. 4. Review current approaches to design, maintenance and installation of traffic signs and make adjustments where easily done. 5. Continue to monitor and review the technology as it develops as a number of the current issues could be resolved before an infrastructure solution is required. 6. Generally, practitioners should follow a principle of future proofing systems and infrastructure by 'thinking modular'. This means that systems and infrastructure should be easily upgradable in the future by adding a 'module', for example: traffic signal control boxes should only be installed if they can be easily upgraded by installing a DSRC 'module'. 7. Encourage harmonisation across jurisdictions for sign design and use and discourage bespoke signs.
	Arterial Roads	●		
	Streets with Conflicts	●		
	Unsealed Roads	●		

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[101] About the Victorian CAV trials, Transurban 2018, https://cAVs.transurban.com/trials/victoria/partial-automation

[102] Austroads engages Arup on Connected and Automated Vehicle Sign Recognition Trials, 2017, https://www.arup.com/news-and-events/news/austroads-engages-arup-on-connected-and-av-sign-recognition-trials

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
	Level 3			
	Motorway	🔴	The results from the Victorian CAV Trials suggest that the traffic sign recognition (TSR) technology has not been developed to a level that is sufficient to automatically control vehicle speeds in Victoria. Camera based technology may never be good enough to be trusted to solely instruct the vehicle's driving behaviour, due to the issues of cameras being obstructed, such as: trucks obstructing signage, cameras becoming dirty or limited by severe glare. Instead, vehicle visualisation is likely going to need to be integrated with other system inputs such as: digital maps and on-board vehicle LIDAR (light imaging, detection, and ranging). Specifically, LIDAR would assist with position prior, colour, laser reflectivity, and 3D geometric features[103]. As LIDAR is considerably expensive, commercially available vehicles in Australia do not generally have LIDAR yet. None of the vehicles tested in the Victoria CAV or Austroads trials had LIDAR, noting phase 2 of the Victorian trials will using an aftermarket 'Bosch' Tesla which incorporates six LIDARs[104]. It is likely that Level 3 AVs will be self-certified (like cars are today), however it is unknown what signs they will be trained to read. It cannot be assumed they will read all signs, especially ones with text based qualifications. For example, a number of strip shopping centres in Victoria have varying time based 40 km/h speed zones, some go to midnight while others stop at 7pm. To adhere to these restrictions other digital solutions will likely be required.	1. Continue to monitor and review the technology as it develops as a number of the current issues may be resolved prior to an infrastructure intervention be needed. 2. Support and encourage the private sector to begin 3D digital mapping of Victoria's road network. 3. Begin to develop a framework and strategy for a digital solution for traffic information. 4. Keep abreast of C-ITS and connected vehicle trials occurring in Australia and globally to obtain learnings and understanding. 5. Work with other jurisdictions and responsible national bodies to understand whether there is a list of signs that vehicles must be able to be read to be declared as operating at Level 3.
	Arterial Roads	🔴		
	Streets with Conflicts	🔴		
	Unsealed Roads	🔴		
	Level 4/5			
	Motorway	🔵	It is suggested that physical signage will potentially not be required for Level 4 or 5 vehicles, as they will instead rely on a combination of connectivity, high definition maps and high-level sensors.	1. Begin to develop a framework and strategy for a digital solution for traffic information.
	Arterial Roads	🔵		

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[103] LIDAR and vision-based real-time traffic sign detection and recognition algorithm for intelligent vehicle, L. Zhou; Z. Deng, https://ieeexplore.ieee.org/document/6957752/

[104] Highly automated driving, Transurban 2018, https://cAVs.transurban.com/trials/victoria/highly-automated-driving

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
	Streets with Conflicts	🔵		2. Keep abreast of C-ITS and connected vehicle trials occurring in Australia and globally to obtain learnings and understanding.
	Unsealed Roads	🔵		
	Level 1/ 2			
Line marking	Motorway	🔴	It is common that a number of owner's manuals for Level 2 vehicles state that there may be detection issues during adverse conditions or variable lighting, suggesting the technology has an unacceptable error rate. The outputs from the Victorian trials suggest that current Level 2 AVs require good quality lane markings, without interruptions e.g. no ghost markings (where line marking has been removed) and no lines under toll gantries. Generally, lines need to be present on both sides of the lane, and have good illumination, especially during dusk/dark conditions. As found during the Victorian CAV trials there were certain instances where vehicles followed solid white lines along motorway off-ramps rather than continuing through, there were also issues with chevron areas. There were particular incidents where vehicles followed old-line markings crossed into the adjacent traffic lane requiring driver intervention. Victoria's motorway system is generally of a high standard, however, trials conducted to date have identified various issues. It is likely that roads could become ready in the near-term as technology improves, noting some small to moderate infrastructure interventions may still be required. It is acknowledged that because Victoria generally uses asphalt on its motorways, it achieves good contrast between the line marking and road surface. It is noted that a paper presented at the Australasian College of Road Safety annual conference suggested that: *typically, lines are re-marked at yearly or two-yearly intervals rather than when their performance has deteriorated. In some cases, poor quality line marking remains untouched for months if not years and in other cases lines are re-marked prematurely. Currently there are very few systems used to measure the condition of day or night visibility of painted road marking, nor in some states is there a wet night visibility requirement.* It also went on to say*: there are no uniform standards for line marking across Australia and too many standards are set at a very low level.*	1. Investigate ways to easily detect and record whether line markings of motorway and arterial roads are distinguishable by camera-based systems. 2. Work with Austroads and Standards Australia to develop a consistent and uniform approach to line marking in Australia. 3. Test and record data for Victoria's motorway system and key arterials, and make changes to unreadable line marking (see point 1 above). 4. Review current approaches to design, maintenance and installation of line marking and make adjustments where cost effectively done. 5. Through Victoria's Safe Systems Road Infrastructure Program (SSRIP), understand the benefits of high quality line marking for all users from a road safety perspective, and develop a program of line marking upgrades, including local roads. 6. Continue to monitor and review the in-vehicle technology as it develops as a number of the current issues may be resolved before an infrastructure solution is required. 7. Long life line marking, such as 'thermoplastic', should become the default product on all motorway and arterial roads for longitudinal lines, within intersections and for general road markings.
	Arterial Roads	🔴		
	Streets with Conflicts	🔴		
	Unsealed Roads	🔵		

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
			Uniform standards set at a high-performance level should be implemented as a matter of priority.[105] The CEO of the Roadmarking Industry Association of Australia puts forward: If (Victoria) is not already doing so, they should work towards specifying 150 mcd/m2/lx dry and 100mcd/m2/lx wet as the absolute minimum levels of retroreflectivity, below which markings must never fall[106]. It is argued that using a retroreflectometer is the only way to objectively evaluate if a road marking or a road sign provides the minimum retroreflection level stated in a given standard[107].	8. Maintenance programs may need to move towards a performance base standard rather than relying on routine time intervals. 9. Consider greater use of retroreflectometer testing on major motorways to ensure a consistent and high level of retroreflection from line marking. 10. Review current Victorian practice of employing yellow line marking in roadworks zones while conflicting white line marking remains in place.
	Level 3			
	Motorway	🔴	A design feature on the road network that caused issues for AVs during the Victorian trials were sharp curves at higher speeds, such as the ramp from the West Gate Freeway to the Bolte Bridge northbound. Several of the driving systems dis-engaged. Camera-based technology may never be good enough to be trusted to solely instruct the vehicle's driving behaviour and therefore additional technology will be required for Level 3 and above vehicles. As discussed above, LIDAR is likely to be a key system to help reduce the error rate. Due to the reflectivity of line marking, LIDAR can accurately distinguish the location and type of line marking. Depending on how AV technology evolves this could require either: More frequent and widespread retroreflectometer testing of the network to ensure standards are being met, or If the technology improves, the status quo could be maintained, as the standard is based on human design requirements. In the future AVs could potentially become test vehicles by feeding back where and when line marking was not detected to a central database, rather than using a retroreflectometer.	1. Continue to monitor and review the technology as it develops as a number of the current issues may be resolved before an infrastructure solution is required. 2. As LIDAR systems can accurately detect the reflectivity of line marking, Victoria should consider ensuring line marking on the metro motorway system meets required standards and is maintained appropriately, at least in the near-term. This will help to ensure LIDAR based systems can operate from day one. 3. Begin to develop a framework and strategy for a digital solution for traffic information. 4. Consider if Victoria wants to collect error data from AVs to inform road design and planning. This will then require the ability to collect and manage the data.
	Arterial Roads	🔴		
	Streets with Conflicts	🔴		
	Unsealed Roads	🔵		

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[105] Road Markings - Cosmetic or Crucial?, B. Carnaby, http://acrs.org.au/files/arsrpe/RS030026.pdf
[106] Pavement Markings Role in Enhancing Road Safety Strategies, P., Thurston http://acrs.org.au/wp-content/uploads/Thurston.pdf
[107] Why retroreflectometer, 2018, https://roadsensors.madebydelta.com/technical-background/introduction/retroreflectometer/

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
			It is possible Level 3 vehicles may only be able to operate on Victoria's road network if they have LIDAR. LIDAR does provide high quality essential inputs for AVs, however it needs to be supported through cameras, radar and 3D mapping. Some of the key limitations to LIDAR include: objects need to be relatively close, measurements are not always sharp enough to distinguish one object from another, and when multiple AVs are on the same road, their LIDAR signals can interfere with one another[108].	
	Level 4/5			
	Motorway	●	There is significant uncertainty on what role line marking will play in the long-term as a guidance mechanism for AVs. It is possible in the early stages of AV Level 4 and/or 5 deployment on main arterials line marking could be a major input into the driving task. However, as technology progresses it may then become a redundant system. Several industry experts have put forward the suggestion that line marking will not be needed at all in a full Level 4/5 AV world. One practical outcome for Victoria is that along major movement corridors where pedestrians and cyclists are not present, line marking could become redundant, however on streets where they are present a degree of line marking would need to be maintained to inform other users where AVs will and will not travel (refer to **section 4 on Planning for All Users**). Though 3D mapping will be an important input into an AVs' driving task, it will be important that AVs can feed back real-time data into the map database if the network changes (e.g. when pot holes appear). It is acknowledged that in the early years of deployment, Level 4/5 vehicles may be restricted to certain areas, or the vehicle manufacturer may only allow the vehicle to operate in autonomous mode in selected geo-fenced areas. There may also be certain types of vehicles that are only ever allowed to operate in defined areas, for example the Autonobus trial at La Trobe University (supported by VicRoads)[109].	1. In addition to the actions above, Transport Authorities should use 'Real Options Analysis' for new projects to understand and consider future proofing (refer to **section 9.5.1**). 2. Work in partnership with vehicle manufacturers to identify appropriate areas for vehicles to operate in full autonomy.
	Arterial Roads	●		
	Streets with Conflicts	●		
	Unsealed Roads	●		

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[108] How Driverless Cars See the World Around Them, 2018, https://www.nytimes.com/2018/03/19/technology/how-driverless-cars-work.html

[109] Autonobus, 2018, https://www.latrobe.edu.au/technology-infusion/autonobus

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
Pavement	**Levels 1-5 (All)**			
	Motorway	🟢	For pavement, though there is no 'error rate' in how the technology performs, it is important to consider the relationship between the infrastructure and technology to understand whether errors may arise. It is acknowledged that for Levels 1-3 vehicles, a human driver would likely need to intervene for potholes in the road or significant pooling of water. This could be an issue for Level 3 vehicles if the driver becomes inattentive. It is expected a connected solution would be used to inform Level 4/5 vehicles of an appropriate action to take, however if no solution was implemented it could be argued that the pavement would create too high an error rate for vehicles to operate. Generally, the assessment of the pavement design used in Victoria suggests that it is fit for purpose to enable AVs. This is assessing the design and build of pavement, not whether current pavement is maintained to a good condition, as the latter is equally applicable to conventionally driven vehicles. It is flagged that as heavy vehicles are a main driver for pavement deterioration it will be important over time to monitor whether the advent of AV technology changes the way freight and logistics is undertaken in the State. However, currently there is little evidence to suggest freight volumes will grow differently in Victoria under an AV future than those forecasted otherwise. Refer to **section 3.4** for further discussion. As discussed in **sections 3.2.1 Vehicle Types** and **3.3.2 Heavy Vehicle Platooning** there are significant possibilities that vehicle types/topologies will change, which has impacts on axle loading and weighting. However, it is suggested that it is unlikely trucks will get bigger beyond the standard B-double weight axle restrictions; they may actually get smaller due to the way the freight task changes. For local streets, it is highlighted that the pavement is probably not ready to cater for AVs, as no Movement and Place strategy has been comprehensively applied to inform AV modal priority. AVs would technically have free rein to use whatever street gets to the destination the fastest without considering place values. An increase in AV volumes on local streets not currently used by human drivers, could impact on pavements not designed to handle the increased vehicle volumes. This problem equally applies to light and heavy	1. Victoria will need to keep abreast of whether AV technology is driving growth in vehicle volumes beyond that forecasted, especially for heavy vehicles. 2. Work with other jurisdictions through Austroads to review pavement design standards to consider heavy vehicle platooning. 3. Victoria to work collaboratively with the freight industry to begin testing heavy vehicle platooning. 4. Develop and apply a Movement and Place framework across the entire road network of Victoria. 5. Re-affirm the role of rail in moving freight across Victoria and to intermodal terminals. This will help identify gaps that AV freight vehicles could assist and allow prioritisation of asset renewal.
	Arterial Roads	🟢		
	Streets with Conflicts	🔴		
	Unsealed Roads	🔵		

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
			vehicles but would be more pronounced on streets and roads that link with key freight destinations, for example Beach Road, Port Melbourne. As outlined in **section 3.3.2** wide-scale heavy vehicle platooning could possibly have impacts for pavements, if no intervention is made operationally.	
Structures	**Levels 1/2**			
	Motorway	🔴	Importantly, for Level 1/2 it is the driver's responsibility to adhere to any restrictions placed on structures. Generally, the assessment of structure design used in Victoria is fit for purpose to enable AVs in Victoria. This is assessing the design and build of structure, not whether current structures are maintained to a good condition, as the latter is equally applicable to conventionally driven vehicles. However, the Victorian CAV trials found that 21% of the disengagements of the Lane Keep Assist system (errors) was due to expansion joints, until further investigation it is difficult to tell whether this is a line marking issue or an interference with the system. The Victorian trials experienced several unexplainable issues on CityLink through the 'Sound Tube' structure causing various AV functions to drop out or behave differently. It is noted that considerations may need to be made around the impact of urban design facades of structures on AV functions. Watch relevant Victorian CAV Trial videos at the links below: https://youtu.be/X1jegmJZ83U https://youtu.be/WWdcHufRU5U https://youtu.be/D3Ijzr0usy8	1. Investigate the issues of expansion joints on Lane Keep Assist systems and rectify as practical. 2. Consider how urban design may impact on the operation of AV technology as part of the design and build on infrastructure.
	Arterial Roads	🔴		
	Streets with Conflicts	🔴		
	Unsealed Roads	🔴		
	Levels 3/4/5			
	Motorway	🔴	An issue prevalent in Victoria is the number of crashes with structures. Level 3/4/5 AV technology could significantly improve this situation. However, the situation could also worsen without data and information on Victoria's infrastructure being readily provided by the Victorian Government. For example, the notorious bridges at Montague Street, South Melbourne and Napier Street, Footscray already suffer a high number of crashes due to driver inattentiveness. This could worsen without accurate real-time data to advise	1. Victoria if not already doing so should review capacity and load bearing capability of existing structures with particular focus on already 'at risk' structures, and those on freight routes. 2. Assess the structures against platooning loading patterns, including higher, more concentrated and prolonged loading.
	Arterial Roads	🔴		
	Streets with Conflicts	🔴		

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
	Unsealed Roads	●	vehicles not to travel through these areas if they exceed height limits. This equally applies to the hundreds of structures across Victoria with weight restrictions. Through this assessment, we are uncertain whether a vehicle could make the right decision to travel on or under the structure if the driver was inattentive. Due to the issues that already occur with human drivers, we have assumed the error rate is too high. It is acknowledged this may be primarily a 'large vehicle' issue and that structures could meet the minimum requirements for smaller/light vehicles. It is likely that the increased level of automation will bring rise to vehicles following each other more closely. This may result in freight trucks travelling in groups with minimal headways, known as 'Platooning'. It could be possible that an increased concentration of vehicle loads becomes one large load rather than several concurrent loads. The reduction of spacing and time between vehicles may mean that flexure in structural elements of bridges will not have adequate time to recover between loadings as it does under current traffic loads. A greater density of vehicles and greater throughput of vehicles not only sees both a higher and more concentrated loading pattern, but also a prolonged loading of bridge structures. This could result in accelerated fatigue of structural elements. Research and information remains limited in this area, so to become certain, detailed modelling and research would need to be undertaken. As no heavy vehicle platoons are present on Victoria's road network and globally they are still in the trial phase, it is unlikely that it will become wide spread issue within Victoria in the next 5-10 years. This suggests coordinated heavy vehicle platooning would be acceptable over this period, in regards to structures.	3. From this review and load assessment, assess the need of additional structures adjacent to existing ones or the strengthening of existing and create a priority list which can be implemented as required. This type of investment is typically required when a clear need is identified for the works. 4. Continue to keep abreast of vehicle design and platooning technology developments 5. Ensure automation and platooning is considered when designing future infrastructure. 6. Begin to develop a framework and strategy for a digital solution for traffic information. A connected vehicle solution (V2I) could be developed to inform vehicles to avoid certain structures or change their driving pattern e.g. longer headways.
Barriers	**Level 1/2**			
	Motorway	●	As discussed, line marking currently provides driving guidance via camera vision, however during trials there were several instances of vehicles following incorrect lines. Watch relevant Victorian CAV Trial videos at the links below: https://www.youtube.com/watch?time_continue=1&v=0JE_laNajuc https://www.youtube.com/watch?time_continue=1&v=rusD7DEJUyw	1. It is important that barriers are consistent and to standard. 2. Line marking that runs close to barriers may need additional maintenance, better consistency and could require changes to make it stand out more e.g. wider, and high reflectivity.
	Arterial Roads	●		
	Streets with Conflicts	●		

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
	Unsealed Roads	🔴	It is hard to predict that if a barrier had been present, whether the on-board radar system would have detected it and taken corrective action. One incident in America involved a barrier intruding over the lane line through a construction zone, and a vehicle hitting the barrier[110]. Watch relevant Victorian CAV Trial videos at the links below: https://www.youtube.com/watch?v=-2ml6sjk_8c There is too much uncertainty that if the vehicle incorrectly tracks towards a barrier close to the lane marking whether it would detect it and take corrective action. Figure 36 after this table illustrates the dotted edge line and changing barrier types on the West Gate Bridge; this is a high-risk situation especially as there is no emergency shoulder on a high speed road. Victoria has several 'managed motorways', which have involved removing emergency shoulders and locating concrete barriers close to lane lines, thus reducing room for error if a human driver needs to take corrective action. For discussion of the design of emergency shoulders, refer to **section 5.5.8.4**. Another trend in Victoria is the wide-scale roll out of wire rope barrier especially across regional highways. There is not a lot of information on how AVs would behave with wire rope located close to lane lines. One particular use of wire rope is along the centre median of undivided highways (see Figure 37). In a crash, wire rope can deflect by up to 3 metres depending on impact and in such a situation an oncoming human driver would see and swerve around the deflection, there is no information on how a Level 1/2 AV would react. It is acknowledged this could be a low risk situation as wire rope has saved a number of people from death and serious injury. Generally, across Victoria's road network there is a significant amount of barrier used from static pedestrian footpath and tram stops barriers through to variable barriers like rail level crossing arms (a major issue for Victoria). There is not a lot of work to understand how Level 1/2 AVs will recognise each barrier type and respond accordingly, especially variable barriers.	3. Where temporary barriers are installed, they may need to be tested with Level 2 vehicles before allowing live traffic, as part of the traffic management plan. 4. Drivers may need to be warned to disengage AV features through road work sites. 5. Barriers close to traffic lanes may need to have increased reflectivity.

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[110] Tesla Autopilot crash caught on dashcam shows how not to use the system, 2018, https://electrek.co/2017/03/02/tesla-autopilot-crash-video-how-note-to-use/

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
	Level 3			
	Motorway	🔴	There are several examples through either trials or real accidents that AVs have not behaved in the manner that is within an acceptable error rate. With barriers, a common occurrence across Victoria's network it will be important that Level 3 vehicles react in an acceptable manner. At this stage, it is unknown how future Level 3 vehicles will behave at rail level crossings. Vehicles may need to be restricted in these locations or alternatively a connected solution may need to be developed to advise vehicles of the correct behaviour. It is acknowledged South Australia is beginning trials, of an AV shuttle bus that crosses a rail level crossing, later this year (2018) as part of the Flinders Flex program[111]. A particular issue in Melbourne is sharp lane changes and unconventional barrier types around Melbourne's 'Safety Kerb' tram stops. Any error could result in serious consequences. Through the Victorian trials, issues were found with systems disengaging. Along motorways with no emergency shoulders, this leaves little room for error and/or handing back control to the human driver. It is possible that vehicle manufacturers will set the areas a Level 3 can operate in AV mode. It is likely to be on motorways first and progressively extended along arterial roads depending on the surrounding conflicts.	1. Assess current barriers in place on motorways to ensure barriers are to a standard to ensure camera and radar technology can determine what they are. 2. Work with vehicle manufacturers to define areas of operation for Level 3 and above. 3. Accelerate program to upgrade Melbourne's tram stops at least along key movement corridors to a consistent standard. 4. Work with other jurisdictions through the responsible national body to investigate treatments that assist AVs to register barriers e.g. additional reflectors, contrasting colour. 5. Develop a concept of operations (refer to **section 7.2.1**) for how AVs should behave around level crossings and other complicated road barriers e.g. car parking barrier arms. 6. Develop a concept of operations around how AVs should behave around temporary barriers, such as in roadworks zones.
	Arterial Roads	🔴		
	Streets with Conflicts	🔴		
	Unsealed Roads	🔴		
	Level 4/5			
	Motorway	🔵	High accuracy of vehicle travel paths, near immediate reaction times and high-level safety features could see the majority of road barriers become redundant. With AVs being connected and taking away the risk of driver error, the likelihood of Vehicle-to-Vehicle accidents could be reduced, further reducing the need for delineation and separation of traffic flows. Removal of other forms of road furniture such as roadside cabinets and traffic signs will eliminate items that are currently roadside hazards which need to be protected by barrier. A connected fully AV fleet would need no such infrastructure and therefore no assets to protect.	1. Consider the decommissioning of barriers - relying either on a fully connected vehicle fleet or all vehicles operating at Level 3 and above. 2. Through street design guides begin to incorporate required barriers into better street design. 3. Develop protocols, including data management processes, required for changes to barriers, including use of temporary barriers.
	Arterial Roads	🔵		
	Streets with Conflicts	🔵		
	Unsealed Roads	🔵		

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[111] Flinders University's driverless shuttle public trial to commence, https://premier.sa.gov.au/news/flinders-university%E2%80%99s-driverless-shuttle-public-trial-to-commence

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
			Barriers may need to remain in certain areas and situations with the primary role of delineating pedestrians and other road users from AVs. It is possible that vehicle manufacturers will set the areas Level 4/5 can operate in AV mode. It is likely to be on motorways first and progressively extended along arterial roads depending on the surrounding conflicts.	
Road Geometry	**Level 1/2/3**			
	Motorway	🔴	Results so far from AV trials in Australia suggest that the error rate (based on this assessment) is too high to suggest a state of readiness. For example, one video clip shows the vehicle unable to detect another vehicle merging at an on-ramp. See video at this link: https://www.youtube.com/watch?v=0KHntO3WSOA It is too early to determine whether road geometry standards and guidelines need to be changed, however there are clear limitations for AVs when it comes to tight or complex geometry at high speeds. This is further exacerbated by their inability to read advisory signs that often precede these sections of road geometry. AV trials have shown limitations in navigating tight curve radii and road undulation with some vehicles gaining a couple of kilometres when travelling downhill in speed limited modes.	1. Follow technology development.
	Arterial Roads	🔴		
	Streets with Conflicts	🔴		
	Unsealed Roads	🔴		
	Level 4/5			
	Motorway	🟢	Victoria remains one of the safest places in the world to operate a motor vehicle. For every 100 million vehicle kilometres travelled there are only 0.38 fatalities placing Victoria 4th among OECD countries based on vehicle kilometres travelled. This has been due to strong leadership from the state road agency and the application of high quality road design (geometry) standards across the network. It is possible that vehicle manufacturers will set areas that Level 4/5 vehicles can operate in AV mode. It is likely to be on motorways first and progressively extended along arterial roads depending on the surrounding conflicts.	1. Embed AVs into the Safe Systems Approach to road design and planning. 2. Consider developing an AV level of service process as part of Movement and Place – to help manufacturers define selected areas. This could be on sustainable safety principles[112]. 3. Develop and provide guidance on how to make streets easily adaptable.
	Arterial Roads	🟢		
	Streets with Conflicts	🟢		
	Unsealed Roads	🟢		

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[112] Background of the five Sustainable Safety principles, 2012, https://www.swov.nl/sites/default/files/publicaties/gearchiveerde-factsheet/uk/fs_sustainable_safety_background_archived.pdf

Physical asset item	Road / Street type	Meets Min?	Commentary & Gap	Possible Actions
			It is assumed that any area selected will be self-certified by the manufacturer for the vehicle to operate within the existing road geometry, it is assumed they would only do this if based on an acceptable error rate. AVs may provide a number of opportunities to have lower design requirements, due to their advanced driving capability. It will be important to future proof certain streets to make them easily adaptable. With some AVs already capable of adapting to road geometry, albeit at low speeds, it is assumed that level 4/5 AVs will be able to ‘sense’ the road. While radar and LIDAR technology may play a large role in this, additional instruments such as inclinometers will play a role in vehicles identifying the 3D geometry of a road. An improved field of vision should address current limitations around peripheral vision in merging situations. It should be noted that current AVs use line markings to detect curve angles and adjust accordingly. With the assumption that line markings will provide little input into the Level 4/5 driving task, it must be considered how vehicles will ‘read’ road geometry. This may be particularly important when it comes to identifying road surfaces and adjusting driving patterns accordingly, a function that already exists for weather conditions.	

Figure 36: West Gate Bridge Edge Line and Barrier (Source: Google Maps)

Figure 37: Proposed Centre Median Treatment Wire Rope (Source: VicRoads)

5.5 Discussion of Impacts and Potential Responses

The following paragraphs provide an in-depth discussion on the impacts and potential responses relating to AVs and Victoria's road assets. For each road asset we have identified:

- The possible impact in relation to either the transition phase/Slow Lane scenario or full connected AV scenario
- Potential responses for existing and future road infrastructure.

5.5.1 Physical Signage

5.5.1.1 Impact - Transition Phase/Slow Lane Scenario

Consistency in sign design and application is key for both road users and AVs. While there are national and state guidelines which advise on sign face design and signage use, the governance structure of road ownership and management sees variances that exist between different assets and corridors. Interpretation of these guidance documents is left to each of the 79 local government authorities when it relates to their part of the 150,000 km road network. This often results in signage that is installed in non-standard locations as well as development of bespoke sign faces. These inconsistencies can cause issues for human drivers, in addition to Traffic Sign Recognition (TSR) systems. [113]

Rationalisation of Victoria's sign face set would reduce the volume of data that TSR systems would need to learn, while also making the road environment less confusing for human road users. Opportunities for rationalisation exist in speed signs qualified by 'END' or 'AHEAD' which could instead be replaced by standard static speed signs which AVs could read more consistently.

Simplification of sign face design - to better align with the Vienna Convention[114] - would be advantageous for both AV and non-AV vehicles. Diversion from the text heavy design standards that are currently employed in Australia would not only allow for easier recognition of signage messages for international drivers, but would also increase the reliability of TSR system reads. A symbol based system that closely aligns with Europe, where most TSR technology is initially developed, would support TSR uptake.

It is important that rationalisation and harmonisation actions are undertaken collaboratively with other states to ensure Victoria's signage does not evolve in a vacuum which could see vehicles and drivers experience TSR issues when travelling interstate.

As reflectivity and readability of signage will become more important as more vehicles use TSR[115], it is recommended that a review of maintenance regimes is undertaken to ensure that signage is kept to a high standard. The safety implications of poor signage may significantly increase as vehicles approach Level 3 and have their speed directly impacted by TSR systems. Maintenance regimes could be expanded to consider reviewing and validating signage with a TSR style system, as well as human vision to ensure all vehicles and road users are catered for.

These practices also lend themselves to pre-road opening inspections before AVs are permitted access, where drive throughs with trial AVs would ensure that signage placement, height, and angle to roadway were acceptable for TSR systems.

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[113] Transurban, 2018, https://cAVs.transurban.com/

[114] https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XI-B-19&chapter=11&Temp=mtdsg3&clang=_en

[115] Transurban, 2018, https://cAVs.transurban.com/

The biggest challenge of this phase will be ensuring that signage design and practices are appropriate for both human drivers and camera vision based TSR systems. Mixed levels of AV technology would require varying amounts of signage with some possibly requiring none, or relying on connectivity to infrastructure to provide this information. A connected solution would cut out readability issues currently encountered by TSR systems and allow for dynamic signage solutions, however it does not accommodate for non-AV vehicles and Level 1 and Level 2 AVs. An innovative solution may be needed for an integrated Slow Lane scenario. One such solution could be the application of machine readable codes being embedded into current road signs. Technology has been developed where a clear sticker type application containing embedded code is applied over an existing sign face. This code cannot be seen by human drivers and therefore facilitates a Slow Lane scenario [116].

5.5.1.2 Impact - Full Connected AV Fleet

It is assumed there will be limited need for road signage in a full AV fleet, as vehicles could adapt to a combination of the road environment and data from connected assets. Ownership and accuracy of these datasets will need to be addressed early, to ensure good governance and avoid safety and liability issues. Data and asset management will need to address issues such as change management processes, whether this be for permanent changes or for temporary situations such as during roadworks.

In a full AV fleet, it is assumed that the majority of road signage will be for other road users rather than for the AVs and their occupants. Pedestrians, cyclists and even public transport users will still require way finding support and signage to warn them of possible vehicle interactions. In a service based scenario, signage that designates pick-up areas will be required.

5.5.1.3 Potential Response

As discussed, a major challenge is likely to be ensuring signage design and practices are appropriate for both human drivers and camera vision based TSR systems during the transition phase or Slow Lane scenario. This will require an innovative approach from both industry and government, and highlights the need for strong collaboration within the industry.

Potential response for existing infrastructure – review of placement of signs is highly encouraged. Incorporating a camera-based drive by audit into maintenance inspections would allow road authorities to determine whether a signs current location is acceptable for TSR systems.

A review of signage design guidelines and standards would allow for rationalisation of sign face design. This review should focus on elimination of text heavy designs and investigate the integration of symbols from the Vienna Convention based signs set. This would not only create a more consistent

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[116] Muioi. D, Business Insider Australia, 2017, https://www.businessinsider.com.au/3m-hides-tech-in-sides-to-help-general-motors-self-driving-cars-2017-8?r=US&IR=T

environment for AVs to operate in but could also reduce the time needed to calibrate vehicles to the Australian market.

It is expected that roll out of most changes is undertaken in a managed and progressive manner which coincides with the replacement life of existing signage. This roll out should also prioritise signage that causes an adverse effect on AVs over those that are not read at all, especially in cases where these signs may compromise road user safety as technology progresses towards TSR controlled vehicle speeds.

Potential response for future infrastructure – the simplification of sign face design and sign use should be considered in the design of all new infrastructure. Pre-opening road safety audits could be expanded to include TSR based drive throughs to ensure signs are installed in appropriate locations and at appropriate angles.

5.5.2 Lane Widths

Conventional road design practice in Australia (and Victoria) preferences a standard lane width of 3.5 metres for urban roads. This is codified in the Austroads Guide to Road Design[117], which states that 3.5 metres is the desirable width to be used for general traffic lanes on all roads. The identified basis for adopting a width of 3.5 metres is that it allows for large vehicles to pass or overtake, without either vehicle having to move sideways towards the outer edge of the lane.

However, there is growing recognition of the external costs, in terms of foregone opportunity for other uses, of wide traffic lanes and the benefits which can potentially be realised by implementing lane widths of less than 3.5 metres. This is reflected in the way Australian road authorities have embraced ‘Movement and Place’ frameworks[118] which seek to shift traditional road design practice towards being more contextually aware of factors other than traffic operation, and in the publication of urban focussed road design guidance[119] emphasising design for people.

A key benefit of adopting narrower lanes in urban areas is road safety. Decreased lane width has been shown to positively correlate with decreased travel speeds[120], which in turn reduces the frequency and severity of traffic incidents. This behaviour is generally attributed to the concept of risk compensation, whereby a reduced perception of safety leads to motorists proceeding with additional caution and alertness. The concept is clearly illustrated in the shared space intersection designs pioneered by Hans Monderman[121]. An additional key benefit, and what could likely be the primary benefit as AV uptake becomes significant, is that

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[117] Austroads, 2016, https://www.onlinepublications.austroads.com.au/items/AGRD03-16
[118] VicRoads, 2016, https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/smartroads
[119] National Association of City Transportation Officials, 2018, https://nacto.org/publication/urban-street-design-guide/street-design-elements/lane-width/
[120] Abdel-Whaed. A.T, Hashim. I.H, Moustafa. Y, 2016, https://www.sciencedirect.com/science/article/pii/S2095756415200165
[121] McNichol. T, 2004, https://www.wired.com/2004/12/traffic/

narrow lanes in urban areas allow for more road space to be allocated to non-private vehicle uses, such as widened footpaths or cycle lanes, without a significant reduction in traffic capacity.

5.5.2.1 Impact - Transition Phase and Slow Lane Scenario

Findings from recent AV trials held in Victoria[122] have highlighted the difficulties which current automated driving technology has in reliably perceiving and reacting to road geometry in a controlled freeway environment. This suggests that in complex urban environments, where the potential benefit of narrow lanes is greatest, uptake of lower level AVs (Level 2, Level 3) into the fleet is unlikely to allow the introduction of lane widths narrower than what is considered the minimum for human drivers (~2.8 metres to 3.0 metres, where heavy vehicle traffic is limited).

As such, during a transition phase, the impact of AVs on the selection of lane widths is likely to be negligible. However, if the fleet was able to achieve a minimum autonomy of Level 2 and greater, the case to maintain 3.5 metres as the standard could be reviewed.

5.5.2.2 Impact - Fully connected AV Fleet

For the purpose of geometric design, a typical passenger vehicle is assumed to be only 1.94 metres wide[123], while buses and other heavy vehicles (rigid and articulated) are assumed to be 2.5 metres wide. Depending on the traffic mix, current road design practice provides lanes which are between 1.5 metres and ~1.0 metre wider than the vehicles which travel along them.

A fully automated vehicle fleet with sensing and control capabilities far more accurate and reliable compared with human drivers, could allow a significant reduction in roadway lane widths across the full spectrum of road and street classifications. In urban areas, adopting lane widths which are closer to actual vehicle widths, could realise substantial ‘place’ benefits through reduced road space allocation to vehicles. Along arterial roads and freeways, reduced lane widths may create opportunities for additional capacity at low cost by permitting additional lanes within the same footprint. For new construction, substantial capital and operational expense benefits could be realised through reduced pavement footprint.

5.5.2.3 Potential response(s)

Potential response for existing infrastructure - no infrastructure response regarding lane width is considered necessary to facilitate the introduction of a fully AV fleet. However, in response to the improved capabilities of a fully AV fleet, reallocation of road space away from vehicle use through the implementation of narrow lanes, should be considered where the benefits of providing increased pedestrian, cyclist or public transport space in the road

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[122] Transurban, 2018, https://cAVs.transurban.com/

[123] Austroads, 2013, https://www.onlinepublications.austroads.com.au/items/AP-G34-13

corridor would be substantial. This effort should be prioritised through existing ‘Movement and Place’ classification and assessment frameworks.

Potential response for future infrastructure - during the transition phase, road design practice should tend towards adopting desirable minimum lane widths under current standards (typically 3.0 metres).

At the point where the vehicle fleet effectively becomes fully automated, road geometry guidelines around lane widths should be updated to reflect the enhanced sensing and control capabilities of a fully AV fleet. This should see desirable lane widths substantially reduced (likely < 3.0 metres), depending on the traffic mix context and actual vehicle performance (i.e. the need to account for trailer sway in multi-combination heavy vehicles may persist, even when autonomously driven).

5.5.3 Line marking

5.5.3.1 Impact - Transition Phase and Slow Lane Scenario

Consistency in line marking arrangements is likely to be key for Level 1 and Level 2 AVs and non-AVs in a Slow Lane scenario. Recent trials have highlighted the need for well maintained, clear and consistent line marking arrangements that are free from conflicting lines and markings[124]. Better enforcement of design standards and a more rigorous maintenance and cleaning program could increase safety of all road users and the accuracy of AV technology.

Victoria has recently endorsed the use of yellow line marking in road works zones[125]. This approach employs yellow line marking paint to depict the temporary arrangements while original white lines remain. Trials of Level 2 vehicles have shown that the yellow lines are generally read well, yet the remaining white lines can cause conflicting messages for on board systems. This further emphasises the need for consistency in line marking arrangements to ensure a safe road environment.

It should be noted that the majority of local roads in Victoria do not have significant levels of line marking. Generally, many local roads do not have a centreline, with line marking limited to intersections with other roads. This restricts the use of Level 1 and Level 2 AVs in these areas and is likely to become a factor in a Slow Lane scenario and transition phase.

5.5.3.2 Impact - Fully Connected AV fleet

Much like road signage, there may be limited need for line marking in a full AV fleet, as vehicles will adapt to a combination of the road environment, map data and information from connected assets. Accuracy of these datasets and any map or location based technology will need to be ensured to guarantee the travel paths of vehicles.

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[124] Transurban, 2018, https://cAVs.transurban.com/content/dam/cAVs/documents/victorian-trials-report.pdf

[125] VicRoads, 2018, http://citylinktullawidening.vic.gov.au/project-updates/follow-the-yellow-lines

Various forms of line marking may be required for other road users with pedestrians, cyclists and public transport users requiring way finding support.

A full AV fleet provides significant opportunity for dynamic lanes without the need for expensive infrastructure and human error issues. Melbourne already has examples of dynamic lanes in use - Figure 38 below shows dynamic lanes on Queens Road, South Melbourne. It is noted that under a full AV scenario the middle lane could be easily switched to better meet demands, currently it is time based.

Figure 38: Queens Road, South Melbourne Dynamic Lanes (Source: Google Maps)

5.5.3.3 Potential Response

As discussed under **section 3.2.2 Fleet Configuration and Lifecycle,** line marking may need to be maintained as the default lane use control for the foreseeable future. It is likely that human drivers and camera based driving systems will need to be removed from the road system before line marking is made redundant for AV operations.

A majority of traffic fatalities in Australia occur at night with the death rate estimated to be between three to four times higher at night than during the day[126]. It is important to highlight that line marking is a road safety issue, not just a road maintenance issue. Ignoring AV requirements, upgrading line marking across Victoria just for human drivers is expected to deliver significant road safety gains. Research[127] undertaken by the Monash University Accident Research Centre (MUARC) to compare enhanced road markings found: *'that participants were better able to maintain lane position and speed with the enhanced markings than with the standard markings. A similar pattern was found for the subjective measures: workload was rated as lower for the enhanced markings; likewise, subjects reported the drives as being easier and were more confident in being able to drive safely when the roads displayed the enhanced markings.'*

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[126] Carnaby, B, 2005, http://acrs.org.au/files/arsrpe/RS050017.pdf
[127] Anderson. J; Horberry. T; Regan, M.A, 2006, https://www.sciencedirect.com/science/article/abs/pii/S1369847805000732

The US Department of Transportation research suggests that: existing line markings reduce crashes by 21%, and edge lines on rural two-lane highways reduce crashes by 8%. It notes improved traffic flow benefits between 6am and 7pm with average speeds increasing by 3.2 km/h. It also cited articles with costs and benefits ranging from 1:21 to 1:103 for line marking.[128]

It is noted that single, solid line marking costs on average $1,600/km in Victoria[129], not accounting for traffic management and associated support costs, which could double the cost. Based on a conservative assumption of 100% of Victoria's non-declared roads (suitable for general traffic) requiring new or improved single, line marking, the cost of this is likely to be in the order of $250 million, excluding the additional costs identified above. This could make the task of line marking all local roads unattainable for local authorities.

It is recommended the Victorian Government review its approach and standard for line marking to better understand the safety benefits of enhanced line marking for both humans and AVs.

5.5.4 Pavement

To a large extent, pavement design is driven by axle load considerations, which means that heavy vehicles contribute disproportionally more to design and maintenance requirements than light vehicles in terms of their volume composition on the network.

Pavement structural analysis quantifies the critical strains and stresses which are induced by the traffic weight onto the existing pavement structure. The layers within the pavement structure are either considered to be fully elastic or visco-elastic, uniform in lateral extent, or variable, and with full friction, or no friction between layers.

Higher critical strains and stresses are induced into the pavement by heavy vehicles. The heavier traffic weight applied can vary - from a single vertical load with a uniform contact stress, to multiple loads with multi-directional components and non-uniform stress distribution. The rate of loading of pavement layers will also vary with traffic speed (in particular heavy vehicles i.e. Class 3 to Class 12 vehicles in accordance with Austroads classification).

Within this context, the following discussion concentrates on issues associated with heavy vehicles and their potential impact on the existing (or future) pavement.

5.5.4.1 Impact - Transition Phase and Slow Lane Scenario

If vehicle demand is increased in an AV world, it may cause more wear on pavements, reducing the design life and accelerating the maintenance regime through greater frequency of routine/periodic maintenance activities. This may be slightly offset by an increased travel speed that reduces loading time, however

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[128] https://www.fhwa.dot.gov/publications/publicroads/93summer/p93su4.cfm

[129] Rawlinsons, 2016, Australian Construction handbook

more research is needed to understand whether this will be realised. A scenario where AVs use dedicated routes could allow for specific parts of the network to be designed to a different, possibly more prescriptive standard to facilitate AVs while other lanes could be reserved for light vehicles (Level 0-3) and designed to a simpler standard, potentially minimising impacts on the overall road pavement and prolonging life rather than reducing it.

With coordinated platooning more likely in a Slow Lane scenario, the concentrated loads which platooning generates could be an issue for flexible pavements, Victoria’s preferred pavement type. Flexure from vehicle loading is likely be sustained for longer periods due to platoon size, not allowing it to ‘recover’ between load cycles as it would if trucks were random and further spaced[130]. Fatigue is possible which could result in a reduced design life for current pavement designs, however this remains uncertain without testing.

With higher level AVs able to connect to infrastructure or receive dynamic information, it may be possible to balance traffic volumes across the network by diverting or re-routing certain vehicles. This could see pavements approaching their design life - or roads noted as having defects such as heavy rutting or potholes - being avoided by AVs. This could reduce the loading on that piece of road and in turn prolong its design life. This strategy could form an important yet complex part of a road authority’s maintenance regime. Likewise, the ability to better monitor vehicle usage means that more sophisticated cost allocation regimes could be applied, allowing for the possibility of better matching charges to actual pavement maintenance costs.

It may be possible in the future that road authorities will be able to utilise the data collected by AVs to better understand the road asset condition and what remedial works maybe required.

5.5.4.2 Impact - Fully Connected AV Fleet

As per a Slow Lane scenario arrangement or transition phase, the design life of pavements may be reduced in a full AV fleet world if vehicle demand is increased, causing accelerated pavement deterioration and increased frequency of routine/periodic maintenance activities such as patch, crack-sealing and resurfacing.

Assuming that a full AV fleet results in highly accurate vehicle positioning - and therefore more concentrated wheel paths - concentrated areas of road pavements will bear the majority of vehicle loads, varying only by vehicle type rather than driver. One advantage of this could be the reduction in lane width and roadway widths as a whole. A reduction or abolition of vehicle ‘wander’ due to high accuracy of vehicle travel paths is likely to allow for narrower road reserves and possible repurposing of some areas of road reserves.

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[130] Technical University of Delft, 2017, https://repository.tudelft.nl/islandora/object/uuid:743e121a-9934-4d73-9b86-92d6eda6aa21/datastream/OBJ/download

5.5.4.3 Potential Response

From concentrated vehicle tracking to a connected system that allows vehicle movements to be dispersed throughout the road cross-section, the planning, design, construction and maintenance of pavements is expected to be different in the future.

At this stage of the AV evolution, it is difficult to quantify the level of extra rehabilitation, periodic and routine maintenance, and resurfacing VicRoads or local governments will need to undertake, given that pavement distress is dependant on many variables, such as:

- The age of pavement
- Structural composition e.g. granular with seal, thin asphalt, cement base or subbase with seal
- Traffic loading the road is exposed to
- Drainage and weather conditions
- Construction history, especially if one section of road has varying composition across the formation
- Pavement change can also occur within one lane.

One possible result of wide-scale AV platooning could be accelerated roughness, cracking, rutting and polishing, requiring a higher frequency of pavement intervention. However, the frequency of invention is also dependant on the type of asphalt mix, and existing waring course type.

Potential response for existing infrastructure – should concentrated vehicle wheel paths be realised from AVs, existing pavements would likely require more frequent maintenance due to the probable increased wear and loading. To retrofit existing roads, the road network would require pavement strengthening works in single lanes or in sections of lanes. This would involve significant operational disruption and capital cost to excavate to the subgrade level required for reconstruction of the pavement to support concentrated heavy vehicle wheel paths.

Given the significant disruption and cost associated with retrofitting existing assets and designing for an uncertain scenario, it is reasonable to expect that a technology/connected solution would be pursued and developed to maximise the asset life of an existing or future road pavement over an infrastructure solution to upgrade the asset. This technology may include lane positioning of a connected fleet such that vehicle tracking is altered over time to ensure uniform wearing of the pavement and maximise the design life of the existing asset.

Potential response for future infrastructure - for infrastructure yet to be built or in the planning phase, there is an opportunity to consider concentrated vehicle loads in the design and construction of the new pavements. This may be achieved through use of higher pavement requirements and more polymer modified binders to increase fatigue resistance[131]. However, the level of certainty on what is

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[131] Roads and Maritime services, 2010, http://www.rms.nsw.gov.au/business-industry/partners-suppliers/documents/specifications/n3252.pdf

required and the ultimate operational scenario is currently low, increasing the risk of investment that is not realised during the life of the asset.

It could become possible in the future to restrict AV heavy vehicles to particular lanes on the freeway. These lanes could then be designed with increased strength to cater for high volumes of heavy vehicles and closer headways. Currently, heavy vehicles are banned from the inside lanes of several freeways in Victoria, therefore changing the way roads are designed and maintained could already be a response for the way roads are managed. However, it could then be argued that the road should be future proofed for truck operations to enable heavy vehicle operation in all lanes.

It is highlighted that recent improvements in road material technology have the potential to enable heavier vehicles or possible platooning vehicles. As previously mentioned in this study, it is suggested that Victorian transport authorities keep abreast of these developments to ensure performance specifications consider new types of materials.

Geographical Information Systems (GIS) have improved significantly in recent years in the types and categories of data that can be held. The Victorian government already holds significant data on pavement and structures. This data could be used to inform vehicles of which lane to travel in or avoid, resulting in prolonging the life of the pavement.

5.5.5 Bridge Structures

5.5.5.1 Impact - Transition Phase and Slow Lane Scenario

It is likely that a Slow Lane scenario environment could bring rise to vehicle and freight platooning. It is possible we may see an increased concentration of the vehicle loads create a situation where the platoon becomes one large load rather than several concurrent loads. The reduction of spacing and therefore time between vehicles may mean that flexure in structural elements of bridge structures will not have adequate time to recover between loadings as they do under current traffic loads where vehicles are more spaced and randomly concentrated. This could result in accelerated fatigue of structural elements.

5.5.5.2 Impact - Full AV Fleet

As noted in **section 3**, AV technology allows for greater vehicle density due to reduced headway distances. This arrangement is advantageous for efficiency of fuel use but may present an issue for structural components of the road network. A greater density of vehicles and greater throughput of vehicles not only sees both a higher and more concentrated loading pattern, but also a prolonged loading of bridge structures. The effects of this loading pattern and scale need to be better understood and considered in design standards with existing structures assessed for their capability to convey these loads.

5.5.5.3 Potential Response

As with pavement, the future requirements of structures will be a function of the way in which the road network is operated and how technology develops.

Potential response for existing infrastructure - changes to existing infrastructure could be an increased number and change in location of traffic lanes, and loading of the structure for which it had not been designed (such as platooning). This may mean additional structures adjacent to existing road assets or strengthening existing road assets. This type of investment is typically required when a clear need is identified for the works. This is expected to be the case for existing infrastructure in the future.

Potential response for future infrastructure - for infrastructure yet to be built or in the planning phase, there is an opportunity to consider how the potential might impact on the structure and how the current design can consider or respond to the potential future requirements. While the ultimate requirements are unlikely to be clear, a design that considers how changes would be made in the future should be developed. The design could consider what type of strengthening works could be easily undertaken in the future, how that would be designed and constructed, and when it would be required within the design life of the asset.

In addition, the Victorian Government already holds a significant amount of information around structures, this could be used to inform vehicles to avoid certain structures or change the way the vehicle is driven. For example, controls could be in place to set a minimum headway on bridges to ensure structure loadings are no different than current heavy vehicle design considerations and standards.

5.5.6 Barriers

5.5.6.1 Impact - Transition Phase and Slow Lane Scenario

The Slow Lane scenarios and early stages of the transition phase are unlikely to change the need for roadside barriers. While human error and the need to protect roadside assets remain a factor, barriers will continue to play a role in protecting road users.

It is suggested that during road work conditions, the efficiencies AVs present may be limited[132] and therefore continued barrier use in these circumstances is recommended. This is due to the inability to respond to the modified road layouts, contra flow style arrangements, and inability to dynamically respond to incidents or construction changes on a daily basis.

5.5.6.2 Impact - Full AV Fleet

High accuracy of vehicle travel paths, near immediate reaction times and high-level safety features could see the eradication of the majority of road barriers.

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[132] http://www.austroads.com.au/news-events/item/418-supporting-the-introduction-of-automated-vehicles

With AVs being connected and taking away the risk of driver error, the likelihood of Vehicle-to-Vehicle crashes could be reduced, further reducing the need for delineation and separation of traffic flows. Removal of other forms of road furniture such as traffic signs will eliminate items that are currently roadside hazards which need to be protected by barriers. A connected and fully automated fleet would need no such infrastructure and therefore have no assets to protect.

Barriers may need to remain in certain areas and situations with the primary role of delineating pedestrians and other road users from AVs.

5.5.6.3 Potential Response

While barriers provide protection to drivers and pedestrians, they also impose a physical constraint on the road corridor, particularly if they are installed within the carriageway such as a centreline to provide separation between two directions of traffic. The removal of barriers such as these in the future may provide opportunities to increase the trafficable operational cross section of a road corridor, increasing capacity and allowing dynamic operation arrangements such as contraflow. Alternatively, the removal of road side furniture and barriers could allow for more landscaping and urban design treatments which reduce the amenity impacts of the carriageway.

Potential response for existing infrastructure - the need to install and maintain barriers is likely to remain until a point where the probability of errant vehicles is very low and human drivers are no longer involved in the driving task.

Potential response for future infrastructure - while the need for barriers for new infrastructure is likely to remain in place for some time, the easy removal of those barriers in the future is something that could be considered in the design of future infrastructure. That is, design should consider decommissioning the barriers, the opportunities for the entire road corridor once those barriers are removed, and how the design of the current road corridor could consider those changes. For example, drainage or utilities that might typically be constructed adjacent to the barriers, outside of the interim running lanes, could be located elsewhere to allow for that area to become a future lane in the ultimate arrangement.

5.5.7 Road Geometry and Intersections

5.5.7.1 Impact - Transition Phase and Slow Lane Scenario

Findings from recent AV trials held in Victoria[133] have highlighted the risks associated with AVs within the current road geometry. Level 2 vehicles demonstrated they have limited recognition of stationary traffic, merge arrangements, entry ramps and exit ramps requirements. Further trials of higher levels of autonomy (Level 3+) will need to test that new technology has overcome these issues.

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[133] Transurban, 2018, https://cAVs.transurban.com/

5.5.7.2 Impact - Full AV Fleet

A connected, fully automated fleet would push the boundaries in relation to intersection design. In many ways, roundabouts would be the most efficient form of intersection for this scenario, as traffic flow is maintained at a higher level than a signalised style intersection. However, this solution can have more significant land impacts and is less than ideal for pedestrians and other road users.

Signalised intersections may be less efficient on the surface, however if they had full connectivity - Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) - they are likely to be far more efficient than current arrangements, while also facilitating pedestrian and bicycle movements.

If higher travel speeds can be achieved on major movement corridors, this will then need to be factored into road design geometry or, conversely, AVs will need to modify operations (e.g. reduce speed) in areas of geometry deemed deficient for the vehicle. While accurate travel paths will allow for more optimised and rigid geometry standards, there will be a point where physics will intervene.

5.5.7.3 Potential Response

Potential response for existing infrastructure - alignment of existing infrastructure may limit the use of Level 1 and Level 2 AVs, due to their inability to fully interpret road geometry and adjust their paths and speeds accordingly. However, large scale modifications to accommodate these vehicles is not recommended. Level 1 and Level 2 AVs and non-AV vehicles will need to rely on human intervention, while highly automated vehicles (Level 4+) should be able to navigate such road geometry independently.

Potential response for future infrastructure - design guidelines will need to evolve in line with uptake and development of AV capabilities. If a full AV scenario is realised, guidelines will need to be amended to ensure the maximum benefits around land use are achieved.

5.5.8 Other Physical Infrastructure

5.5.8.1 Improving Public Transport Priority

Achieving a greater public transport mode share is a key priority for Victoria[134]. The ability to carry out seamless multi-modal journeys is an enabler to achieving this goal. However, some of the existing multi-modal infrastructure, such as ‘Park and Ride’ facilities, are currently impacting on the multi-modal customer experience[135]. Automated vehicles, and the potential car share models that could be enabled through AVs and ZEVs, have been identified as having the potential to address ‘first and last mile’ requirements to make public transport more attractive.

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[134] Infrastructure Victoria, 2018, Five-year focus: Immediate actions to tackle congestion

[135] Rogers. A for Herald Sun, 2017, Doncaster Park and Ride an overcrowded nightmare for long-suffering bus commuter

Modelling carried out for European cities, such as Lisbon, suggests that the integration of high-capacity public transport with automated car sharing services could lead to significant (up to 37.5%) average travel time reductions for users choosing to travel by a combination of car sharing and high capacity public transport, over using a private vehicle[136].

To support greater public transport usage through seamless multi-modal journeys, Victoria could consider opportunities to improve the integration of automated car sharing fleet services with public transport stations and hubs. Examples may include re-purposing sections of 'Park and Ride' facilities, where they are close to stations, to allow quick and easy pick-up and drop-off of passengers.

Under Infrastructure Victoria's Fleet Street scenario, where automated shared vehicles are predominant, the re-purposing of 'Park and Ride' facilities for urban realm improvements and property developments could help to achieve better integrated land use and transport outcomes. Further, Transit Orientated Developments (TODs) could be pursued through improvements to amenities and economic opportunities on the old parking sites.

It is suggested that current road planning should begin to consider how roads could be easily changed in the future to carry more shared and public transport vehicles. The example below from NACTO highlights possible changes within the same road corridor – how could this flexibility be built in the start of a project?

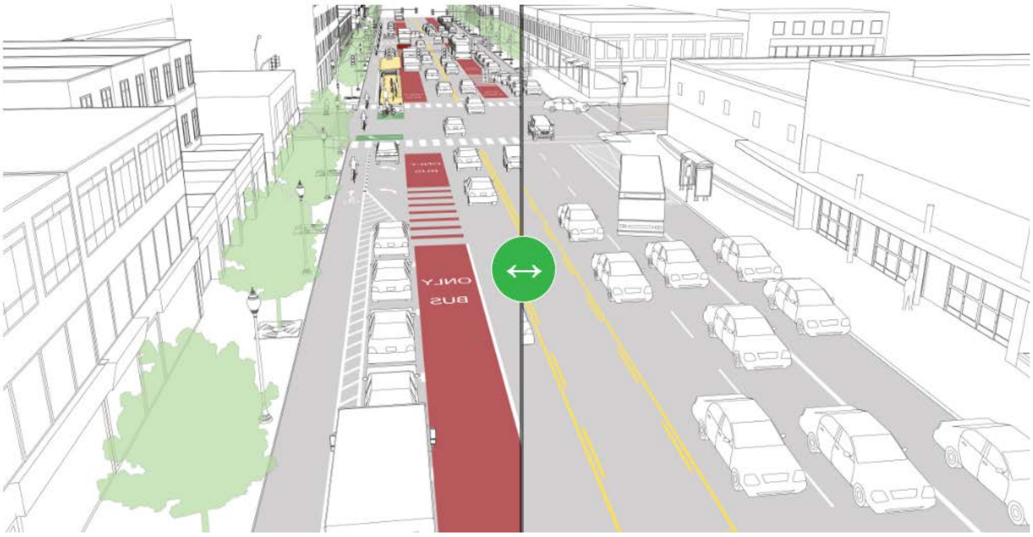

Figure 39: NACTO Transit Street[137]

5.5.8.2 Drainage

Drainage design could also change dramatically with the advent of a full AV fleet, especially an EV one. Concentrated pavement strips and accurate wheel paths could facilitate drainage assets which exist very close to the running lane and

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[136] OECD/International Transport Forum, 2015, Urban Mobility System Upgrade: How shared self-driving cars could change city traffic.

[137] National Association of City Transportation Officials, 2018, https://nacto.org/publication/transit-street-design-guide/transit-streets/street-environments/

possibly between wheel running paths. Accuracy of vehicles could allow for pits to no longer have trafficable lids and would also reduce maintenance costs due to damage and impact. The ability to regain road reserve space could allow for more green space and natural infiltration, potentially resulting in less manmade drainage assets.

5.5.8.3 Noise Attenuation

A fleet of electric AVs could see noise walls become less relevant. Reduced engine noise, no heavy engine braking and no horn use could see a reduction in noise pollution. However, the realisation of this benefit will be greatly dependent upon advancements in wearing course design – i.e. the upper layer of the roadway.

5.5.8.4 Emergency Parking Bays - Minimum Risk Condition

Catapult Transport Systems' study into 'Infrastructure Requirements for CAVs'[138] highlights the issues involved when an AV malfunctions. This issue is known as 'fallback' or 'minimum risk condition'. General Motors states:

'Fallback is transition to a minimal risk condition (safe state) in the event of a problem with the self-driving system that prevents continued safe operation without the transition.'

'Should a malfunction occur, the diagnostics system determines whether the appropriate response is a fail-operational state or a fail-safe state, and transitions the vehicle to the corresponding safe state. When required, the self-driving system will operate the vehicle at a reduced speed or pull to the side of the road and execute a safe stop, as appropriate'.[139]

The Arizona Department of Transport, where Waymo has advanced testing of Level 4 and Level 5 vehicles, prescribes that for AVs without a human present, the operator is required to submit a statement to certify:

- If the automated system fails, the AV will achieve a **minimal risk condition.**

Arup has observed from trials in Australia that the minimum risk condition greatly differs between manufacturers.

AVs coming to a stop in the vehicle lane, driving at a low speed or weaving across to a shoulder, may all cause significant issues for operations and safety. It should also be noted that emergency shoulders are not safe havens; the NSW Government reported there were 146 crashes in emergency lanes between 2007 and 2011, resulting in eight deaths and 104 injuries[140].

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[138] Catapult, 2017, https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2017/04/25115313/ATS40-Future-Proofing-Infrastructure-for-CAVs.pdf

[139] General Motors, 2018, https://www.gm.com/content/dam/gm/en_us/english/selfdriving/gmsafetyreport.pdf

[140] Keep your eyes on the road, 2012, http://www.keepyoureyesontheroad.org.au/pages/Side-of-the-road-dangers

If AVs are used on high speed roads in Victoria, road authorities may need to be proactive in instructing vehicles on what to do in minimum risk condition mode and/or understanding what provisions may need to be designed into the road network.

Catapult Transport Systems suggest that safe harbours need to be appropriately designed, contain enough space for an appropriate number of vehicles to stop, and to stop frequently enough so AVs can access them when required. It is suggested that vehicles not in ‘fallback’ position should be restricted from these areas.

The roll out of managed motorway systems in Victoria (e.g. overhead lane management) has resulted in several emergency shoulders on Victorian freeways being converted to traffic lanes. Figure 40 highlights a stretch of the Monash Freeway managed motorway and a possible safe haven/emergency bay for AVs. Future projects will need to consider, on a case by case basis, the requirements to ensure minimum risk condition. This could be done through developing a Concept of Operations (refer to **section 7.2.1.2**), which considers minimum risk.

Figure 40: Monash Freeway - Emergency Bay (Source: Google Maps)

5.6 Case Studies – Local Road Challenges

The following case studies have been developed to highlight roads and streets that will have particular challenges for the operation of AVs.

5.6.1 Unsealed Road - Grammar School Road, Merrijig

Unsealed roads have the potential to limit the effectiveness and uptake of AVs in regional areas. Unsealed roads are common in many tourist-driven localities of Victoria including the wine and snow regions. An example of this is Grammar School Road in Merrijig which provides access to a school educational facility. This particular road is unsealed and carries several different types of vehicles including school buses and agricultural vehicles. Figure 41 shows the intersection of this unsealed road with the sealed Mount Buller Road.

Figure 41: Intersection of Grammar School Road and Mount Buller Road, Merrijig (Source: Google Maps)

In a Slow Lane scenario or transition phase, there will be various vehicles that will require human drivers to navigate such arrangements. The lack of line marking, often narrow or single bi-directional lane configuration and unsealed surface course. Unless additional infrastructure such as V2I or detailed digital mapping was provided, AVs would be unable to use their automated driving functionalities. In Australia, relatively large fleets of automated trucks already operate on unsealed roads within several mines, however these sites have detailed mapping and high levels of connectivity with a control centre (V2I) and with other vehicles (V2V).

5.6.1.1 Potential Response

It would be possible to upgrade these roads to be sealed, wider and line marked removing the need for human intervention - however this not seen as a practical or cost-effective solution.

AVs could be restricted to automated operation on sealed roads only, with operation on unsealed road resulting in control being handed back to the human driver. This could be as simple as developing a symbol based unsealed road warning sign that is recognised by AVs. Upon recognition of this sign non-AVs would proceed with the same caution as present vehicles, Level 1 and Level 2 AVs could be programmed to request that the human driver take back control of the vehicle for this stretch of road.

In the future, highly automated vehicles could either rely upon their high accuracy maps and ability to adapt to road environments to navigate the unsealed road, or take a similar approach to the operation of AV trucks in mine sites. When an AV vehicle determines it is unable to operate within the environment, a person in a remote-control centre could take over and manoeuvre the vehicle through the situation.

5.6.2 Narrow Unmarked Street with Parking – Clarke Street, Northcote

Similar to the issues identified in the previous example, local roads provide limitations for some levels of AVs. The majority of these issues relate to the lack of line marking and presence of parked cars. One example of a local road that interfaces with a major road is Clarke Street, Northcote. Located just 5 km from central Melbourne, this local road conveys a high volume of traffic including heavy vehicles due to its convenient link between the main roads of neighbouring suburbs. As seen in the figure below, this local road has no line marking, with the exception of intersections with other roads, and parking on both sides.

Figure 42: Clarke Street, Northcote (Source: Google Maps)

At least in the transition phase most vehicles will likely require human drivers to navigate local roads similar to Clarke Street. The lack of line marking will limit the ability of lower level AVs to navigate, and the presence of parked cars - and the need to give way to oncoming traffic between the parked cars - is a task that lower level AVs are not currently capable of, although this could change.

Removal of parked cars would be difficult in a suburb such as this where many dwellings do not have garage structures or driveways. This situation is very common in Melbourne’s inner suburbs and could prove a barrier to AV uptake in these areas. Unless there is a move towards a full AV shared fleet scenario, AVs will need to be able to navigate their way between parked cars and oncoming traffic. A shared fleet scenario could reduce or eliminate parked vehicles and therefore reduce this as an obstacle.

A signage or C-ITS solution could be considered, similar to that proposed for unsealed roads, which forces a human driver to take back control of the vehicle when driving in these areas. This could circumnavigate these issues in the shorter-term. It is assumed that in a full AV scenario, vehicle technology and precise mapping will allow high level AVs to navigate local roads environments.

5.7 Conclusion, Findings and Recommendations

5.7.1 Conclusion

The potential physical infrastructure responses will vary significantly based on the penetration rate of AVs, connected vehicles and the length of the transition period. Solutions will need to be developed which integrate the needs of all road users, not just AVs. It is also clear that a high level of uncertainty exists within this space and as such Victoria must keep abreast of progress and emerging trends as a priority.

Further research into the practicalities of freight platooning, and its possible impact upon infrastructure - particularly regarding pavement and bridge structures - is highly recommended; this is expected to be led from a national level. This will aid in future proofing investments in new infrastructure and identify priorities for retrofitting existing infrastructure to extend/maintain asset life and also ensure safety of all users.

A framework should be developed to assist all levels of government to identify roads and corridors that are most likely to be affected by AVs and ZEVs, or that can gain significant benefits from changes or upgrades. This would assist in ‘base lining’ against present AV technology to identify deficiencies and will also assist with future proofing.

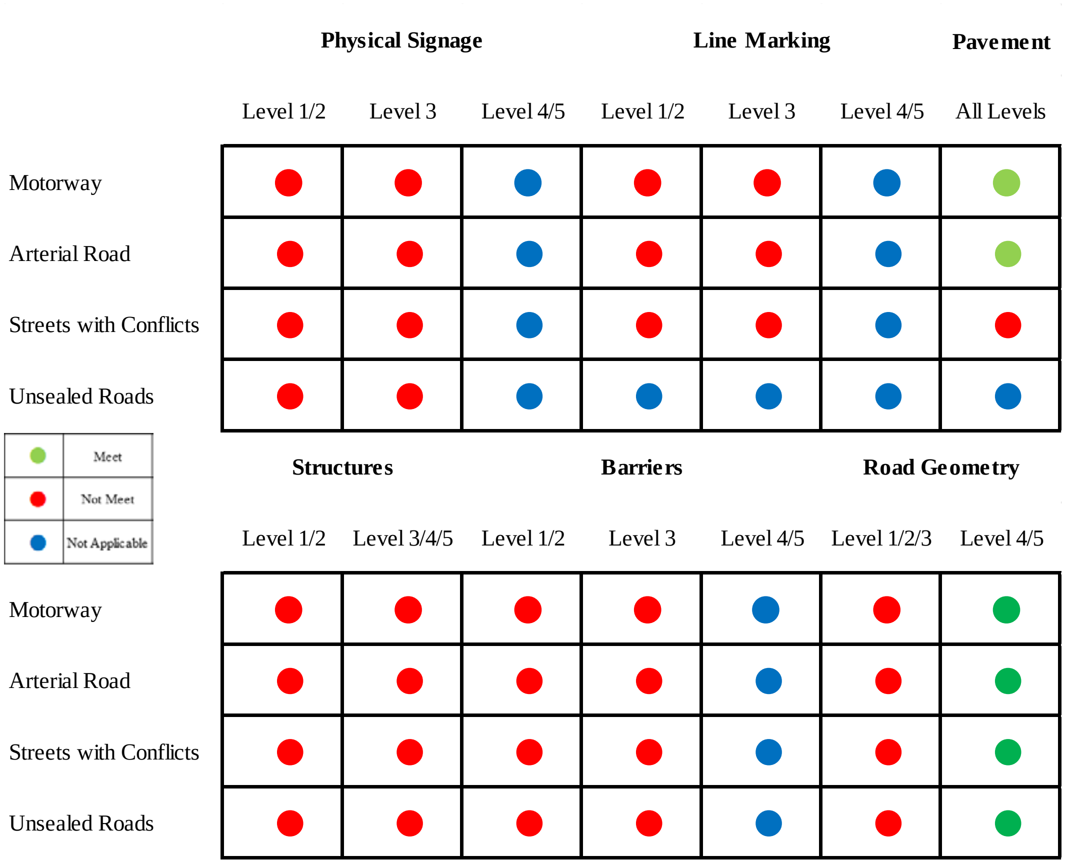
It is suggested that Victorian Government consider changes to its procurement strategies, which encourage and reward design innovation and discourage redundancy in infrastructure. These may include workshops, scenario testing of design solutions or measurement tool/s to assess designs that fully understand the requirements of AVs and ZEVs.

5.7.2 Key Findings and Recommendations

In summary, when considering the potential impacts and responses regarding road assets, brought about by AVs and ZEVs, the following key findings and recommendations are highlighted:

Minimum Requirements Met?

The following figure summarises the outcomes from the minimum requirements assessment discussed in **section 5.4**.



	Physical Signage			Line Marking			Pavement
	Level 1/2	Level 3	Level 4/5	Level 1/2	Level 3	Level 4/5	All Levels
Motorway	🔴	🔴	🔵	🔴	🔴	🔵	🟢
Arterial Road	🔴	🔴	🔵	🔴	🔴	🔵	🟢
Streets with Conflicts	🔴	🔴	🔵	🔴	🔴	🔵	🔴
Unsealed Roads	🔴	🔴	🔵	🔵	🔵	🔵	🔵

🟢	Meet
🔴	Not Meet
🔵	Not Applicable

	Structures		Barriers			Road Geometry	
	Level 1/2	Level 3/4/5	Level 1/2	Level 3	Level 4/5	Level 1/2/3	Level 4/5
Motorway	🔴	🔴	🔴	🔴	🔵	🔴	🟢
Arterial Road	🔴	🔴	🔴	🔴	🔵	🔴	🟢
Streets with Conflicts	🔴	🔴	🔴	🔴	🔵	🔴	🟢
Unsealed Roads	🔴	🔴	🔴	🔴	🔵	🔴	🟢

Figure 43: Summary of Minimum Requirement Assessment

Build in an Ability to Adapt and Change Design Standards and Performance Requirements

As AV technology evolves, road authorities will need to potentially adapt or change design standards and performance requirements to either take up the opportunity presented or mitigate the risk. For example, road planners/designers could re-consider the layout and design of the road and street network, such as: narrower roads, smaller intersection layouts and reduced parking requirements.

Designing and planning roads of the future may need to take a more outcome led design process which focuses on the desired performance for a particular corridor, rather than set standards, this is discussed in **section 9.4.2**. Moving forward, Victoria in conjunction with other jurisdictions, should investigate how standards and guidelines could better respond to the rapid changes presented by AVs and ZEVs, this is discussed in **section 9.5.2**.

Physical Road Assets Could Be Considerably Impacted by Unplanned and Uncoordinated AV Deployment

The level of autonomy, penetration rate of Level 4/5 and how it is achieved, is likely to have the greatest impact on physical infrastructure. Both a fully automated vehicle fleet for Victoria and a Slow Lane scenario would see significant changes in the way Victorians use their road network. A fully automated scenario resulting in an increase in traffic throughput could increase the demands placed upon road infrastructure. Higher accuracy and pre-defined vehicle paths could concentrate wear and tear upon road elements such as pavements and bridges, however this issue could be addressed through a technology and/or connected solution. There remains a significant amount of uncertainty on the actual impacts from AVs on the physical infrastructure. Victoria should participate at a national level to stay abreast and review design standards (including future proofing) as more certainty is developed.

A Clear Plan to Manage the Transition Phase is Needed

Designing and maintaining a network that caters for all types and autonomy levels will require significant coordination. The transition phase will need a clear plan that identifies and sets out how Victoria can support the deployment of AV technology towards potential full automation of the transport system. This forethought is likely to avoid construction of assets that will become redundant and/or significantly future proof change of use of assets in due course while balancing the safety needs of vehicles of lower levels of autonomy. The plan will need to be adaptable and focus on the outcomes that Victoria seeks to obtain. It would be of benefit for this plan to be consistent with other Australasian jurisdictions and begin development in the near-term.

A Need to Monitor Heavy Vehicle Platooning

While it is put forward by some industry observers that heavy vehicle platooning could cause damage to structures and pavement, there remains uncertainty on what the potential impacts could actually be. If wide-scale heavy vehicle platooning eventuates, Victoria will need to monitor potential damage to pavement and structures. However, it could be feasible that any identified issues could be addressed through a technology solution, for example vehicles are programmed to increase headways or travel slower over particular segments of the carriageway or structure. It is an issue that is being looked at globally, and for Victoria it will be important to work with other jurisdictions through the Austroads, National Heavy Vehicle Regulator and National Transport Commission to become certain of what the actual impacts could be for the network.

The Ownership Model Will Impact on Parking and Drop-Off Facilities

The ownership model is likely to have a significant impact on parking and drop-off facilities, particularly in highly urbanised centres. These facilities will cater largely for awaiting passengers rather than the vehicles themselves and localised infrastructure will need to support this. This is further discussed and assessed in section **8 Parking and Land Use**.

6 On-Road Electric Charging Infrastructure

6.1 Purpose

This section discusses key considerations and areas for further investigation relating to electric vehicle charging infrastructure, which may have a direct impact on the road network. It is important to highlight that EV charging may be quite different for light and heavy vehicles due to the power requirements and uses. Where possible these differences have been discussed.

With regards to charging, this section outlines the high-level considerations under the following three headings:

- Stationary Charging
- Charging In-Motion
- Removable Batteries (Light Vehicle).

Each of the methods of charging, noted above, brings unique challenges and requirements, to both the road network and the power network. While this study discusses these different charging methods, it is important to note that they are not mutually exclusive, rather, they are potentially complementary pending installation and acceptance by the automotive industry.

It is important to note that charging infrastructure has a direct relationship with parking design and management, and therefore, this section should be read in conjunction with section **8.6 Design of Parking**.

6.2 Context

As the prospect draws closer of AVs becoming a mainstream transport mode, it is becoming more widely accepted that AVs have the potential to completely change the way we live, as the iPhone did just over 10 years ago. Coupled with this view is a common acceptance that we will also see a major change in the fuel type used, moving away from fossil fuels towards battery electric and fuel cell vehicles. While an electrified or hydrogen powered fleet has significant benefits, it also brings major infrastructure challenges once penetration rates increase.

The EV market is evolving rapidly, in the last 18-months alone we have seen several major announcements from around the world, including: Volvo announcing all new vehicles produced from 2019 will be EVs or hybrid; City of Paris officials stating that by 2040 all petrol and diesel vehicles will be banned from Paris streets; China aims to have at least one-fifth of all vehicles sold in that country be EVs by 2025; and London, UK is investing £18m to support the roll out of EV ‘traditional’ black cabs as standard.[141]

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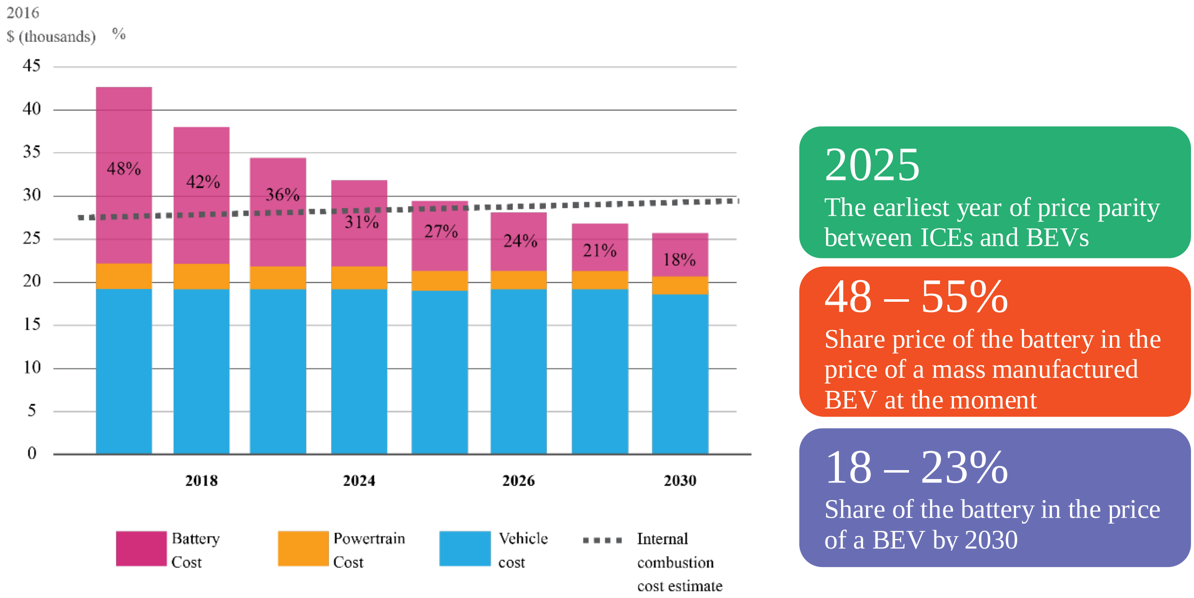
[141] Road Safety Authority, 2017, http://www.rsa.ie/Documents/Press%20Office/Autonomous,%20connected,%20electric%20and%20shared%20vehicles.pdf

Like Volvo, several vehicle manufacturers have set ambitious targets for producing and selling EV within the next five to seven years. However, concerns still exist around the cost and the acceptance of the public to purchase EVs. Figure 44, from Bloomberg New Energy Finance, highlights the cost parity between traditional ICE vehicles and EV vehicles. Their work suggests that electric cars will be more expensive for the next seven to nine years, noting this will vary depending on vehicle type and market, it may be assumed the Australian market could be noticeably longer due to lack of incentives and infrastructure.

With regards to the Australia market it is important to highlight that three of the top five selling vehicles in the country are small cars[142], though the average price of EVs will be cheaper than a comparable ICE, the gap for small cars will likely be marginal. Australia's second best-selling brand, Mazda, claims its petrol engine has the potential to reduce emissions from an internal combustion engine to below that of an electric vehicle when measured well-to-wheel[143].

A final point which is important to make in setting the context - Bloomberg highlights that policy is critical, as tough fuel economy regulations have played an important part in driving the scale-up in EV manufacturing over the next five to seven years. However, watering down of fuel economy rules globally may have the potential to derail the trajectory of price declines they have forecasted.



2025
The earliest year of price parity between ICEs and BEVs

48 – 55%
Share price of the battery in the price of a mass manufactured BEV at the moment

18 – 23%
Share of the battery in the price of a BEV by 2030

Figure 44: ICE vs EV Costs Projected[144]

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[142] Drive, 2017, https://www.drive.com.au/motor-news/top-selling-cars-in-2017-revealed-116814
[143] Fleet News, 2018, https://fleetautonews.com.au/new-mazda-petrol-engine-can-rival-electric-vehicles-for-well-to-wheel-emissions/
[144] Bloomberg New Energy Finance, 2017, When Will Electric Vehicles Be Cheaper than Conventional Vehicles? Estimated $US pre-tax retail sales price for battery-electric vs internal combustion vehicles (similar mid-sized family vehicle)

6.2.1 Current Charging Landscape – Stations and Ranges

In Victoria, there are currently approximately 135 charging stations[145]. The stations are mainly concentrated within the city area and are being installed by a range of membership organisations and vehicle manufacturers. Currently there is no official uniform charging plug as each existing charging station provides different plugs or is restricted to a particular vehicle brand, meaning some vehicles cannot charge there.

A study by the Victorian Department of Transport (now TfV) highlighted that the range of private electric vehicles since 2010 has approximately doubled in the intervening period[146]. The new Nissan Leaf E-Plus Version (Australian release early-2019) is quoted as having a range of 362 km[147], compared to 135 km range for the original Leaf produced in 2010. To charge the Leaf to 80%, is quoted by Nissan as being 40-60 minutes from a publicly available 'speed charger' and less than six hours to fully charge at home[148]. With the average car trip length in Melbourne approximately 15 km[149] (less in regional towns) and moderately priced EV ranges achieving at least 380 km[150], the need to constantly recharge/top-up light vehicle EVs will potentially decline.

Although not hugely prevalent, some state governments in Australia are planning or have installed electric charging stations. The biggest example is the Queensland Government who in collaboration with local councils and other partners is rolling out the Queensland Electric Super Highway in 2018. The Queensland Electric Super Highway will be the world's longest electric super charger highway in a single state. It will allow Queenslanders and tourists to travel from the Gold Coast to Cairns and from Brisbane to Toowoomba in a low or zero emission vehicle[151].

6.2.2 Infrastructure Victoria Scenarios

In relation to IV's Scenarios, the issue of charging for EVs is considered:

- Not to apply to scenario 4 (Hydrogen Highway) and scenario 7 (Dead End)
- To have some application to scenario 5 (Slow Lane), as this scenario contemplates the continued use of dual power sources in vehicles (hybrids) and based on the current crop of such vehicles, any electric charging is only partially relevant
- Highly relevant for each of the remaining scenarios.

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[145] Plugshare, 2018, https://www.plugshare.com/
[146] Transport for Victoria, 2013, https://transport.vic.gov.au/content/docs/creating-a-market-victorian-electric-vehicle-trial-mid-term-report.docx
[147] Smith. L.J, for Express, 2018, https://www.express.co.uk/life-style/cars/900488/Nissan-leaf-new-2019-range-price-specs
[148] Lambert. F, 2018, https://electrek.co/2018/01/04/nissan-leaf-2019-specs-range-charging/
[149] Australian Government, Department of Infrastructure and Regional Development, 2015, https://bitre.gov.au/publications/2015/files/is_073.pdf
[150] Chevrolet, 2018, http://www.chevrolet.com/electric/bolt-ev-electric-car
[151] Queensland Government, 2017, https://www.qld.gov.au/transport/projects/electricvehicles/super-highway

6.2.3 Key Principles of Charging Infrastructure

The following summarises key principles around charging infrastructure, as detailed in the Queensland EV Charging practice note [152]. Given the similarities to Victoria, this is applicable in considering light EV charging infrastructure however, the practice note is written based on current behaviours, low penetration rates, vehicle specifications (e.g. range) and to some degree current/near-term levels of autonomy. As this is a rapidly evolving field, so too will be the approach and principles that are applied. Some of the key principles from the note are as follows:

- Perceived range of 'range anxiety' is one of the main deterrents in using EVs, therefore infrastructure may need to be planned to ease this anxiety and create public awareness.
- A key difference between ICE and EVs is how people currently behave in ‘re-fuelling’. ICEs are irregularly ‘filled up’ once they are low, while EVs are usually topped up regularly.

Figure 45: Hierarchy of EV Charging Infrastructureshows the hierarchy of EV charging infrastructure which displays the observed general distribution of EV charging across different types of charging infrastructure.

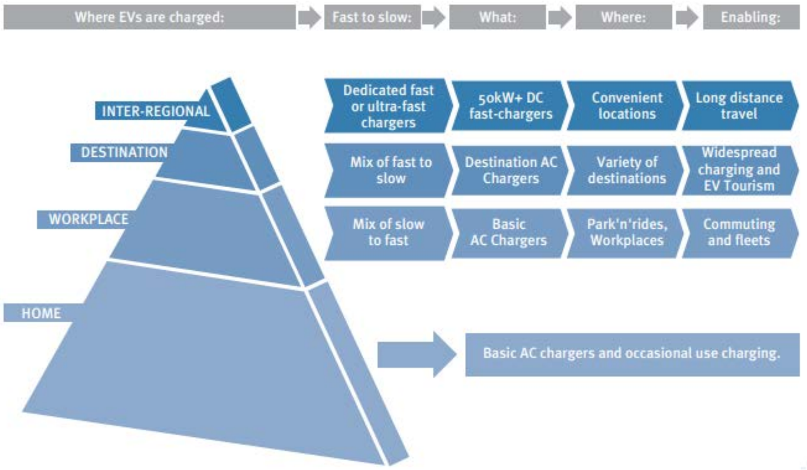

Figure 45: Hierarchy of EV Charging Infrastructure (Source: [152])

Figure 46 shows the EV ecosystem charging curve. It suggests that the current charging behaviour leads to a need for a widespread distribution of EV charging points, suggesting that every existing accessible standard power socket is a potential 'topping up' location.

The EV ecosystem put forward suggest at-home charging will be supported by dedicated public EV chargers, in a wide variety of locations, and a relatively smaller number of fast DC chargers. It is acknowledged that the practice note only considers stationary plug-in charging.

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[152] Queensland Government, March 2018, Electric Vehicle (EV) Charging Infrastructure, Practice Note

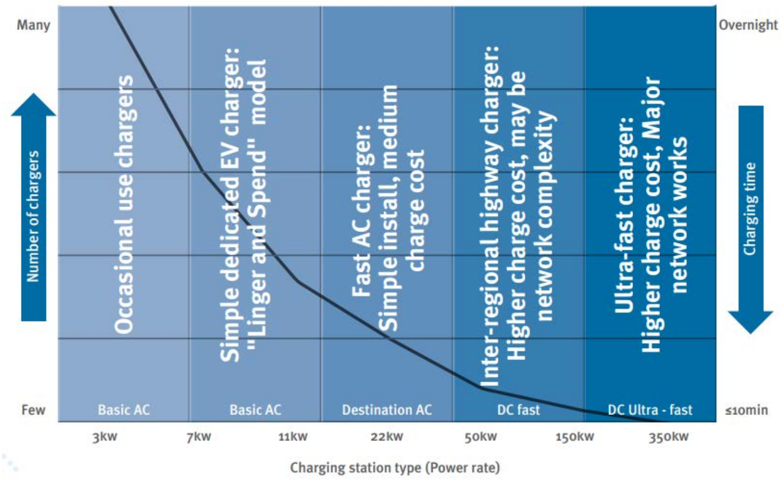

Figure 46: EV Ecosystem Charging Curve (Source: [152])

6.3 Charging Methods

The following sections detail the charging methods available for electric vehicles.

6.3.1 Stationary Charging

Charging times for EVs vary across the market, with certain methods quoted at 15 minutes for speed charging[153] and up to 24 hours for normal domestic connections - although this is possible, it is not recommended as the regular/default charging mechanism. High-powered domestic charging points are available and encouraged as the default home charging solution. Speed charging is only available at dedicated locations with special infrastructure, however this is vehicle manufacturer dependent in a number of locations.

While private cars are regularly quoted as being idle for more than 90% of their lifetime[154], it is reasonable to argue that charging at regular destinations may be a realistic possibility, including at home and in large car parks where vehicles may be parked for long durations. This covers scenarios 1 and 2, where private ownership is the primary model, however, under scenario 6 (and to a lesser extent scenario 5) where cars may be shared, it is likely that these driverless vehicles would or could be programmed to automatically maximise their distance travelled and use between charges.

Ultimately, there are two ways of delivering a stationary charge - either through a direct connection or wireless (inductive) charging. Industry observers put forward that for the convergence of AVs and EVs to occur, then the future is inductive charging for EVs[155].

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[153] Speed charging refers to charging to 80% capacity quickly using specialist equipment. Using this technology, obtaining the final 20% (100% from 80%) is more time consuming

[154] Today's Cars Are Parked 95% of the Time, http://fortune.com/2016/03/13/cars-parked-95-percent-of-time/

[155] Harris. M, for Spectrum, 2016, https://spectrum.ieee.org/cars-that-think/transportation/self-driving/google-wants-its-driverless-cars-to-be-wireless-too

6.3.1.1 Direct Connection

For light vehicle EVs, direct connection is likely to be always through a ‘plug-in’ cord. For heavy vehicles, other options such as pantographs are being investigated (discussed further in this section).

The Queensland EV Charging practice note[156] sets the standard for Queensland as the Type 2 Mennekes. Given that so many vehicle manufacturers have already commenced the roll out of the Type 2 Mennekes connector, it is considered likely that this standard will be universally adopted[157]. However, there is still a risk that chargers will have different connections (like mobile phones) and in that event, motorists would need to carry adapters for each type with them, or each public charging facility would need to be fitted with the various connections to suit all vehicles on the market, or have a separate charging area for each type of connection. This is unlikely to be a feasible situation.

Figure 47: Static On-Street Charging Point (Source: JLLRealviews.com)

Where local and state road authorities seek to install suitable equipment on the street (kerbside), there are applications where the power provision has been supplied through street lighting infrastructure. German company Ubitricity is working with local government in London to install charge points[158]. This solution is very much in its infancy and it has a number of issues to overcome, such as: slowness of charge, messy cables (which are a trip hazard and

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[156] Queensland Government, 2018, www.dsdmip.qld.gov.au/resources/guideline/pda/guideline-electric-vehicles.pdf

[157] It must be noted that Tesla electric vehicles in different jurisdictions use different connections: in Japan and the US the J1772 connector is used whilst everywhere else the Type 2 Connector is used.

[158] Eleftheriou-Smith. L.M, for the Independent, 2017, https://www.independent.co.uk/environment/london-street-lamps-electric-car-charging-points-ubitricity-tech-firm-hounslow-council-richmond-a7809126.html

inconvenient), may increase time people park, and not competitive with other ways of charging.

Figure 48: Street Light Charging Socket (Source: Ubitricity)

6.3.1.2 Wireless (Induction)

Inductive wireless charging is essentially two aligned magnetic coils which send power to the EV over an air gap between the vehicle and a wireless charging station[159]. This type of charging is becoming more widespread, is now available in several countries and is being offered by increasing numbers of vehicle manufacturers.

In the near future, it is expected that a majority of charging will continue to be plug-in. There is uncertainty whether plug-in will remain in the long-term, as under a fully shared AV future it is assumed that humans would be taken out of the re-charging process and therefore induction charging would likely be required.

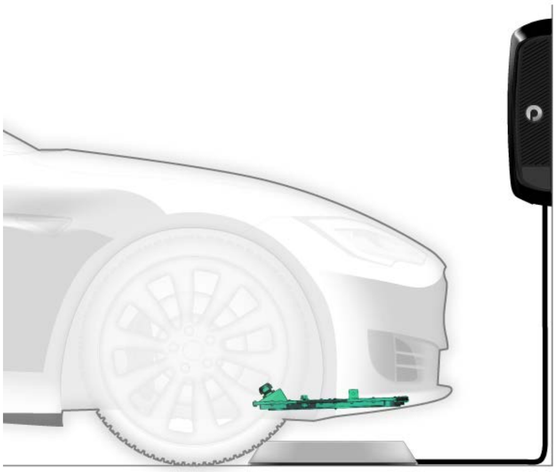

Figure 49: Wireless Charging in Parking Bay (Source: cleantechnica.com)

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[159] Evatran Group, 2018, https://www.pluglesspower.com/learn-about-plugless/

A key challenge with inductive charging is the energy loss (approximately 20%) and limits on the actual output[160]. SAE previously only provided guidance on chargers up to 7kW, which is essentially equivalent to a 'Basic AC charger', however a recent update provides guidance on charging up to 11kW, which is at the low end of a destination charger[161].

The SAE practice report also outlines recommendations for an industry-wide charging specification for static wireless charging[162]. It is likely this will be finalised in late-2018. With the technology continuing to improve, we could see energy losses down to 10% and outputs in the future of potentially 20kW[163], which is at the high end of a destination charger. It is worth considering that energy losses usually transfer as heat, a 10-15% loss on a 20kW charge could potentially generate the same amount of heat as the average home electric heater.

6.3.1.3 Wireless Bus Charging

In 2014, Transport for London (TfL) introduced inductive charging units for hybrid buses at bus stops around London[164] and have continued to expand this network.

Figure 50: London Buses Inductive Charging (Source: [164])

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[160] Morris. C, for Charged, 2017, https://chargedevs.com/newswire/sae-j2954-recommended-practice-enables-automated-wireless-charging-to-11-kw/

[161] Morris. C, for Charged, 2017, https://chargedevs.com/newswire/sae-j2954-recommended-practice-enables-automated-wireless-charging-to-11-kw/

[162] SAE, 2017, https://www.sae.org/standards/content/j2954_201711/

[163] Alba. M, 2017, https://chargedevs.com/features/dynamic-wireless-charging-whats-feasible-qa-with-qualcomms-graeme-davison/

[164] Transport for London, 2017, http://content.tfl.gov.uk/sshr-20170123-item08-update-on-ev-charging.pdf

6.3.1.4 Wireless at Home Charging

Although at-home wireless charging will not directly impact the road network, it may drive the types of future solutions that are incorporated into the road network.

At home chargers are now widely available to facilitate wireless charging, however they are relatively expensive. Such products are available from several manufacturers, who are producing generic equipment to charge vehicles (Figure 51 and Figure 52).

BMW has made wireless charging available for its overseas EV and Hybrid models. A 100% charge can be achieved via a wireless charger on the floor in approx. 3.5 hours[165]. It is claimed to have efficiency of between 80-87% (Figure 52).

Figure 51: Plugless 'Generic Charger' (Source: pluglesspower)

Figure 52: BMW Charger (Source: theverge.com)

6.3.2 Overhead Charging - Buses

This report does not go into depth regarding bus charging other than to mention some emerging trends for charging electric battery powered buses through overhead infrastructure.

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[165] AutoCar, https://www.autocar.co.uk/car-news/new-cars/bmw-530e-iperformance-get-world%E2%80%99s-first-wireless-charging-system

There are now several trials underway globally to charge public buses while they are dwelling. Two key trends for overhead charging are:

- Super charging
- Capacitor charging.

Super Charging

Figure 53: Bus Super Charger[166]

Buses are charged at the end of the line, and only carry enough battery storage on-board between charge stations. A 450kW charger energises the bus in four to six minutes (please note the ultra-fast DC charger mentioned previously is around 100-120kW).

Capacitor Charging

One manufacturer in China advises that a full charge can be completed in approximately 10 seconds[167], however a capacitor can only hold about 5% of charge compared to lithium batteries. To overcome this, overhead chargers are located at bus stops and the bus charges itself while dwelling. One charge provides approximately five kilometres of travel. It is also suggested by the manufacturer, that the bus consumes 30% to 50% less energy than other electric vehicles.[168]

It is important to highlight that there is little information available to suggest that the three different methods (including wireless) of charging buses discussed, will fully replace the more common practice of direct connection 'plug-in' slower charging. Over the past five years the City of Shenzhen has converted their 16,000 bus fleet to full electric plug-in charging, taking approximately five hours to charge, for a 250 km range[169]. This is an evolving field with other methods of direct connection being developed.

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[166] BusHeliox's fast charger for electric buses, 2017, https://ec.europa.eu/easme/en/news/helioxs-fast-charger-electric-buses-creates-business-case-emission-free-public-transport

[167] SupercapTech, 2017, https://www.supercaptech.com/world-fastest-charging-electric-bus-10-seconds-thanks-to-supercapacitors

[168] SupercapTech, 2017, https://www.supercaptech.com/world-fastest-charging-electric-bus-10-seconds-thanks-to-supercapacitors

[169] Roberts. D for Vox, 2018, https://www.vox.com/energy-and-environment/2018/4/17/17239368/china-investment-solar-electric-buses-cost

6.3.2.1 On-Road Charging Type and Location

It is expected an ‘eco-system’ of direct charging will have varying degrees of output depending on where the vehicle is being charged. The following table summarises: charging type, likely locations and key characteristics.

Table 8: Charging Type, Location and Characteristics

Likely Locations	Key Characteristics	On-Road Possible Response/Trigger Points (TP)	Uncertainty & Intervention
Basic AC Charging			
Long dwell time destinations such as homes, apartments, workplaces, tourist attractions, retail centres, cinemas, beach, council car parks, multi-residential buildings, entertainment and restaurant precincts.	Adds 10 - 45 km range per hour. Time: minimum two hours to overnight. Max. electricity consumption per charge: 10-35kWh ($2.70-$9.45).	Local government authorities in Europe are installing charge points within street lighting infrastructure[170] to allow people who need to park on-street to charge over an extended time. State Government may wish to consider installing this type of charger at ‘Park and Ride’ stations, state attractions/destinations where visitors are for a minimum of two hours and are closer to metropolitan areas. TP: high number of EVs parked overnight on-street and lack of quicker charge facilities.	There is high uncertainty regarding street lighting, due to access issues with the asset owner, the length of time it would take to charge would limit its application where parking is encouraged to have a higher turnover rate. For people without home charging, it is suggested they might prefer Fast DC charging instead once or twice a week. It is unlikely that providing basic AV charging would be widely useful for vehicles parked on arterial roads.
Destination Charging			
Tourist attraction with short dwell time, tourist information centre, retail centre, council car park, council pool, fast food location, service station with dwell facilities. Multi-residential or workplaces with fleet vehicles are also suitable locations, where they may be installed to complement a larger number of slower chargers.	Adds 50 - 130 km range per hour. Time: 30 minutes to two hours. Max. electricity consumption per charge: 8-32kWh ($2.16-$8.64).	If a response was to be provided on-road, for parked cars this would be the most likely. It would not be expected to be provided for all spaces, but targeted deployment. State Government may wish to consider installing this type of charger at ‘Park and Ride’ stations, state attractions/destinations where visitors are for a minimum of 30 minutes and in regional areas. Private destination landholders like shopping centres would be encouraged to install this type of charger.	Though Victoria has a lot of on-street ‘destination’ parking (e.g. street shopping centres) there are usually off-street locations close by. It would make sense for destination chargers to locate off-street. Where it is required authorities might like to consider ‘Re-Charge Parklets’ to house the destination.

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[170] https://www.independent.co.uk/environment/london-street-lamps-electric-car-charging-points-ubitricity-tech-firm-hounslow-council-richmond-a7809126.html

Likely Locations	Key Characteristics	On-Road Possible Response/Trigger Points (TP)	Uncertainty & Intervention
		TP: high number of EVs parked on-street, inability to provide off-street EV charging close by.	
Fast DC charging			
A fast charging station is best placed on major inter-regional transport routes, at key locations within inner cities, or near major airports where there is high daily EV traffic. Also located in areas without access to overnight EV charging, or where high demand daily users (fleet vehicles, taxis, ride sharing and share cars) require regular access to fast charging.	Adds 100 to over 300 km range per hour. Time: 20 minutes to one hour. Max. electricity consumption per charge: 15 - 90kWh ($4.05-$24.30).	Distances between regional stations should be minimised ideally to 70 km but no more than 200 km as to provide EV drivers choices in their trip planning. Suited to areas with adjacent land-uses and amenities. More likely in metro Melbourne, towns and regional centres. To create a comprehensive network State Government may need to intervene in early days of deployment. TP: high EV Ownership.	These types of chargers are quite expensive, with a high number of people choosing to charge at home, there is the potential for over investment. If for some reason a charger needed to be located on an arterial road, it should be encouraged to use this type to minimise time the vehicle is charging.
Ultra-fast DC Charging			
Carefully selected, strategically located, travel service centres on highly trafficked major highways.	Power: full range. Time: five to 20 minutes. Max. electricity consumption per charge: 20 - 100kWh ($5.40-$27.00).	State Government may wish to make available current rest stops of the highway network for ultra-fast charging. Especially on route to key destinations and attractions such as the Bass Coast Highway and Great Ocean Road.	Ultra-fast chargers will require a significant investment in the local electrical network, and therefore extensive planning is necessary.

6.3.3 Charging In-Motion

There is a lot of interest globally in charging vehicles while in motion, with benefits including helping to reduce range anxiety and reducing the battery size required. Battery size is a main contributing factor to the cost of a vehicle, therefore, reducing the battery size could bring down vehicle purchasing and operating costs.

There are currently several different forms of vehicle in-motion charging trials across the globe, three commonly discussed forms are:

- Wireless (induction) in-road charging
- Overhead lines
- In-road rails.

6.3.3.1 Wireless In-Road Charging

A frequently suggested method of charging vehicles is via induction charging built into roads. This involves the introduction of inductive units into or onto the road surface at regular intervals (Figure 54).

Figure 54: Proposed Induction Charging Lanes in the UK[171]

With the information available, we are uncertain whether this will eventuate in Victoria for the foreseeable future. There are certain inherent flaws that would need to be overcome for this to be a viable solution. While it is technically feasible, the high cost, low efficiency and field emissions when transmitting high power remain insurmountable challenges[172]. Assuming these challenges are overcome in the future, it is likely it would only be limited to small parts of the arterial network, and would potentially need to be driven by the private sector.

However, introducing such units into the road surface would require significant additional maintenance, to ensure a quality road surface. Understandably road surfaces can crack and warp over time, requiring periodic maintenance and surface replacement (every 10-15 years), the existence of charging infrastructure could make this a difficult task.

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[171] Mashable.com

[172] http://batteryuniversity.com/learn/article/charging_without_wires

Where this response may have demand is for heavy freight, however there is a lack of evidence to suggest the current or planned inductive charging units (up to 20kW) would have enough current to charge an electrified B-double. A current diesel engine produces up to 450kW[173].

6.3.3.2 Overhead Lines

Several studies, including one from Carnegie Mellon University[174], highlight the issues with powering a semi-truck over a large distance. A main issue is the required size of the battery, using current technology. Carnegie Mellon's study suggests a 14-tonne battery pack would be needed to deliver an approximate 950 km range[175], when including the weight of the vehicle and trailer would be approximately a third of the weight of a B-double truck, significantly reducing payload.

One potential method for charging heavy vehicle trucks, is using overhead wires and a pantograph (similar to a tram). Figure 55 shows current truck trials in the UK. This would power the vehicles *and* re-charge batteries, which may mean that trucks would then only need to carry enough battery storage until the next re-charge point. For example, an approximately seven-tonne battery would achieve a 480 km range[176].

Figure 55: Overhead Powered HGVs (Source: ETA.co.uk)

6.3.3.3 Siemens e-Highway

German engineering company Siemens[177], argues it can power unlimited-distance electric trucks with intermittent overhead wires that provide enough energy for

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[173] MAN, 2018, https://www.engines.man.eu/global/en/index.html
[174] Carnegie Mellon University, 2017, https://pubs.acs.org/doi/full/10.1021/acsenergylett.7b00432
[175] Cadogan. J, for Autoexpert, 2017, https://autoexpert.com.au/posts/the-truth-about-the-tesla-semi-battery-powered-electric-truck
[176] See 148 as above
[177] Siemens, 2017, https://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2017/mobility/pr2017110069moen.htm&content[]=MO

fast-moving, long-haul highway journeys. With on-board batteries added to the trucks, the company estimates all of Germany's roads could be outfitted for long-distance electric hauling with just 4,000 km of wire. Trucks would be able to recharge on highways and operate on battery power while on rural and urban streets. The system would cost a fraction the price of alternatives like the infrastructure for hydrogen fuel cells. For comparison, Germany's road network length is 644,480 km, Victoria has approximately 150,000 km of road network open for public use.

Siemens are currently trialling their eHighway in Carson City, California. The truck's pantograph can connect and disconnect automatically with the line via a sensor system while the truck is moving, giving them the same flexibility as conventional diesel trucks. This allows the trucks to easily switch lanes or pass other vehicles without being permanently fixed to the overhead systems. To further ensure the same flexibility as conventional trucks, eHighway vehicles can use battery or other on-board energy sources, when driving outside of the catenary lines to produce a zero emissions outcome.

6.3.3.4 In-Road Rails

Another potential method of charging vehicles in the future, is via rails set into the surface of the road – see Figure 56 below. Sweden has built the first road that will allow electric vehicles to charge as they drive using this rail system[178]. While in-road rails may extend the range of electric vehicles beyond what was previously possible, there are significant concerns around cost of technology, road damage, disruption to existing road users' safety and possible skid hazard on high-speed roads (resulting from the steel rails).

Figure 56: Charging Rail In Road (Source: independent.co.uk)

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[178] Gabbatiss. J, for Independent.co.uk, 2018, https://www.independent.co.uk/environment/electrified-road-sweden-first-ever-charge-cars-trucks-vehicles-stockholm-a8302656.html

6.3.4 Replaceable Batteries (Light Vehicle)

EV batteries are heavy (e.g. 540 kg for the Tesla Model S[179]) and therefore the process for changing a battery is not a simple task - like refuelling a petrol car) - however it is not an impossibility. Car manufacturer Tesla did establish a battery swap pilot program with the process taking approximately 90 seconds and was expected to cost around Au$90 per change[180] Although this has not yet progressed beyond the 2017 pilot, Tesla has patented a second battery swapping station in the US.

Although there a several issues which need to be addressed with battery swapping - such as ownership and maintenance of the battery - a fundamental issue which needs to be resolved is what type of battery the facility should provide. Should the swapping station hold a number of each type or commit themselves to a single vehicle manufacturing group or battery type? The batteries in use by the different manufacturers have widely varying characteristics.

Batteries are specifically designed for vehicles taking into account various factors such as: weight distribution, handling and safety performance. Figure 57 and Figure 58 show the difference in a battery pack for a Tesla Model S and a Nissan Leaf.

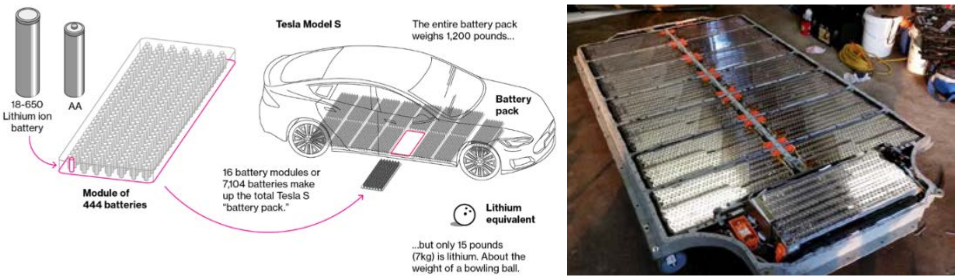

Figure 57: Tesla Model S Battery [180]

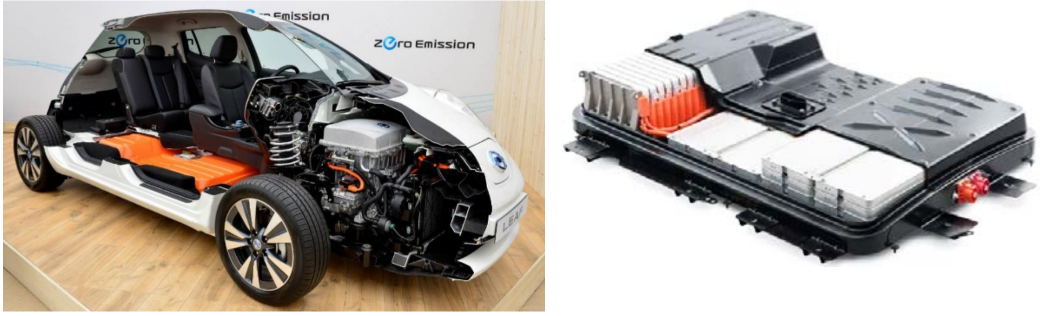

Figure 58: Nissan Leaf Battery[180]

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[179] Wikipedia, 2018, https://en.wikipedia.org/wiki/Tesla_Model_S

[180] Business Insider, 2015, Tesla's battery swapping plan is a mere shadow of the promise it once showed https://www.businessinsider.com.au/teslas-battery-swapping-plan-isnt-working-out-2015-6?r=US&IR=T

6.3.4.1 Case Study: 'Better Place' – Australian Battery Swap Proposal

In 2010, Israeli company 'Better Place', announced its intention to establish a significant network of both EV charging stations and battery switch services (Figure 59) in Australia. Their first charging location was installed in Canberra in late 2011, a roll out of 500 charge stations was planned to begin in major east coast cities before expanding nationally.

It was estimated this would give it comparable coverage to the existing 13,000 petrol stations then in operation. The total cost of this roll out was claimed to be between AUD$1- $1.25 billion. 'Better Place' was the preferred provider of home and dealership charging stations for the Holden Volt, with the partnership announced in July 2012. However, by 2013 went into bankruptcy after spending more than AUD$850 million on charging infrastructure globally.

Figure 59: Better Place - Battery Swap

6.4 Charging Infrastructure Readiness

The following paragraphs provide discussion on preparing for EV charging infrastructure in Victoria, noting another assignment commissioned by IV is investigating the supply and distribution of electrical charging infrastructure for vehicles across the State.

It is argued that because Victoria does not have a comprehensive EV charging ecosystem, or is planning one through a strategy which sets the direction for Victoria's EV future, it is not ready for a wide-scale deployment of EVs across the State.

Figure 60 has been created to highlight the types of key questions a future EV strategy for Victoria should try to answer. Following this figure, a suggested future 'EV Readiness Tool' is outlined for Victoria.

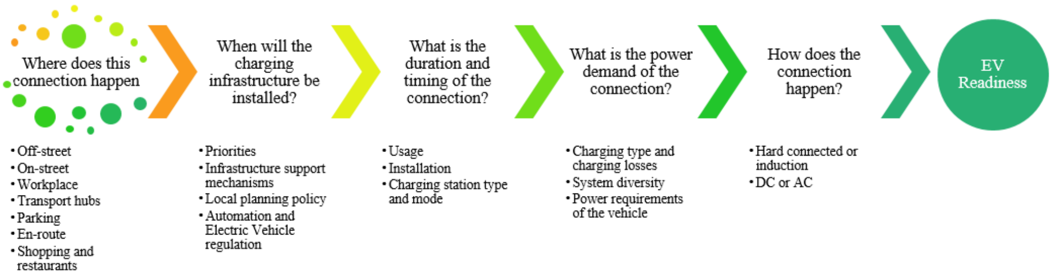

Figure 60: EV Readiness Key Questions

6.4.1 Future Readiness Tool?

The accurate forecasting of EV charging demand and vehicle-to-grid (V2G) potential is critical in establishing the available distribution network capacity, as well as providing a robust justified case for investment ahead of need.

This determination requires a clear integrated understanding and objective data driven analysis of segmented EV uptake, charging locations, usage profiles and electricity network capacity.

It is suggested a tool could be created to understand Victoria's EV readiness. The tool could be developed from an existing platform which can be used to test hypothesis sensitivity to various credible scenarios in key forecasts or casual relationships.

The tool would be data driven based on the forecasting of spatial and temporal impacts to electrical distribution from EV charging, utilising an integrated combination of transport modelling, demographic change analysis and electrical network capacity to inform justified asset investment ahead of need or objective influence on EV roll out plans. The tool would enable recognition of:

- EV charging spatial effects and associated parameter sensitivity
- Links between demographic forecasts and EV penetration patterns
- Links with travel patterns and destination charging effects
- Recognition of EV charging infrastructure characteristics and associated parameter sensitivity. Slow, fast, rapid and ultra-rapid charging.

Figure 61 below illustrates how and what the tool would consider.

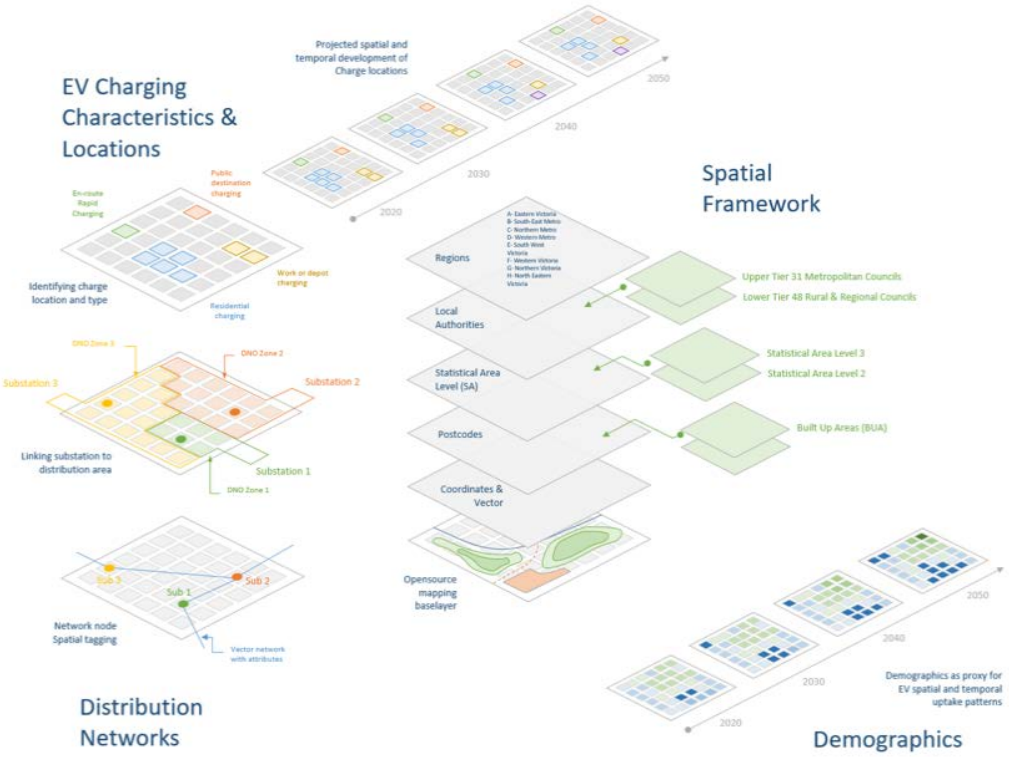

Figure 61: EV Development Tool (Source: Arup)

6.5 Conclusion, Findings and Recommendations

6.5.1 Conclusion

While the topic of EVs and charging infrastructure is vast, this section has touched upon key elements the State Government will need to consider as part of encouraging and enabling an EV future. The focus of this section was on on-road EV charging infrastructure and how it may impact on the road network and possible responses.

Some of the major existing challenges to the uptake of EVs are: range anxiety, recharge time, battery cost, vehicle weight, battery longevity and replacement cost. Commentators argue that the timeframe for charging must reduce for it to become a viable alternative to ICEs. However, it is noted that the convergence of EVs with a fully AV future could eliminate this issue as a human driver/passenger would no longer experience the delay of charging.

The migration from fossil fuels to other sources, such as electricity or hydrogen, has commenced and automotive manufacturers are now manufacturing vehicles and investing in improving the various power supplies. This means that the industry is already changing, and the impact of positive action from authorities would accelerate the change. Inaction may lead to petrol cars remaining on the road network a lot longer than is necessary, as the cost parity between small petrol cars and EVs will possibly be similar towards 2030 and beyond.

6.5.2 Key Findings and Recommendations

The following summarises the main points raised in this section and relevant findings:

Decision or intervention from the Government is Required

It could be argued that Victoria is not ready for a wide-scale EV future. Given increasing numbers of EVs are being built globally, a choice needs to be made whether Victoria wants to encourage manufacturers to sell their vehicles in the local market. Beyond direct subsidies in the vehicles, authorities can play an active and positive role in supporting the establishment of an EV charging 'eco-system' and establishing an EV base through government fleet purchases and encouraging car share companies to go electric.

Moving to a EV future is beyond just transport planning and engineering, it can help other parts of government meet their objectives through better air quality and reducing Victoria's carbon emissions faster.

Battery Powered Light Vehicles Likely to be the Winner

It is expected that light vehicle AVs will be mainly powered by batteries, with other fuel sources likely to be used for specific use cases. With the average car commute length in Melbourne approximately 15 km[181] (less in regional towns), and moderately priced EVs now having ranges of at least 380 kms, the need to recharge daily or even weekly has diminished. It is expected over the transition phase and Slow Lane scenarios, that an EV plug-in ecosystem will be developed. If there is a high penetration of shared AVs/EVs in the future it is expected that humans will be taken out of the re-charging process, and induction charging will likely be required. This suggests Victoria may need to be aware of not over investing in 'plug-in' infrastructure. Wireless technology is not as high a priority if AV use is not widespread, as human drivers can manually plug into a charging point.

Charging for Light Vehicles

With 'in-motion' charging still in early development, the near-term response for light vehicle EVs will likely be focused on stationary charging, primarily through plug-in and secondarily through induction charging.

Government has a role to support the development of a charging ecosystem either through providing strategic planning guidance and/or possibly initial funding to enable the first phase of a charging ecosystem to be implemented.

From evidence and information available, the need for wide-scale on-street charging does not seem to be required in Victoria. There may be some limited applications, such as on-street car share. However, even in this case it is likely the charging would take place away from major conflicts with traffic and pedestrians (as discussed in **section 4**) on quieter streets. On-street charging may become more feasible if for some reason a comprehensive EV charging ecosystem is not

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[181] Australian Bureau of Statistics, 2016, http://www.abs.gov.au/ausstats/abs@.nsf/mf/9208.0/

established. Therefore, for both the transition phase/Slow Lane scenario and full AV/EV scenario discussed below, there is an emphasis on off-street charging.

Transition Phase/Slow Lane Scenario

From information currently available, the following is a suggested high-level approach for Victoria during the transition period or ultimate 'Slow Lane' scenario:

- Very high number of at-home chargers
- High number of destination chargers located in parking buildings, 'Park and Ride' stations and shopping centres
- Small to moderate number of fast DC chargers to create a comprehensive EV charging network
- Very small number of ultra-fast DC chargers across the State strategically located.

Full AV/EV Scenario

In an ultimate scenario where vehicles are shared and fully electric it is expected that humans will be taken out of the charging process. This is likely to require induction charging to be used over 'plug-in'. This suggests Victoria may need to be aware to not over invest in 'plug-in' infrastructure, however even if the last Level 1-3 AV/EV (plug-in) was sold in 2031 (IV High Speed scenario), then an EV charger installed today could still be in use in 20 years' times.

NB: Wireless technology is not as high a priority if AV use is not widespread, as human drivers can manually plug into a charging point.

Public Transport Charging Similar to Light Vehicle Approach

There are several trials, occurring globally, into various methods of propulsion including hydrogen. Regarding Victoria, trials so far do not seem to suggest overhead charging is required to be future proofed. Instead it would seem a model similar to light vehicles may be more likely, where buses are charged 'at-home' in a depot overnight and then if required receive fast charges during the day.

High Level of Uncertainly Around Heavy Vehicles

For heavy vehicles, there remains a lot of uncertainty around power source e.g. battery versus hydrogen – noting hydrogen infrastructure was outside the scope of this report. It is likely that *charging while moving* will be significantly expensive, Victoria will need to watch and wait for developments in this space. If the future for heavy vehicles is battery powered, options for in-motion charging and locations are likely to be explored by the private sector, however are likely to require support and encouragement from government.

7 Road Operations and Management

7.1 Purpose

The following section highlights how movement occurs on the Victorian road network - from an operations planning and traffic management perspective - and how AVs could be considered within this context. Road user experience and perception in planning for AVs and ZEVs is considered under the **section 4 Planning for All Users.**

Road operations encompasses network monitoring, road maintenance, traffic control, user information, and demand management[182]. Traffic management involves the management of traffic flows (people, vehicles and goods) by demand management, traffic information, traffic control and other measures[183].

7.2 Context

Operations planning and traffic management are essential elements of the current system, in optimising the efficiency and safety of Victoria's road network. In Victoria, best practice for operations planning is shifting from a focus on the management of vehicular traffic flows, towards a transport system which provides greater emphasis on the needs of all road users as well as land-use outcomes.

In a fully automated and connected system, the theoretical efficiency gains and improvements to the way movement occurs in the system are significant[184]. The challenge is therefore likely to be facilitating these advancements while managing and minimising the potential challenges and risks. In unison with advancements in AV technologies, there are equally impressive changes occurring to communications technology and architecture - which have significant impacts on how operations planning and traffic management is undertaken. Connectivity is likely to enhance and support AV operations significantly, creating a fully connected ecosystem, and is therefore being developed alongside AV technology in many circumstances. With this in mind, this section discusses some impacts of communications technology which are intertwined with impacts of AVs.

The successful integration of AVs into the transport network as a mainstream transport mode relies on AVs being considered in strategies, plans, and policies which inform operations planning and traffic management. Because these guiding documents are developed and owned by various organisations, a cross-organisational approach is required to successfully adapt to the changes.

VicRoads is the statutory road and traffic authority for Victoria. One of its main responsibilities is road operations and traffic management of Victoria's declared road network and all signalised junctions. In June 2016, Transport for Victoria

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[182] World Road Association, 2003, https://www.piarc.org/en/order-library/4379-en Road%20Network%20Operations%20Handbook.htm

[183] World Road Association, 2015, https://www.piarc.org/en/calendar/World-Road-Congresses-World-Road-Association/XXV-World-Road-Congress-Seoul-2015/

[184] Fagnant, 2015, Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers, and Policy Recommendations

(TfV) was established and has become a statutory authority under the Transport Integration Act (2010). TfV brings together the planning, management and coordination of Victoria's transport system under one organisation[185]. As Transport for NSW has set up its Future Transport 2056 program and strategy[186], it is expected TfV may do something similar in the near future.

VicRoads previously developed a Network Operations Planning framework consistent with the Austroads Network Operations Planning Framework[187] called 'SmartRoads'. The SmartRoads framework put in place a structure to manage the competing demands for road space, by encouraging priority based on the importance of mode, times of day and place. Key elements of this framework included a road user hierarchy which set the priorities. Importantly, the SmartRoads framework approach enabled planning decisions to be made in a way that supports access and the surrounding land use, and helped to manage the competing transport interests for limited road space[188]. Figure 62 illustrates an example of the road use hierarchy by mode.

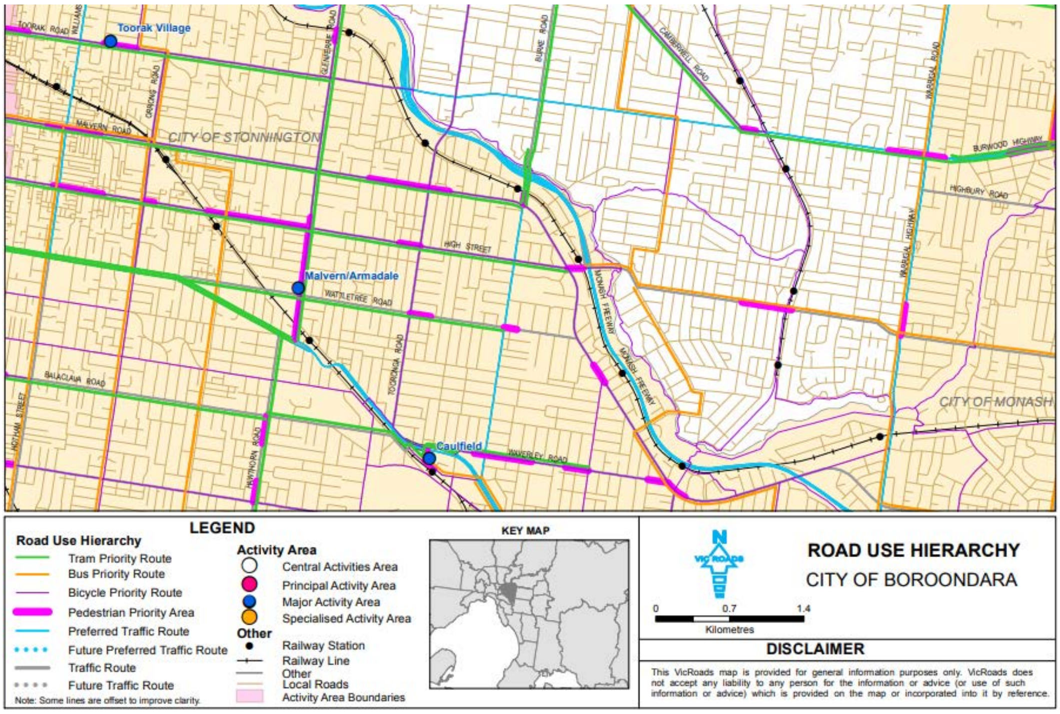

Figure 62: SmartRoads Classification of Inner East Melbourne Suburbs[189]

VicRoads stated they are currently in the process of evolving the SmartRoads framework towards a 'Movement and Place' approach for planning and operating

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[185] Transport for Victoria, 2018, https://transport.vic.gov.au/about/

[186] Transport for NSW, 2018, https://future.transport.nsw.gov.au/

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

[188] VicRoads, 2016, https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/smartroads

[189] VicRoads, 2016, https://www.vicroads.vic.gov.au/~/media/files/documents/traffic%20and%20road%20use/smartroadsprioritymapcityofboroondara.ashx.

the road network[190]. This change is consistent with the updated Austroads Guide to Traffic Management Part 4: Network Management[191]. VicRoads has stated that the application of 'Movement and Place' thinking is expected to better consider the role streets play as destinations, not just as conduits for movement[192].

Traffic management for declared roads and traffic signals in Victoria is centrally controlled within the VicRoads Traffic Management Centre (TMC). This includes managing system faults, hazards, special events, crashes and emergencies. The strategies implemented by the TMC are governed by the Austroads Guide to Traffic Management and the relevant VicRoads supplements to Austroads[193].

It is important to recognise the VicRoads TMC is not part of an 'integrated transport and emergency management centre' and individual toll road and public transport operators (such as: Yarra Trams, Metro, VLine and Transdev) run their own separate operations centres. Additionally, the State Control Centre which manages emergencies and incidents across Victoria is independent of the VicRoads TMC. However, these independent centres do have a level of coordination. In a fully 'connected' AV scenario, maintaining separate management of Victoria's transport network could make it highly difficult to successfully integrate and fully realise the potential benefits of AVs.

7.2.1 Systems Engineering and the Concept of Operations

7.2.1.1 Systems Engineering

Systems engineering focuses on how to design and manage a complex system over its life cycle and is a particularly useful process for managing risk in technology based projects and systems. Figure 63 illustrates the adopted systems engineering 'V-diagram' for Victoria's managed motorway system. It shows how the purpose of active management to achieve the desired network operational outcomes (green) by developing and using traffic optimisation methods (blue) which are reliant on the right technology (pink). This systematic way to viewing a complex system provides a possible method for considering AVs within the transport system.

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[190] https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/smartroads
[191] https://www.onlinepublications.austroads.com.au/items/AGTM04-16
[192] https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/smartroads
[193] https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management

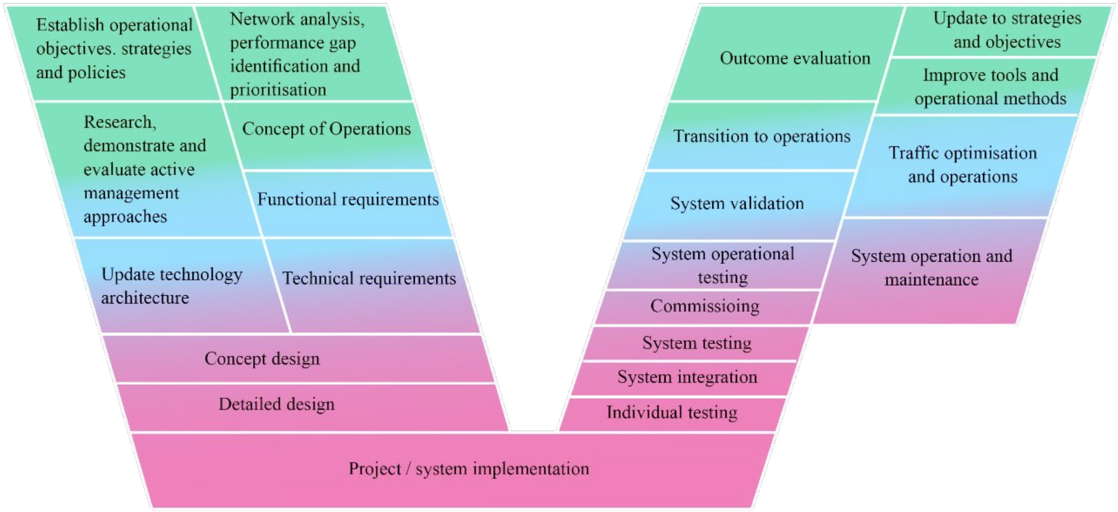

Figure 63: V-Diagram Systems Engineering - Victoria's Managed Motorway System[194]

7.2.1.2 Concept of Operations

Of particular relevance to the management of AVs is the development of a Concept of Operations (ConOps). The ConOps is a document describing the characteristics of a system from the viewpoint of an individual who will operate that system. This will become a key document as AVs become more connected and interact with the road system, as it will ensure the people responsible for operating the system understand the interactions between it and the AVs. The preparation of a ConOps usually involves engaging with key stakeholders on operational scenarios to record how the system will function from their perspective. The use of scenarios and stakeholder engagement gives the ConOps a focus on active management of the road network and ensures interventions are well conceived and controlled.

The Collaborative Sciences Centre for Road Safety (affiliated to the US Department of Transportation) is in the process of developing a ConOps for an automated vehicle remote operations centre[195]. The outcome of this project will be a document including the following components:

- Description of relevant characteristics of current dispatch systems and environments
- A detailed description of the system including justification
- Scenarios illustrating use of the system in real-world environments including internal and external factors.

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[194] VicRoads, Managed Motorways Framework: Network Optimisations & Operations Rationale and Technical Requirements, March 2017

[195] https://www.roadsafety.unc.edu/research/projects/2018r9/

7.2.2 Austroads: Automated Vehicles – Framework for Road Operations

As outlined in **section 2.5**, Austroads has a significant research program underway into preparing Australia's road network for AVs. Of particular mention is the research project being undertaken by the Australian Roads Research Board (ARRB) to develop an Operational Concept Framework for AV operations on public roads. It is expected this project will look at several use cases, such as:

- Motorway
- Metro/urban
- Rural highway
- Platooning
- Work zones
- Complex signalised Intersections, and
- Passenger drop-off/pick-up.

7.2.3 Road Safety Management – Safe Systems Approach

Ensuring the safety of all users is a key imperative in the operational management of a road network. Victoria's Road Safety Strategy 'Towards Zero' is based on the Safe System approach to improving road safety. The approach is embedded across Victorian Government for managing the network, encompassing the design, maintenance and operation.

Using Safe Systems enables a holistic view of the road transport system and the interactions among roads and roadsides, travel speeds, vehicles and users. It is consistent with the approaches adopted around the world, including several countries with the lowest rate of road fatalities, such as Sweden and the Netherlands [196]. Figure 64 highlights the key pillars of the safe systems approach:

- Safe roads and roadsides
- Safe speeds
- Safe vehicles
- Safe people.

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[196] http://www.who.int/gho/road_safety/mortality/traffic_deaths_number/en/

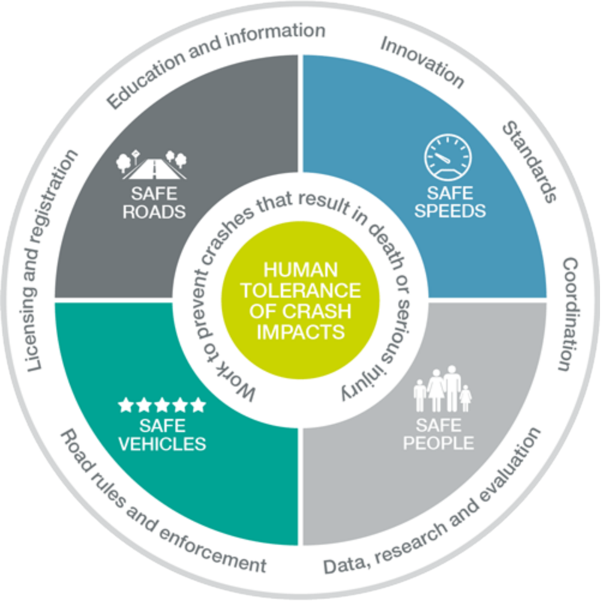

Figure 64: Safe System Approach Summary Diagram[197]

The key guiding principles to the approach are:

- Humans will make mistakes, and the transport system must accommodate these. The transport system should not result in death or serious injury as a consequence of errors on the roads
- There are known physical limits to the amount of force our bodies can take before we are injured
- A Safe System ensures that the forces in collisions do not exceed the limits of human tolerance. Speeds must be managed so humans are not exposed to impact forces beyond their physical tolerance. System designers and operators need to take into account the limits of the human body in designing and maintaining roads, vehicles and speeds.

Austroads has published an assessment framework designed to help road agencies methodically consider Safe System objectives in road infrastructure projects. The framework is useful in assessing how closely road design and operation aligns with the Safe System objectives, and in clarifying which elements need to be modified to achieve closer alignment with Safe System objectives.

The framework involves identifying the key crash types which result in death and serious injury, and using a risk assessment approach, identifying elements that might contribute to severe outcomes. The risk elements considered include road user exposure to risk (e.g. traffic volumes), likelihood of a crash, and the severity of the outcome in the event of a crash. The use of AVs in the fleet could have the potential to substantially alter road safety outcomes and how road safety could be approached from a road operations perspective.

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[197] http://www.who.int/gho/road_safety/mortality/traffic_deaths_number/en/

7.3 Potential Impacts and Responses

The following table identifies some of the potential changes that may occur, the impacts of the changes, as well as potential responses to manage risks or take advantage of opportunities. Given potential impacts may vary depending on street and road types, our assessment has categorised the road network into four broad groups:

- **Multi-lane arterials:** this includes roads equal to or larger than dual lane carriageways. They generally have a moderate to large movement function. Examples within Melbourne include Nepean Highway, Eastern Freeway and Bell Street.
- **High streets:** this includes main street arterials and collector roads, mixed use collector and streets through areas of high activity. They generally have a low to moderate movement function with moderate to high place function. Examples within Melbourne include Chapel Street, Flinders Lane and Malvern Road.
- **Local streets:** this includes neighbourhood collector, local and access streets, and local streets through light industrial and residential areas. They generally have a low to moderate movement function with low to moderate place function. Examples within Melbourne include Drummond Street in Carlton, Salmon Street in Port Melbourne and typical residential streets.
- **Regional roads:** this includes two-lane single carriageway roads that connect regional centres and areas. The generally have a moderate to high movement function and low place function. Examples include the Geelong-Ballan Road, Tylden-Woodend Road and Three Chain Road from Carlsruhe.

The following impacts where considered:

- Vehicle types
- Fleet configuration
- Energy
- Connected vehicles
- Road safety and community acceptance
- Density
- Signage and wayfinding
- Ownership versus shared
- Vehicle kilometres travelled.

Table 9: Risk/Opportunity, Impact and Response Assessment

The assessment summarises the potential risk or opportunity, trigger point, impact and response as outlined below:

- **Risk or Opportunity**: the potential event that may occur without intervention
- **Impact**: the potential impact of the unmitigated risk or opportunity, either positive or negative as shown to the right
- **Trigger Point:** when the potential impact may become a reality
- **Response**: possible actions to consider.

Impact Levels

🔴 Major negative impact
🟠 Negative impact
🟡 Minimal/negligible impact or not applicable
🟢 Positive impact
🟩 Major positive impact

Risk or Opportunity, and Trigger Point (TP)	**Impacts**				**Potential Response**
	Multi-Lane Arterial	**High Street**	**Local Street**	**Regional Roads**	
'Right Sizing' - new vehicle types/modes are not considered within the network operation planning framework (SmartRoads/M&P). This leads to not realising the network efficiencies or benefits in supporting these new modes. People using the new modes may negatively impact other corridor users. For example, e-bikes are already presenting some challenges for existing cycle lane infrastructure. TP: mode share of 'new modes' increases noticeable amount e.g. >2% or the number of incidents involving alternative modes is greater than average.	🟠	🟠	🟠	🟡	Consider the degree of priority and encouragement given to a particular mode. SmartRoads/M&P framework could be reviewed to include these new modes. This will help to determine what level of service the road operator aims to provide that mode.
Due to the ownership structure of fleet based CAVs, and sensors the vehicles contain, the private sector may have access to the best data to make informed operational and maintenance decisions for the network.	🟢	🟢	🟢	🟢	A framework, process and system for the collection, arbitration and distribution of data should be developed, by working collaboratively with key stakeholders such as other Australian jurisdictions, private firms and other domain experts. This would include an investigation into Australia's data privacy laws to ensure all data collection is anonymised and legally obtained. NB some organisations are already sharing data such as, for example, Uber Movement[199].

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[199] https://movement.uber.com/?lang=en-us

Companies such as HERE, Tesla, Google and Uber already own real-time datasets that hold information regarding roadside objects and traffic conditions[198].					
The increase in connected vehicles to improve safety may increase the requirement for additional equipment on the network. More likely on key movement corridors and high streets. TP: wide-scale use of connected vehicles.	🟠	🟠	🟡	🟡	Find opportunities to provide required equipment in a cost-effective manner. NB: developments in public wireless telecommunications systems (i.e. 5G mobile network) mean vehicle specific infrastructure may not be required.
Road pricing information could be provided in the vehicle for connected AVs. TP: driverless AVs available.	🟢	🟢	🟢	🟢	Road pricing will enable better decisions by people when and how they travel based on the most efficient mode and time. Appropriate road pricing strategy will assist to manage demand.
AVs may struggle to interpret changed or dynamic conditions such as roadworks or in the event of an incident if there is a lack of clarity. TP: use of AVs on the road network.	🔴	🟠	🟠	🔴	Collaboration with vehicle manufacturers to understand how temporary line marking and barrier installation guidelines can be developed to be compatible with the existing lane guidance systems. Incident response and traffic management plans to identify the required physical and digital infrastructure, such as real-time high definition mapping, to provide clarity to AVs in changed circumstances.
On-road EV charging is installed due to increased demands. TP: wide-scale adoption of ZEVs.	🔴	🟢	🟢	🟡	Need to develop EV charging strategy early in process to achieve behaviour change, and prevent poor location choices of EV infrastructure. Avoid locating charging infrastructure directly on busy arterials. There may be a case for regional roads at rest stops and the like.
A significant increase in unoccupied vehicles, increasing congestion, VKT and delaying other sustainable mode. TP: high penetration of privately owned AVs.	🔴	🔴	🟠	🟠	Vehicles should be required to share occupancy data – empty vehicles would be on the bottom of the hierarchy. Appropriate road pricing strategy will assist to manage demand and ensure that the user is paying for the infrastructure required. Dedicated AV lanes could be considered for occupied vehicles, to ensure people are prioritised over empty vehicles (refer to **section 7.4.1**).

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[198] http://www.geomarketing.com/here-is-bringing-3d-maps-to-bmw-group-and-daimler-mercedes-benz-models

Data sharing is poor from vehicles to traffic management centres and vice versa, reducing optimal efficiency of the network. TP: a vehicle fleet that is capable of communication.	🔴	🔴	🟡	🟠	Working collaboratively with other Australian jurisdictions, develop a broader framework, process and system for the collection, arbitration and distribution of data. This is a must for an effective system and therefore should be done within the next five years.
Greater demand for kerb space (i.e. drop-off and pick-up zones) causes traffic issues and bottle necks around key destinations. TP: wide-scale use shared AVs.	🟠	🔴	🟡	🟡	Consider reviewing the current guidelines on traffic management (Austroads and supplementary documents) to update for the new demands for pick-up and drop-off zones. For example, current legislation (VicRoads, 2000) does not allow private vehicles in drop-off zones. Investigate 'dynamic' kerbside lane management (refer to **section 7.4.2**).
In the case of a breakdown or malfunction, vehicles behave inconsistently, presenting a safety issue as well as a potential congestion issue. TP: wide-scale use of AVs.	🔴	🟠	🟡	🟠	In collaboration with vehicle manufacturers, develop a ConOps that caters for vehicle breakdowns and incidents e.g. stop in lane or find nearest rest stop. Design minimum risk condition into infrastructure (refer to **section 5.5.8.4**). If AV breakdowns/fallback mode become a relatively common occurrence a dedicated lane may need to be established (refer to **section 7.4.1.1**).
Severe weather event results in AV stopping e.g. flooding across road etc. causes major disruption and community angst. TP: wide-scale use of AVs.	🔴	🔴	🟠	🟠	In collaboration with vehicle manufacturers, develop a ConOps that tests various scenarios to ensure the management of the system is actively managed rather than reactively. Connectivity would help with this by providing AVs with road hazard warnings and/or route advice. Design minimum risk condition into infrastructure (refer to **section 5.5.8.4 - Emergency parking bays**).
Without the necessary infrastructure or training AVs will be unable to give way to or engage with emergency vehicles, causing unnecessary delay[200]. TP: arrival of AVs on road.	🔴	🔴	🔴	🔴	Enable V2V and V2I infrastructure and enforce legislation that ensures vehicles are able to communicate and manoeuvre appropriately.

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[200] https://storage.googleapis.com/sdc-prod/v1/safety-report/waymo-safety-report-2017-10.pdf

AVs use different processes/methods for wayfinding and decision making (camera vs digital mapping), need to ensure all relevant parts of the infrastructure they rely on are maintained, otherwise it could create a safety issue as technology gets old. TP: Slow Lane scenario including L2 to L5 vehicles.	🔴	🟠	🟠	🟠	Monitor and watch situation - it may require older models to be removed off the network or to be retrofitted. Connectivity would help with this by connecting all vehicles into an integrated system for wayfinding. Refine and review Safe Systems assessment to include AV considerations (refer to **section 7.2.3**).
AVs unable to interpret unusual road rules/inconsistent in Victoria e.g. hook turn. TP: Level 3 AVs.	🟠	🟠	🟠	🟠	Before a vehicle can operate in L4 or L5 mode they must obtain correct certification, either national or state. Continue to run test and trials to pick-up issues sooner. Consider removal of road rules and signs that are particular to Victoria to make consistent nationally and internationally. Refine and review Safe Systems assessment to include AV considerations (refer to **section 7.2.3**).
In a mixed fleet scenario, half the vehicles are not connected meaning driving practices by AVs are a lot more conservative considerably decreasing the capacity of the corridor. Human drivers become frustrated and take undue risks. TP: Level 3+ vehicles make up more than 10% of the fleet.	🔴	🟠	🟢	🟢	Consider making key movement corridors (including key public transport routes) ‘fully connected corridors’. Consider establishing a designated lane for AVs to operate within (refer to **section 7.4.1.1**). Refine and review safe systems assessment to include AV considerations (refer to **section 7.4.3**).

7.4 Key Response Considerations

In the table above management of traffic lanes and kerbside lane management were raised as potential responses, these are further explored below.

7.4.1 On-Road Lane Management

7.4.1.1 Lane Allocation

Several industry observers have suggested that in order to enable and encourage the safe and efficient operation of AVs, segregation to some degree may be required[201]. To clarify, there are four broad types for how a lane(s) could be potentially managed for AVs:

- **Separated**: human drivers would be physically separated from AVs
- **Dedicated**: human drivers would be banned from operating in a particular lane(s) allocated to vehicles operating in AV mode
- **Designated**: a lane(s) would be set up to encourage AVs, however they would not be restricted from other lanes, unlike a dedicated lane, human drivers could choose to travel in that lane as well (preferably in a connected vehicle)
- **Shared**: AVs and human drivers freely mix in whatever lane.

There are already a significant number of vehicles that operate successfully on the road network with limited automation, including steering assistance. The use of advanced driver aids such as cruise control, adaptive cruise control and lane keep assist are already widespread without the need for segregation on our major trunk roads and motorways[202]. Currently, the information available suggests there is no reason why segregated lanes will be necessary. Segregated lanes could potentially impact the efficiency of the road network, by taking away road space. It could be prohibitively expensive to implement segregated lanes across the network.

During the transition, a dedicated lane seems unfeasible as a high rate of Level 4 and Level 5 penetration would need to be achieved, and even at that point, AVs are likely to choose to travel in other lanes, especially during peak times and short motorway trips. Issues could arise when there are low numbers of AVs travelling on a particular road but a high number of human drivers, and also less efficient and poor public perception. Implementing a high occupancy lane (three or more people in a vehicle) could potentially deliver the same benefits. Noting that HOV lanes are difficult to police, therefore it is possible that designated lanes would need high levels of connectivity to be policed. Under a shared scenario with higher occupancy levels, (three or more people) a dedicated AV-HOV lane could be a possible long-term outcome, this could be managed dynamically to optimise people and goods throughput. Another possible need long-term for a designated

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[201] https://venturebeat.com/2017/04/25/why-highways-should-isolate-self-driving-cars-in-special-smart-lanes/
[202] Interview with Tim Armitage – Project Director UK Autodrive

lane(s), could be to prioritise people and goods over vehicles travelling around empty, this could be managed through dynamic lane management.

It is likely to be many years before AVs form the majority of the Victorian vehicle fleet and therefore managing the transition phase will be key. To encourage uptake and help the travelling public to become comfortable with AVs on the road, it has been suggested a designated lane could be created on motorways and some major arterials[203]. This would allow people to choose to travel with AVs, and this assumes that for Level 4 vehicles and below, AV mode would only be selected in that lane.

It is highlighted that if the Slow Lane scenario eventuated, then a designated lane could make sense to encourage and support the benefits of AVs – the policing issue is assumed to have been resolved. A possible solution could be for interurban roads to have a dedicated AV lane which would be linked to booking slots, to ensure journey time reliability and prevent too many vehicles simultaneously.

7.4.1.2 Contraflow

In **section 5.5.3.2 Impact - Fully Connected AV fleet** the current practice of contraflow on Queens Road, South Melbourne was discussed. Contraflow is simply the practice of switching the direction traffic travel in a particular lane. Another example of permanent contraflow in Melbourne is Johnson Street, Abbotsford.

Contraflow is often used as a temporary measure during road works or when a crash occurs, requiring traffic lanes to be closed for an extended amount of time. With regards to temporary uses of contraflow, road authorities will need to keep a close watch on how AVs behave during the transition phase as it is assumed in the long-term that a technology solution will be developed to inform vehicles on how to behave through the site.

Though used often temporarily, it is not a widely used permanent traffic management technique. This is due to several factors, including potential safety issues, cost of installing and operating, it suits roads with constant lower counter peak volumes, and may impact on adjacent places. AVs potentially solve a number of issues as they would not require costly infrastructure, would eliminate the safety issues, and the lane could be managed dynamically i.e. if counter peak flows changed then the lane could be reallocated. One benefit from greater use of contraflow in an AV future is lane space could be reallocated to alternate uses other than a movement function, to better support place values – see Kerbside Management below for further discussion.

It is assumed that human drivers would need to be taken out of the system to dynamically manage contraflow lanes, however having a fully connected fleet may allow this traffic management technique to eventuate a lot sooner, without waiting for the entire fleet to be Level 4/5 vehicles.

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[203] https://www.bbc.com/news/av/technology-40382959/hyperlane-a-special-lane-for-self-driving-vehicles

7.4.2 Kerbside Management - 'FlexKerbs'

In addition to on-road lane management, road authorities and local councils will need to begin turning their attention to kerbside management. Arup is currently working with in partnership with the National Infrastructure Commission (UK)[204] to design streets fit for Connected and Automated Vehicles (CAVs). The initiative is called FlexKerbs and is looking at how CAVs can co-exist with all road users, and the future management of the kerbside lane through the introduction of flexible kerb space. Driven by real-time data and local policy, FlexKerbs will intelligently adjust permitted kerbside uses throughout the day and week to ensure that space both meets demand and achieves local transport goals. Over the course of a day, for instance, a single FlexKerb segment can function as an automated vehicle rank at rush hour, a cycle path at lunchtime, a pedestrian plaza in the evening and a loading zone overnight (Figure 65).

A feasibility study to demonstrate how the FlexKerb concept could benefit cities once CAVs have been introduced, will be finished in late 2018. The study will test strategies for simulating CAV behaviours with traffic modelling software.

While shared CAVs allow for a breadth of opportunity for urban spaces, they will place increasing demands on space with the need to manage a range of transportation times and programmes throughout any one day. We see busy urban streets such as Melbourne's Brunswick Street, Fitzroy Street and Swan Street, as iconic public spaces, home to an array of commercial, residential and recreational uses. These spaces which embody landmark vibrancy, alongside their dynamic activities throughout, require complexity in the approach to CAVs management. Ensuring space is kept active but well managed while maintaining neighbourhood character and functionality is crucial to the efficient and lasting operation of these corridors. This management needs to embrace new technology while prioritising rich diversity and pedestrian experience of space throughout all realms of activity.

Flexkerbs strives for an innovative and all-encompassing approach to harness the dynamic nature of busy urban streets into an efficient and holistic program, without taking away from vibrant use and character of space.

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[204] https://www.nic.org.uk/news/five-shortlisted-to-develop-roads-for-the-future-and-driverless-cars/

Figure 65: Arup FlexKerb Concept (Source: Arup)

7.4.3 Refining the Safe Systems Approach

The international transport forum recently stated in their report into Safer Roads with Automated Vehicles[205]: ‘*Claims of a more than 90% reduction in road traffic deaths resulting from automation eliminating crashes linked to human error are untested. It seems likely that the number of road casualties will decrease with automation, but crashes will not disappear. In certain circumstances, more crashes may occur among ‘average’ drivers that are not prone to risky behaviour. This is particularly likely in circumstances where drivers must take over from automated driving in emergency situations’*.

They go on to recommend: ‘*Automation places even greater importance in achieving an effectively integrated Safe System approach to operation’*[206].

The expectation of enhanced situational awareness and control capabilities of fully autonomous vehicles will likely have substantial positive implications for road safety. Arup and Safe Systems Solutions have explored how the Austroads Safe Systems assessment process could be adapted to better consider how the enhanced capabilities of AVs may be incorporated to assist with the design and operation of the road network. The Safe Systems assessment considers risk in terms of exposure, likelihood and severity. AVs have the potential to substantially change how each of these could be assessed. For example, Figure 66 illustrates how improved reaction times of AVs would substantially reduce expected crash severity with no other infrastructure changes.

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[205] https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf
[206] https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf

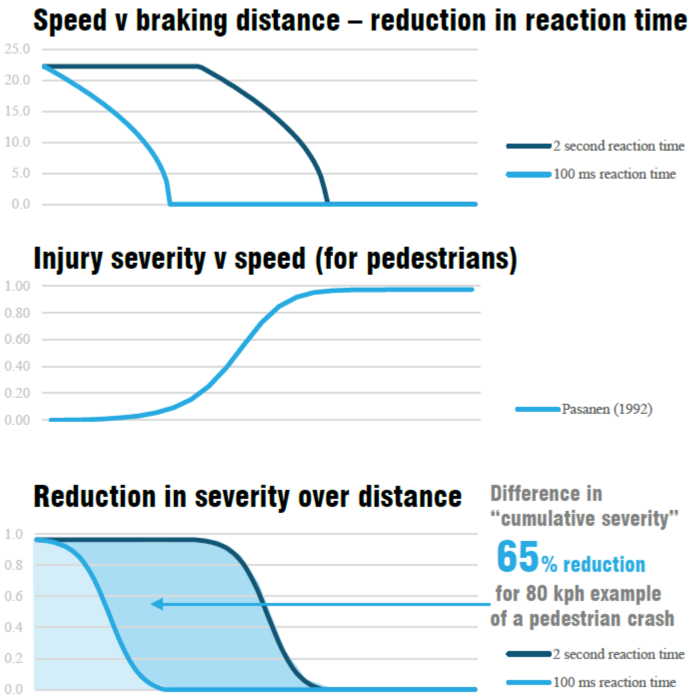
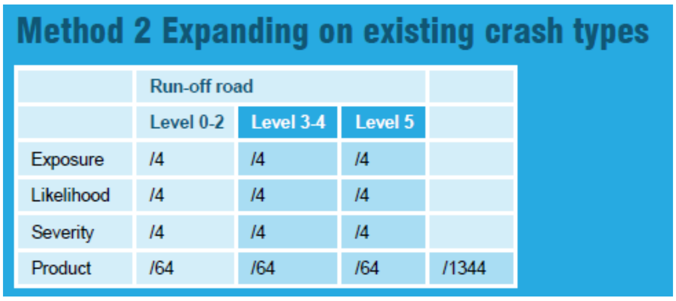


Figure 66: Adapting Assessment of Severity for AVs[207]

One way AVs could be introduced into the Safe Systems approach would be to create new crash types specific to AVs, with scoring assigned.

A key element of the adapted process could be consideration of two types of AVs as separate modes: Levels 3-4 and Level 5 AVs, Figure 67 illustrates this suggested change to the assessment framework.



Method 2 Expanding on existing crash types

	Run-off road			
	Level 0-2	Level 3-4	Level 5	
Exposure	/4	/4	/4	
Likelihood	/4	/4	/4	
Severity	/4	/4	/4	
Product	/64	/64	/64	/1344

Figure 67: Potential Revised Safe Systems Scoring System[208]

In addition to changing the assessment process, in the future AVs could be included in the road safety treatment hierarchy, as outlined in the Austroads Safe Systems framework. Road safety and blackspot programs may wish to prioritise infrastructure responses to encourage and enable the safe use of AVs, for example line marking upgrades or traffic sign consistency.

It is suggested based on the research and trial findings to date, the relevant road authority or organisation may want to consider developing a guidance note or

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[207] https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf
[208] https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf

checklist for road designers and planners, to consider AVs within the road design. Figure 68 shows an excerpt from the ‘Roads that Cars Can Read Checklist’[209]:

Consistency Between New Design and Existing Design
Is there consistency between new line markings and existing line markings (e.g. colour, width, etc.)
Do existing line markings near those of new line markings need to be upgraded?
Is the transition from old work to new work satisfactory? (i.e. no uncertainty or ambiguity at the transition?)
Are line marking materials consistent with existing line marking material?

Figure 68: Checklist Roads that Cars Can Read

7.5 Conclusion, Findings and Recommendations

7.5.1 Conclusion

The introduction of AVs and ZEVs on to the Victorian road network will have significant impacts on operation and management. In response to these changes, it is suggested that several existing frameworks and guidelines, such as the M&P framework, Safe Systems approach and incident response and traffic management plans are reviewed to better consider these new modes.

In addition to the changes in guidelines and policies, there are a number of direct technological and infrastructure requirements, such as digital communication of emergency signals that may need to be explored and invested in to enable the changes in approach. It is noted that IV have procured a separate report on ICT infrastructure requirements which will expand on the technological requirements.

7.5.2 Findings and Recommendations

The Need for Connected Vehicles to Deliver Full Benefits

It is generally accepted by subject matter experts that the full benefits of AVs may only be achieved if they are connected to the transport system, such as: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Vehicle-to-Other-Systems (V2X). In some circumstances road operations may get worse without connectivity, for example vehicles may allow more conservative headways or have the inability to use complex intersections and road layouts.

Road Operations Needs to be Outcomes and Performance Led

Following on from ‘Movement and Place’, it will be important for the design and operation of infrastructure to be led from an outcome and performance perspective. AVs provide opportunities and challenges, and it is only through agreeing on desired outcomes and required performance that infrastructure can be planned for the optimal use of AVs. AVs cannot just be about the technology i.e. ‘a solution looking for a problem’. They need to operate to support broader

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[209] Source Safe Systems Solutions

societal outcomes and ultimately AVs will play a central role in the planning and design of the road network.

Time to Bring All Control Centres Under One Roof

Victoria does not currently have a single central control centre for its transport system, nor is it fully integrated with the State Emergency Control Centre. Having several control centres responsible for different transport modes and networks, could create significant issues in an automated future. To enable and ensure AVs are part of an integrated transport system, Victoria could begin planning for a Central Control Centre for Transport and State Emergencies. In the future, a Concept of Operations document may need to be created to help people, responsible for the operation of the transport system, understand the interaction between it and the AV fleet.

8 Parking and Land Use

8.1 Purpose

This section outlines analysis of the impact of AVs and ZEVs on the design, management and operation of car parking. Following this initial discussion, this section goes on to explore case studies and the repurposing of car parking for alternative uses.

8.2 Context

Infrastructure Victoria's seven test scenarios feature various combinations of fully or semi-independent technological variables. These include:

- Driving mode: driverless or driver
- Ownership and access to transport
- Power type (fossil fuels/electric/hydrogen).

Notably, research already demonstrates that growing Mobility as a Service (MaaS) offerings (refer to **section 8.2.1 Mobility as a Service (MaaS)**) are reshaping certain transport behaviours, albeit for selected segments of the population and at a limited scale. The following effects are independent of vehicle automation and power type:

- Some car share subscribers dispose of their private vehicles or choose not to buy their own vehicle[210]
- MaaS can substitute for conventional public transport for some trips especially in decentralised cities and where public transport service is weak[211]
- MaaS can complement public transport and provide alternatives to private driving for some trips[212].

Our analysis of impacts of future mobility scenarios relating to parking supply, design and management, focuses on the independent variables rather than IV's Scenarios. In **section 8.4** our work is tied back to the scenarios in order to evaluate differences which may be observable. Impacts are analysed by exploring how they are affected by key dimensions of change which are inherent in differing future mobility scenarios.

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[210] https://www.researchgate.net/publication/297592848_Carsharing_and_sustainable_travel_behavior_Results_from_the_San_Francisco_Bay_Area

[211] http://www.demand.ac.uk/wp-content/uploads/2018/01/28-EC1-Circella-Alemi-2017.pdf

[212] http://www.apta.com/resources/reportsandpublications/Documents/APTA-Shared-Mobility.pdf

8.2.1 Mobility as a Service (MaaS)

MaaS has become a popular way to describe the following, sometimes jointly, interchangeably or discretely:

- Travel options that are available at the discretion of the user and avoid locking them into ownership of a mode (e.g. a private vehicle) with its ensuing and significant sunk costs and ongoing maintenance, insurance and fuelling expenses
- Interfaces and platforms that provide users with access to specific - or a selection of - travel options, sometimes with a variety of supplementary data and functionality included e.g. access to timetables, locational data, congestion information, payment options, travel-time estimates and comparative costings[213].

8.3 Implications

8.3.1 Residential Parking Demand

The key dimension of change affecting the level of residential parking demand in the future is likely to be the level of uptake of shared ownership and operation via a MaaS offering. Automation of transport is likely to have lesser effects.

If all vehicles on the network are privately owned and operated AVs:

- There is potential for increased independent mobility and therefore vehicle ownership. Demographic groups that do not have the facility to drive themselves (including seniors, children and the mobility-impaired) may be driven by an AV. Research from the United States predicts that the added light vehicle-based mobility (measurable in vehicle miles travelled) may be up to 14%[214]
- Increased independent mobility may be offset by increased efficiency in the way vehicles are shared between members of the same household, with one study finding that vehicle ownership could drop by 43% supported by a 75% increase in travel per vehicle[215]. There may not be meaningful change to residential parking demand because of the balancing effects of induced mobility and increased intra-household vehicle usage. Privately owned vehicles will require a place to be parked at or near the home, especially overnight.

In contrast, if all vehicles on the network are AVs operating as part of a MaaS fleet, residents can order a vehicle to pick them up from their home or from a designated pick-up location in relative proximity, eliminating demand for private

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[213] https://www.arup.com/-/media/arup/files/publications/m/mobilityasaservice-the-value-proposition-mar18.pdf.

[214] https://www.researchgate.net/publication/308392875_Estimating_potential_increases_in_travel_with_autonomous_vehicles_for_the_non-driving_elderly_and_people_with_travel-restrictive_medical_conditions

[215] http://www.driverlesstransportation.com/wp-content/uploads/2015/02/UMTRI-2015-3.pdf

vehicle parking at the home. There may be a small number of exceptions to this such as tradespeople who require work vehicles containing tools or other specialist equipment. Specialist personal vehicles could either be parked in longer-term on-street bays, or inside a secure external facility and summoned depending on restrictions placed on zero-occupant vehicle travel.

Any significant decrease in residential parking demand will be correlated with near-full or full uptake of MaaS and may be relatively independent of vehicle automation. Low levels of MaaS will not necessarily lead to meaningful reductions in residential parking demands if mobility services are used occasionally, and while people retain private vehicles to fulfil other travel demands. Nevertheless, effects on parking are likely to vary significantly depending on urban geography, with research showing that today's more frequent mobility service users – especially those who relinquish private vehicle ownership owing to access to shared services - tend to be located in city centres and other major activity centres[216].

8.3.2 Commuter Parking Demand

As per residential parking demand, the key dimension of change affecting the level of commuter parking demand in the future is likely to be the level of uptake of MaaS. Automation of transport is likely to have an important, albeit less significant effect[217]. Similar effects are anticipated for other types of longer-stay parking, including student parking at educational institutions and 'Park and Ride' at public transport stations.

If all vehicles on the network are privately owned and operated AVs:

- Commuters will prefer to be dropped as close to their ultimate destination as possible. Vehicles will then be ordered home (or to another location), where they can stable at lowest relative cost. In practice, user choice decisions regarding assignment of vehicles after drop-off will depend on personal circumstances accounting for the needs of households, marginal pricing of zero occupancy operations versus parking, and convenient access to the vehicle once it is called for pick-up[218]
- We are likely to see a relatively moderate decrease in the overall level of commuter parking demand, shifting demand to PU/DO facilities. Some parking demand may re-assign from parking stations near workplaces, to more remote stabling facilities (parking lots provided as a staging area for vehicles while they await call-up for trips).

If all vehicles on the network are AVs operating as part of a MaaS fleet:

- Passengers are dropped at their destination utilising PU/DO facilities, either adjacent to the end destination or at the nearest drop-off node. The increase in

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[216] http://onlinepubs.trb.org/onlinepubs/excomm/18-01-Shaheen.pdf

[217] http://www.calgary.ca/Transportation/TP/Pages/Strategy/Future-of-Transportation-in-Calgary.aspx

[218] https://www.vtpi.org/avip.pdf

demand for convenient PU/DO, in many instances kerbside, may be similar to a privately owned AV scenario

- After drop-off, the passenger will release the vehicle back into circulation to serve other customers. The original user will have no demand for nearby parking or more remote stabling.

8.3.3 Recreational/Retail Parking Demand

As was the case for residential and commuter parking demand, the key dimension of change impacting the level of recreational/retail and other types of short-stay parking demand in the future, is likely to be the level of uptake of MaaS. However, automation of transport is likely to have important, but less significant effects.

If all vehicles on the network are privately owned and operated AVs:

- Passengers will prefer to be dropped as close to their ultimate destination as possible. Some vehicles will then be assigned to parking on-site or nearby (particularly for shorter trips, for convenience), and some sent home or elsewhere to cheaper parking. In practice, user choice decisions regarding assignment of vehicles after drop-off will depend on personal circumstances accounting for the needs of households, marginal pricing of empty vehicle operations versus parking, and convenient access to the vehicle once it is called for pick-up
- We are likely to see a relatively moderate decrease in the overall level of recreational/retail parking demand for these uses, shifting demand to PU/DO facilities.

If all vehicles on the network are AVs operating as part of a MaaS fleet:

- Passengers are dropped at their destination utilising PU/DO facilities, either adjacent to the end destination or at the nearest drop-off node. The increase in demand for convenient PU/DO, in many instances kerbside, may be similar to a privately owned AV scenario
- After drop-off, the passenger will release the vehicle back into circulation to serve other customers. The original user will have no demand for nearby parking or more remote stabling.

8.3.4 Total Residential and Non-Residential Parking Demand

Various studies have attempted to estimate changes to parking demand for different land uses in cities as a consequence of technology-led disruption in the mobility sector. Current evidence demonstrates that shared mobility options – both availability of mobility services that allow consumers to avoid vehicle ownership and multiple-occupancy motorised services – are likely to have the most significant impacts on overall parking demand. Automation of transport is also likely to have significant, albeit secondary, effects.

A study of Atlanta in the US concluded that a 5% market penetration of shared AVs could lead to a 4.5% reduction in land requirements for parking[219].

If all vehicles on the network are privately owned and operated AVs, meaningful changes to residential parking demand may not eventuate. However, moderate reductions in both long and short-stay parking at destinations is conceivable. In contrast, if all vehicles on the network are AVs operating as part of a shared fleet, significant decreases in both residential and destination-end parking demand are anticipated. These reductions are likely to be off-set by increased demands for remote stabling facilities and kerbside facilities, which are discussed in the following two sections.

8.3.5 Demand for Stabling Facilities

Stabling requirements will rise as uptake of shared services increases and vehicles become automated[220]. As services emerge and capture passengers, the demand for stabling facilities will likely grow at a faster rate. At higher market shares of travel, stabling requirements are likely to plateau.

At low levels of deployment, passenger trip density will create inefficiencies in fleet operation and high numbers of vehicles (relative to travel demands) to maintain the levels of service expected by customers. Significant vehicle down-time is anticipated, especially during the inter-peak. Fleet operators may opt to geo-fence their services while supply and demand remain low, in order to mitigate inefficiencies and limit fleet size and stabling needs.

At high levels of deployment, greater operating efficiencies are possible and stabling needs (for example bays per fleet vehicle) should reduce. Fleet size may be 9-10% of current light passenger vehicle supply. Stabling facilities may be used both temporarily during daylight operating hours while vehicles wait to be assigned to their next trip and overnight (for example between midnight and 6am) when off-peak travel demands (which may be about 5% of the peak) require a much smaller available shared AV fleet. Nevertheless, the size and distribution of stabling facilities will depend on a range of factors, including:

- The number of fleet operators in the market
- Land tenure
- Any regulation of shared AV operations and potential stabling sites
- Target levels of service (for example average delays for passengers when mobility is demanded)
- Any government levies on dead-heading
- The geographic distribution of travel demands.

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[219] https://www.researchgate.net/publication/312057636_Parking_spaces_in_the_age_of_shared_autonomous_vehicles_How_much_parking_will_we_need_and_where

[220] Anderson. J, Kalra. N, Stanley. K, Sorensen. P, Samaras. C. and Oluwatola. O, 2014, Autonomous Vehicle Technology: A guide for policymakers, Washington D.C.: RAND Corporation

In particular, if there are relatively low barriers to entry into the mobility market, significant competition between vendors and limited regulation to control fleet sizes and operating areas, the overall operation of the shared AV system will be inefficient and lead to a suboptimal stabling outcome.

An inefficient stabling scenario, featuring many service providers each with their own facilities, may mean that multiple bays are provided in the aggregate per shared AV. This would enable providers to maintain their service coverage and performance thresholds (e.g. passenger wait times). Alternatively, an efficient scenario whereby there is more optimal distribution of stabling facilities, provided in common for service operators to meet typical patterns of demand, would yield a lower ratio of bays to vehicles.

In practice, in both inefficient and efficient staging scenarios, maximum real demand for stabling bays may equate to considerably less than 95% of the fleet even when off-peak travel demands are around 5% of peak values (because more vehicles are required to be in circulation to maintain levels of service). Nevertheless, real supply of stabling bays will be more than this (and potentially quite a lot more); especially in lieu of regulation.

Other research has presumed significant parking space savings associated with shared AV operations. These estimates may be overstated assuming inefficiencies occur[221].

In contrast, if all vehicles on the network are privately owned and operated AVs, there may be some demand for stabling facilities if parking is not provided at destinations. However, these needs are likely to be much less than in the shared AV scenario although again, it will depend on location (availability of stabling hubs), household travel demands (including whether vehicles are shared between family members) and pricing variables (stabling levies, empty-running charges).

8.3.6 Kerbside Access Demand

Increased kerbside access demand is one of the more significant and likely implications of automation of passenger transport. An increase in demand is anticipated whether AVs are owned and used privately or are shared in a shared service fleet. Demand for kerbside space will inevitably increase as the deployment and use of AVs increases.

If all vehicles on the network are privately owned and operated AVs:

- Kerbside PU/DO is expected to become the prevalent arrival/departure facility for every non-residential land use
- Passengers are likely to opt to be dropped off at PU/DO as close to their destination as possible
- Short-term on-street parking demand is also likely to increase, primarily serving shorter trips. These bays will be popular for vehicles to assign to after drop-off, and for convenient access when called for pick-up

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[221] http://www.caee.utexas.edu/prof/kockelman/public_html/TRB14SAVenergy_emissions.pdf

- Private passenger vehicles will compete with service vehicles and surface running public transport for limited kerbside space. This issue will be more acute in major activity centres and city centres.

If all vehicles on the network are AVs operating as part of a MaaS fleet:

- Kerbside PU/DO becomes the prevalent arrival/departure facility for vehicle trips associated with all land uses
- Passengers are likely to opt to be dropped off at PU/DO as close to their destination as possible
- Private passenger vehicles will compete with service vehicles and surface running public transport for limited kerbside space. This issue will be more acute in major activity centres and city centres
- A significant increase in kerbside access demand is anticipated for all trips with residential ends compared to the privately owned scenario.

8.3.7 Integration of Refuelling Infrastructure with Parking

Should the vehicles of the future run on conventional petrol/diesel, no significant changes to refuelling infrastructure are anticipated. In particular, refuelling stations are not anticipated to become integrated with parking facilities. In contrast, if electric or hydrogen powered vehicles become the norm, step changes to refuelling infrastructure will occur and this will include implications for parking facility design, at least for electrical recharging. Design implications are addressed in the following section of this report.

The level of uptake of shared services will also affect demands on recharging infrastructure and by implication, design standards for parking facilities in an ‘electric’ future. If all vehicles within the mobility system are privately owned and operated AVs, aggregate VKT is likely to be significantly higher than if all vehicles on the network are AVs operating as part of a shared on-demand fleet due to the higher number of passenger vehicles and proportion of zero occupancy vehicle trips anticipated. The relatively higher VKT will contribute to greater supply and distribution of refuelling stations.

8.4 Implications for IV Scenarios

The following documents the analysis of Infrastructure Victoria’s seven future scenarios against the direct implications of AV and ZEV implementation, discussed above, along with additional derived impacts including:

- **Decreased parking revenue:** a consequence of less demand for parking, especially in activity centres and Central Business Districts (CBD) where pricing is used as both a travel demand management tool and revenue-generating scheme
- **Layout efficiency gains:** opportunities to redesign parking areas owing to vehicle automation to achieve greater yields

- **Parking land reuse opportunities:** opportunities to reclaim parking space for other land uses either through new build or adaptive reuse.

The purpose of the analysis is to demonstrate the relative strength and directionality of impacts across the scenarios, which themselves represent different combinations of dimensions of change: automation/conventional drive, private ownership/shared use, fossil fuel-powered/electric/hydrogen. It was completed largely by qualitative variable analysis, informed by extensive literature review and professional judgement and supplemented by quantitative information where relevant across the dimensions of change (as the scenarios are comprised of different combinations of the dimensions of change). A limitation of research of this nature at present is that there is no direct empirical basis; it is forecasting only. As a result, the outputs are not intended to be precise, and should not be interpreted as such.

The full analysis can be found in the matrix provided in **Appendix B**, and is based on a comparison of the base case present day situation with full realisation of each scenario; this varies between 2031 and 2046. The magnitude of impacts expected across each scenario were allocated a rank according to Figure 69. The outermost ring in each figure represents a score of ‘1’, while the innermost ring represents a score of ‘3’.

Score	Magnitude of impact
1	Significant
2	Minor
3	Negligible

Figure 69: Key Implications Legend

8.4.1 Electric Avenue

The defining attributes of ‘Electric Avenue’ are shown in Table 10.

Table 10: 'Electric Avenue' Attributes

Year	Driving mode	Power source	Ownership/market model
2046	Non-driverless	Electric	Private ownership

The web of implications across key variables in ‘Electric Avenue’ are shown in Figure 70. Overall findings include:

- Nine of the 10 variables are unlikely to be impacted marginally compared to the base case, because of a lack of automation and uptake of shared mobility
- There are significant new refuelling requirements due to the electric power source of vehicles.

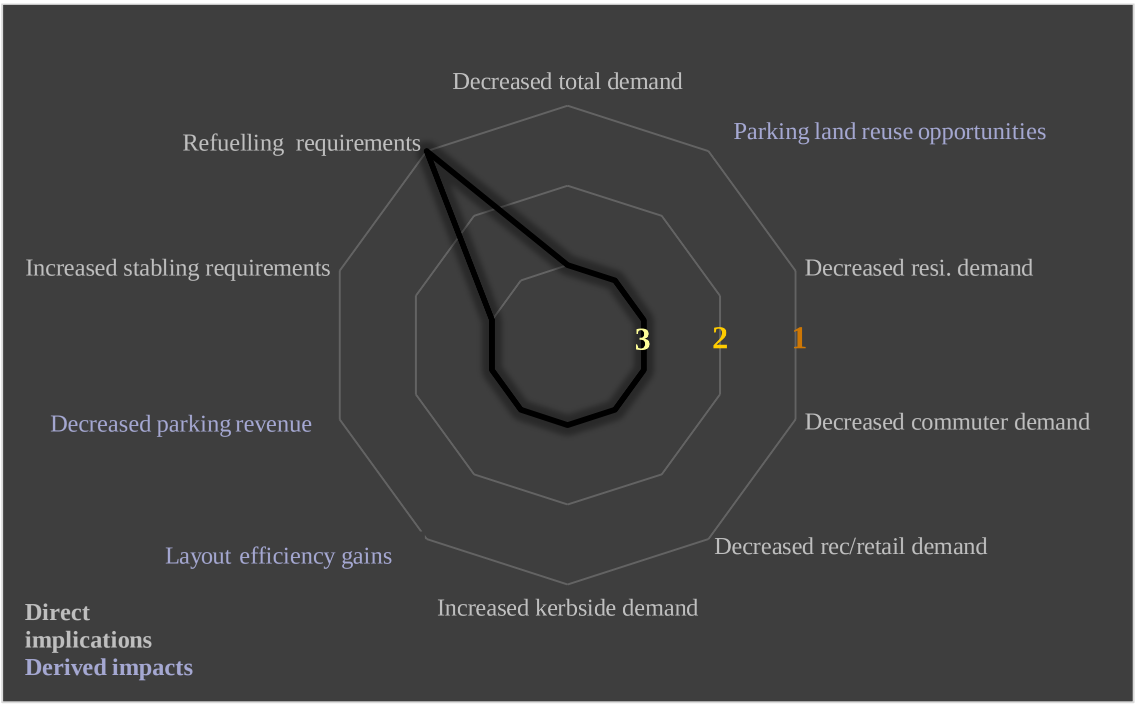

Figure 70: AV and ZEV Implications for 'Electric Avenue'

MABM output data shows that the mode shares for the 2046 base-line scenario (‘Dead End’) and the ‘Electric Avenue’ scenario are the same (81%). A similar mode share is likely to be correlated with similar overall fleet sizes and demands for parking. This validates the implications presented in Figure 70, given the only change from ‘Dead End’ is that of the vehicle fleet’s power source (electric versus petrol/diesel).

8.4.2 Private Drive

The defining attributes of ‘Private Drive’ are shown in Table 11.

Table 11: 'Private Drive' Defining Attributes

Year	Driving mode	Power source	Ownership/market model
2046	Driverless	Electric	Private ownership

The web of implications across key variables in ‘Private Drive’ are shown in Figure 71. Overall findings include:

- The increase in kerbside access demand and requirement for integration of new refuelling infrastructure with parking are both significant
- Residential parking demand and stabling facility requirements are not expected to change significantly compared to the base case.

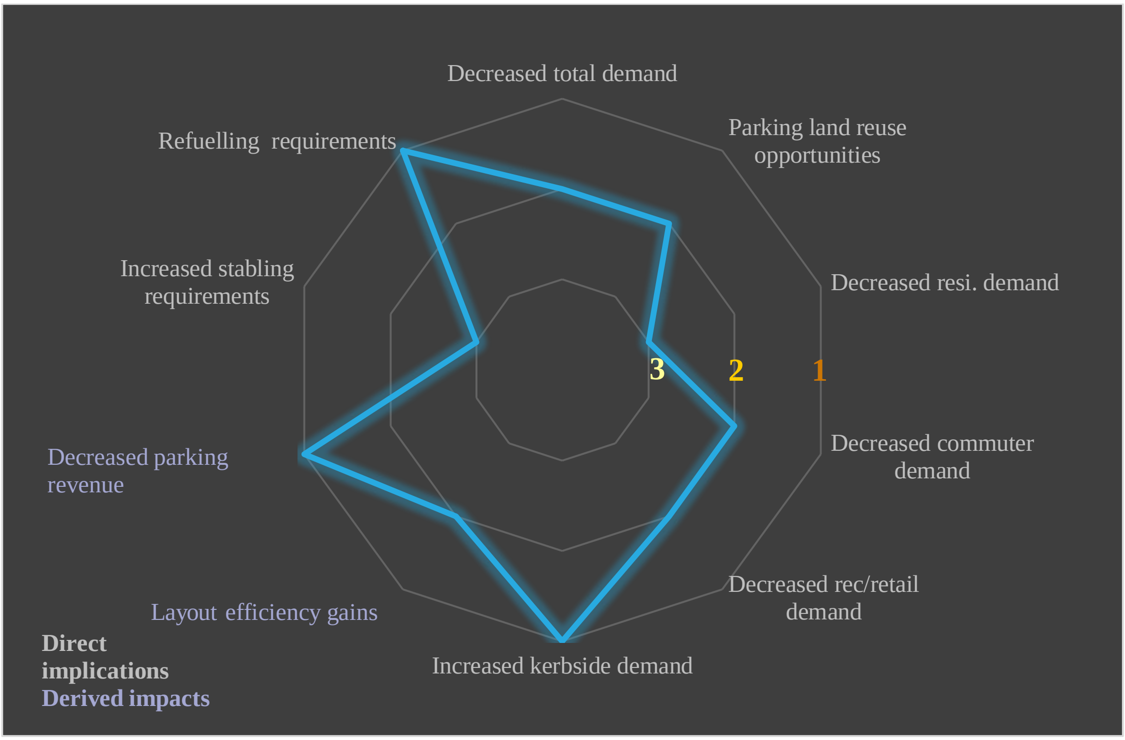

Figure 71: AV and ZEV Implications for 'Private Drive'

The MABM outputs show a slight increase in the mode share of privately owned and operated vehicles, from 81% in the ‘Dead End’ scenario to 86% in ‘Private Drive’. The higher mode share for private transport is likely to lead to added demand on kerbside space rather than destination-end parking while residential parking demands may increase also depending on the extent to which households share vehicles.

8.4.3 Fleet Street

The defining attributes of ‘Fleet Street’ are shown in Table 12.

Table 12: 'Fleet Street' Defining Attributes

Year	Driving mode	Power source	Ownership/market model
2046	Driverless	Electric	Shared, on-demand services

The web of implications across key variables in ‘Fleet Street’ are shown in Figure 72. All AV and ZEV variables are impacted considerably in this scenario.

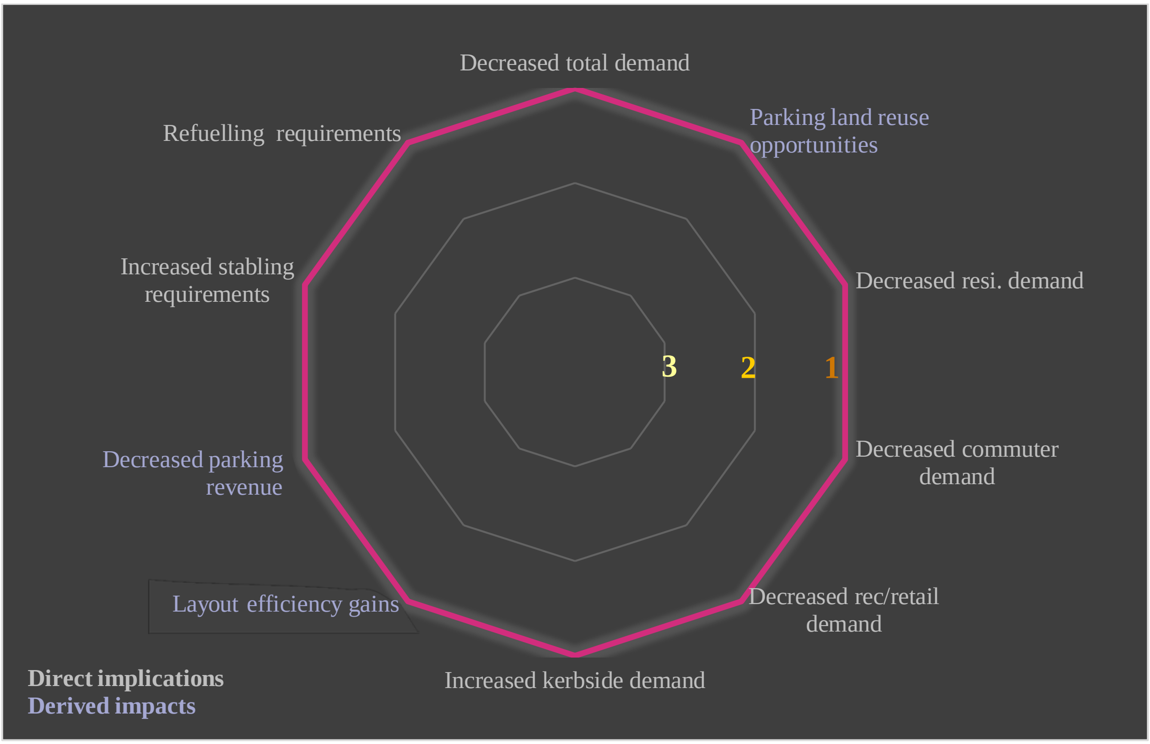

Figure 72: AV and ZEV Implications for 'Fleet Street'

MABM forecasts a significant decrease in light vehicle mode share for the ‘Fleet Street’ compared to ‘Dead-End’ scenario (from 81% to 69%) given the influence of shared mobility. While the model output does not correlate directly with our findings, the change in mode use forecast does not contrast with the significant decreases anticipated in demand for off-street parking, increased kerbside access demand and other implications noted in Figure 72. In this scenario, the use of PU/DO is likely to be prevalent and vehicles will serve multiple users, allowing for trips to be ‘chained’ by the vehicle (if not individual users) and negating the need to park for extended periods (excluding refuelling and periods of low demand).

8.4.4 Hydrogen Highway

The defining attributes of ‘Hydrogen Highway’ are shown in Table 13.

Table 13: 'Hydrogen Highway' Defining Attributes

Year	Driving mode	Power source	Ownership/market model
2046	Driverless	Hydrogen	Private ownership

The web of implications across key variables in ‘Hydrogen Highway’ are shown in Figure 73. Overall findings include:

- A similar magnitude of impact across variables is anticipated in ‘Hydrogen Highway’ as ‘Private Drive’. The key difference is the use of hydrogen as a power source rather than electricity

- As in ‘Private Drive’, the increase in kerbside access demand and requirement for provision of new refuelling infrastructure are both significant
- Residential parking demand and stabling facility requirements are not anticipated to change significantly compared to the base case.

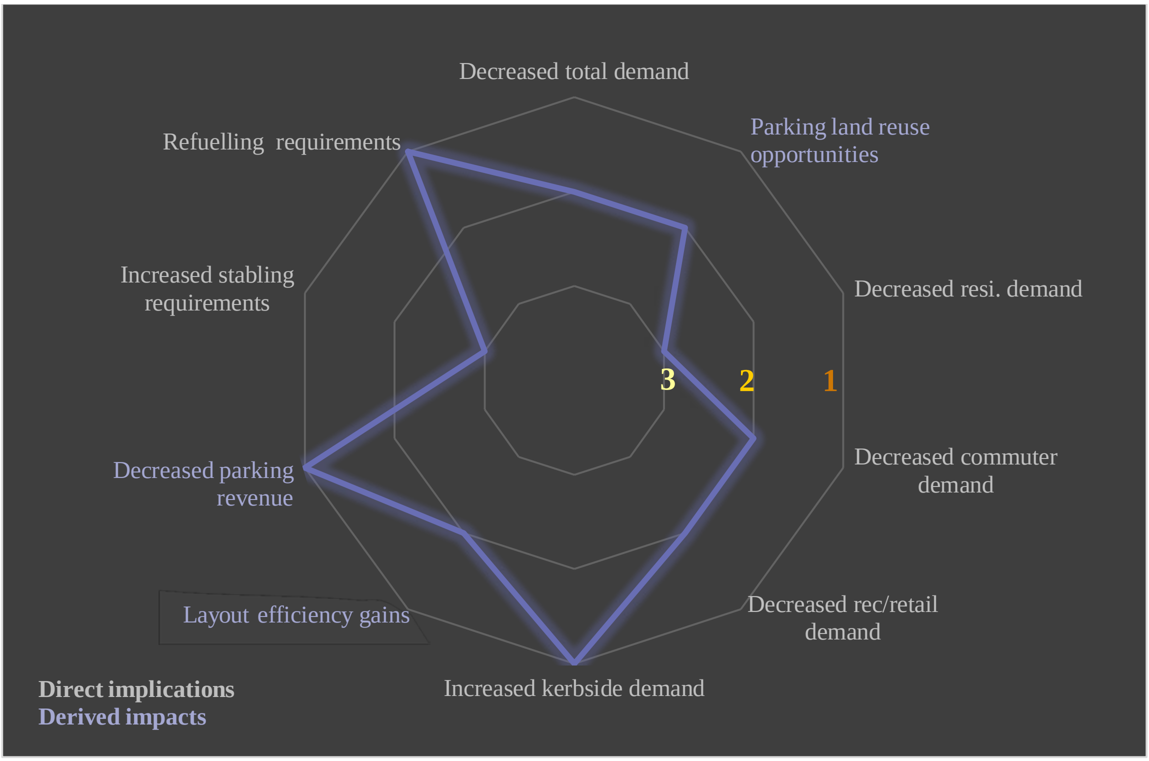

Figure 73: AV and ZEV Implications for 'Hydrogen Highway'

The MABM outputs for ‘Hydrogen Highway’ show the same mode share difference compared to ‘Dead End’ as is evident for ‘Private Drive’, which is expected.

8.4.5 Slow Lane

The defining attributes of ‘Slow Lane’ are shown in Table 14.

Table 14: 'Slow Lane' Defining Attributes

Year	Driving mode	Power source	Ownership/market model
2046	Non-driverless and driverless	Electric and petrol/ diesel	Shared, on-demand services and private ownership

The web of implications across key variables in ‘Slow Lane’ are shown in Figure 74. Overall findings include:

- The mix of non-driverless/driverless mobility and shared/private vehicle ownership and use in this scenario limit the magnitude of impacts across the variables analysed. The impacts are present but of lower scale generally

- The presence of human driven vehicles on the network eliminates potential gains in parking layout efficiency, and parking demand for commuters is limited by the uptake of automated mobility
- Impacts are limited again by mixed success of shared mobility.

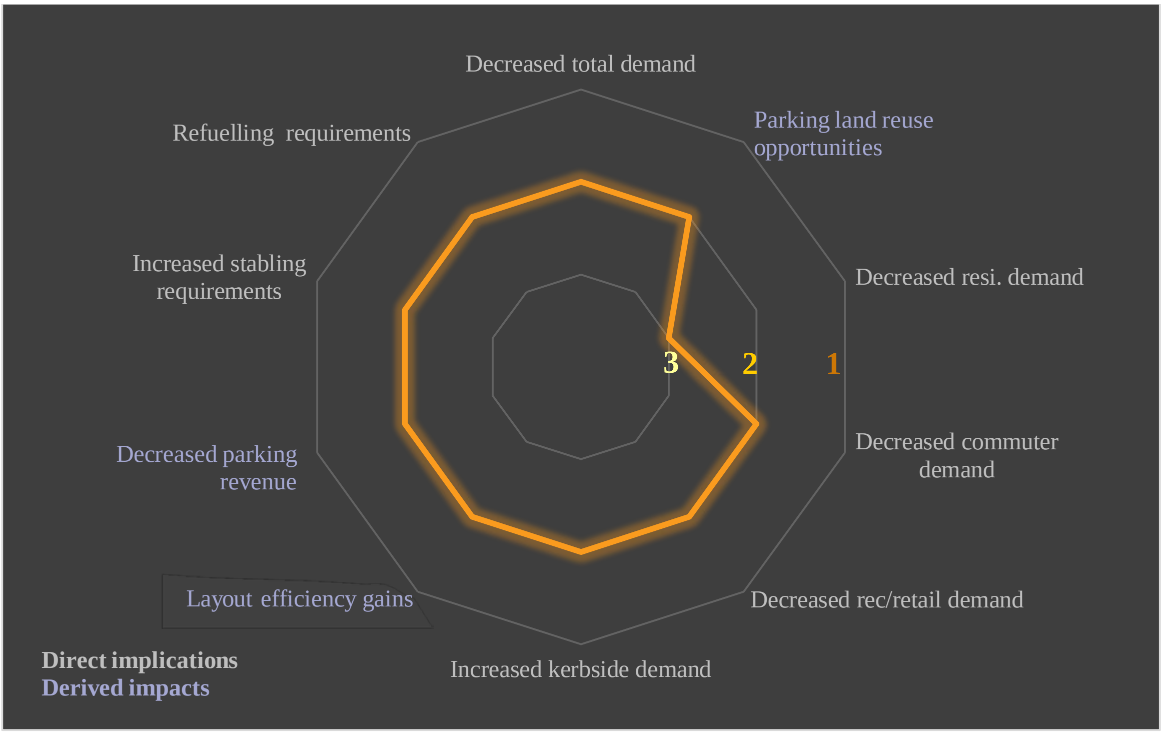

Figure 74: AV and ZEV Implications for 'Slow Lane'

MABM shows a relatively small decrease in vehicular mode share for the ‘Slow Lane’ scenario compared to ‘Dead End’ (from 81% to 77%). The minor change is associated with limited deployment of automated transport and mixed results of MaaS. This is consistent with moderate effects across the variables analysed.

8.4.6 High Speed

The defining attributes of ‘High Speed’ are shown in Table 15.

Table 15: 'High Street' Defining Attributes

Year	Driving mode	Power source	Ownership/market model
2031	Driverless	Electric	Shared, on-demand services

The web of implications across key variables in ‘High Speed’ are shown in Figure 75. All AV and ZEV variables are impacted considerably in this scenario. The only difference between this scenario and ‘Fleet Street’ is the shorter timeframe for significant impacts to be realised: by 2031 compared to 2046.

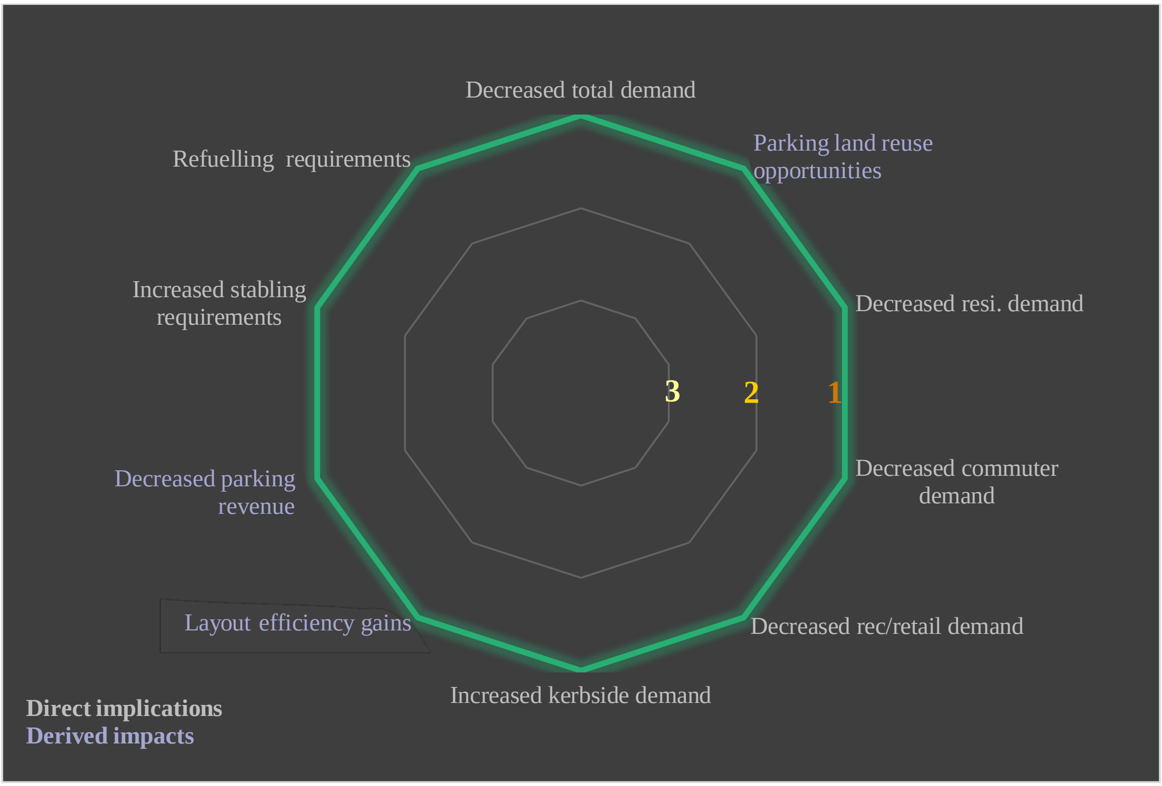

Figure 75: AV and ZEV Implications for 'High Speed'

‘High Speed’ was not modelled in MABM due to its similarity with ‘Fleet Street’ and therefore there are no results to compare in the analysis presented in this study.

8.4.7 Dead End

The defining attributes of ‘Dead End’ are shown in Table 16.

Table 16: 'Dead End' Defining Attributes

Year	Driving mode	Power source	Ownership/market model
2046	Non-driverless	Petrol/ diesel	Private ownership

The web of implications across key variables in ‘Dead End’ are shown in Figure 76. Due to the lack of driverless mobility in this scenario, minor or negligible impacts are anticipated across the variables. ‘Dead End’ was utilised as the base-case scenario in MABM.

Figure 76: AV and ZEV Implications for 'Dead End'

8.5 Delivery of Parking

8.5.1 On-street parking

Kerbside Parking Supply

Sweeping changes are required to the current supply and management of kerbside access, given the increase in demand and level of competition for space which is likely to arise from the automation of transport. Some impacts are already being seen – more so in city centres and activity centres – owing to growth in availability and use of mobility services.

This section of the report describes the potential substitution rates of PU/DO for common types of parking – long-stay and short-stay – and potential spatial impacts. The analysis was conducted at a modular level (for example assuming standardised blocks of demand/parking supply). Short-stay is defined as parking for equal to or less than three hours and long-stay, greater than three hours.

Table 17 compares potential substitution rates and associated spatial demands for kerbside and long-stay parking. The table includes various assumptions which have been applied. The demand rate for PU/DO is double for long-stay parking to account for vehicles utilising slots twice: once to drop-off a passenger and the second time, to pick them up. In a conventional, long-stay parking scenario, a vehicle occupies the same slot while the driver is undertaking their activity.

Demand was generated assuming random arrivals. The ultra-peak demand equation was based on the possibility of block arrivals - for example, at a ‘Park and Ride’ station in advance of a train departure. Assumptions applied include kerbside dwell time for PU/DO being based on a reasonable time for loading/ unloading of vehicles; standard parking duration for comparative purposes being based on an average dwell time for retail trips; increased aisle width being required per bay for PU/DO compared to conventional long-stay parking; and block demand of 100 vehicular arrivals in the peak hour.

Table 17: Long-stay Conventional Parking Versus PU/DO

Access Characteristics	Conventional long-stay parking	PU/DO	PU/DO (ultra-peak demand)
Demand rate/hour	100	200	600
Dwell time	9 hours	30 seconds	30 seconds
Spaces required (95th percentile)	100	3	8
Average space per bay (including aisle)	28m^2	35m^2	35m^2
Spatial demand (m^2)	2,800	115	280

Our analysis shows that similar levels of demand may yield 90-95% savings space set aside for vehicle storage **at or near to destinations**. While some of the assumptions may be adjusted, the spatial efficiency benefits will remain significant. Critically, **any remote stabling space needs are in addition to PU/DO**. However, these may be located in less valuable areas where there is a lower opportunity cost.

Table 18 compares potential utilisation of PU/DO rather than short-stay parking. Again, even following adjustment of assumptions, considerable spatial efficiencies are possible. In our example, we are assuming a kerbside dwell time of 45 seconds to account for retail customers loading goods.

Table 18: Short-stay Conventional Parking Versus PU/DO

Access Characteristics	Conventional short-stay parking	PU/DO
Demand rate/hour	100	200
Dwell time	90 minutes	45 seconds
Spaces required (95th percentile)	170	5
Average space per bay (including aisle)	28m^2	35m^2
Spatial demand (m^2)	4,760	700

Kerbside Parking Management

Conventional kerbside management involves the allocation of spaces based on adjacent land use and relatively limited understanding of both overall and temporal demands. Meters and time limits are used to create turnover in business areas. The role of the local authority is generally to update regulations periodically, based on changes to land use or in response to specific requests (for example for loading zones at supermarkets). The meaningful use of data for planning and management is relatively uncommon, and there is a lack of real-time kerb availability data. This is changing with invention and uptake of apps that track bay availability using in-bay monitoring technology platforms[222].

The considerable added demand for kerbside access - envisaged as an implication of the automation of light vehicle passenger transport (and to a lesser extent uptake of mobility services) - will drastically increase competition for limited spaces. This necessitates that governments manage kerbside space dynamically (refer to **section 8.3.6)** and define restrictions using appropriate pricing tools. Critically, management measures need to be adjustable so changes in demand can be responded to. It is therefore important that broader urban data policies include capture of demand and usage statistics and this information is analysed to enable dynamic management.

A dynamic kerbside management system allows kerbs to serve a variety of functions throughout the day according to the type of demand exhibited on the network. For example, in the AM peak, kerbs in central urban areas could be dedicated primarily to commuter drop-off, before shifting to mail and package business deliveries in the late morning. Over lunchtime, street vendors may be permitted while commuter operations are favoured during the evening peak. Larger delivery/service vehicles may be allowed for in the later evening along with transport for recreational/food and beverage patrons. Across all times-of-day and in peaks especially, public transport-only zones must be designated and protected from overspill. Finally, kerbside management practices must be integrated with the overall transport strategy for core urban areas, which should focus on higher capacity public transport and active transport as the primary modes for access.

There are opportunities to define PU/DO nodes at block or sub-precinct levels as a means of managing kerbside access across centres in lieu of a more disaggregated policy of supply and management. Nodes could be located strategically to activate specific streets by maximising footfalls, as well as to contribute to population health goals and mitigate interaction of small vehicles with larger, higher-capacity transit vehicles. A ‘premium’ service could even be offered, charging more money to those who wish to be dropped directly at their end destinations with exceptions for the mobility-impaired.

Both the definition of kerbside zones and sizing of nodes will be context-dependent, reflecting the heterogeneity of demands for PU/DO, servicing, public transport access and so on, from street-to-street and across different areas of cities. It is therefore important for government to define kerbside and nodal approaches at-scale (corridor, precinct or suburb levels). From a policy perspective, the approaches for CBD and other major activity centres should be investigated now, given impacts already from mobility services and ahead of the much greater impacts that will follow deployment of more highly automated vehicles. Design-wise, it would be premature to amend Australian Standards for car parking in

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[222] E.g. http://www.theparkerapp.com/; http://sfpark.org/

anticipation of greater vehicle manoeuvring capabilities, for the following reasons:

- Passenger tolerances (comfort-wise) for sharper manoeuvres have not been resolved
- Vehicle manufacturers are likely to introduce a range of different product-types to market and these may include ‘luxury’ and/ or larger vehicles as well as more basic, smaller vehicles.

8.5.2 Off-street parking

Implications for Parking Supply

The expected decrease in parking demand enables a decrease in parking supply, which should be reflected and embodied in policy, via techniques including the removal of minimum requirements, and the decrease in parking maximums. It may even be appropriate in some cases to not allow *any* parking to be provided.

The decrease in non-residential parking demand (and therefore locations for decreased supply) will vary by location. The largest decrease is likely to occur in high-density urban areas, with high-value land. It is likely to become increasingly feasible for parking to be relocated to the fringes of these areas – although there may be social implications of relocating parking to low-value areas.

In the case of full uptake of MaaS AV use, significant opportunity is also likely to be created to decrease residential parking supply. This can be achieved by removing all parking minimums, and setting appropriate parking maximums.

Opportunities for Parking Area Reuse

The decrease in off-street parking demand - expected to occur as a result of automation of transport - means that many parking structures may become surplus to the needs of the network or fewer parking provisions will be required. This presents both opportunities and challenges associated with adaptive reuse.

Parking utilises significant space across Melbourne and wider Victoria. One study estimates that new urban AV-designated areas could offer between 15-20% additional developable area compared to a typical layout – mainly due to the removal of parking[223]. If a substantial decrease in parking demand occurs in Victoria, a significant area of land spread across the State (but mostly concentrated in urban areas) will be freed up for alternative functions.

There are many potential alternative uses for spaces devoted presently to parking, and opportunities depend on location (for example land in a metro area is generally more valuable than land in the suburbs). These uses include the following, depending on the needs of the city and precinct:

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[223] http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf

- Town square/public space – for example in New York, where several blocks surrounding Times Square were transformed into pedestrian hangouts[224]
- Park/green space/urban farm
- Playground
- Residential
- Commercial/office space
- Retail
- Culture and arts.

If new infill opportunities are enabled by parking reform, a suite of secondary benefits are possible including economic agglomeration and increased return per square metre of activity [225]. Infrastructure Australia noted in 2016 that the removal of parking spaces would allow for more productive land use, increased density, and the more efficient utilisation of existing transport infrastructure[226].

If parking structures are built to be adaptable to future uses, the structures themselves can be reused in any number of ways, including apartments, offices and more. At the time of writing this report, Melbourne City Council is considering changes to parking policy, which would require parking to be located underground in most city and office developments. In addition, high-rise developments with soil conditions unsuitable for basement parking would be required to build parking adaptable for future uses. This is explained in more detail in **section 9.4.2 Outcome Led Design.**

Furthermore, as of 2016, around 92% of Victorian households had access to at least one private motor vehicle[227]. In future mobility scenarios including the wholesale uptake of shared MaaS solutions, demand for residential parking is likely to decrease significantly. This presents opportunities for households to reclaim the space previously used to store vehicles. The effect could be two-fold: it increases the living space per existing household without altering the property area and allows increased density of new builds without compromising the amount of living space available in today's dwellings.

Provision of Additional Stabling Facilities

Stabling facilities are likely to be required as the fleet penetration of AVs increases, and would tend to relate specifically to the shared scenario of AV use, as compared to a private ownership and use model.

The only exception would be if, in a private scenario of AV use, there is less destination parking available but owners can assign their vehicles to a remote station while not in use.

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[224] Thompson, 2016, No Parking Here, January/ February, New York

[225] Thakur. P, Kinghorn. R, Grace. R, 2016, *Urban form and function in the autonomous era*. Paper presented at the Australian Transport Research Forum, Melbourne

[226] Infrastructure Australia, 2016 '*Australian Infrastructure Plan Priorities and reforms for our nation's future'*, February Australian Government

[227] .id, 2018, https://profile.id.com.au/australia/car-ownership?WebID=110

8.6 Design of Parking

8.6.1 On-Street Parking

The dimensions and physical requirements of on-street parking bays may not change significantly from current infrastructure. The size and manoeuvring capabilities of automated vehicles may not differ markedly from today's fleet: different vendors can be anticipated to offer different mobility products from prestige to basic. Occupant comfort and kerbside efficiency requirements will be factors limiting the ability for AVs to manoeuvre sharply and repeatedly before accessing bays.

Integration of Refuelling Infrastructure with Parking

The widespread uptake of electric vehicles could require a proportion of on-street parking bays to integrate electric charging infrastructure to meet a range of consumer needs.

Electric vehicle charging infrastructure is typically banded into three levels[228]:

- **Level 1 (basic AC charging):** typically used for at-home charging
- **Level 2 (fast AC charging):** these are the most common destination public chargers
- **Level 3 (DC-fast charging):** suitable for longer trips and cars used very frequently on a daily basis (such as taxis).

For further discussion on charging types and infrastructure (refer to **section 6.3**).

Different levels of charging are appropriate for parking with different dwell times. The majority of on-street parking in a future with EAVs is likely to be high-turnover PU/DO, vehicles will not dwell long enough to justify incorporating charging infrastructure. Furthermore, charging infrastructure would incentivise longer dwell times creating inefficiencies in busy locations.

Instead, Level 2+ chargers may be integrated with bays in stabling facilities and in designated recharging stations (see below). Any on-street recharging stations, which may be provided where kerbside access demands are otherwise minor, can be integrated into charging posts, wall-mounted chargers, and retrofitted, multifunction lamp posts. Refer to **section 6.3** for further discussion on charging infrastructure. Specific on-street charging infrastructure can also be built into public transport and truck stops to serve buses and heavy vehicles. Arup has also created a concept called ‘Re-Charge Parklets’ that could be built to house charging infrastructure (refer to **section 4.4.1**).

Specific on-street charging infrastructure can also be built into public transport and truck stops to serve buses and heavy vehicles. These consist of a charging arm extending from the stop and connecting to the roof of the vehicle. Refer to **sections 6.3 and 6.3.3** for further explanation of possible charging infrastructure.

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[228] Mader. T, Braunl. T, 2010-2012, Western Australian Electric Vehicle Trial, Western Australia

Recent technological advancements have led to increases in efficiency of wireless induction charging, which could be employed among the suite of other charging methods in the design of on-street parking[229]. Several issues face this form of charging, namely the lifecycle and maintenance requirements of road pavement. Damage to the road, such as cracking, can also damage the charging infrastructure. Refer to **section 6.3.1.2** for further information on induction charging.

At the present time, hydrogen recharging infrastructure is unlikely to be of a form and function suitable for integration with on-street bays. We anticipate hydrogen refuelling to occur off-street.

8.6.2 Off-street parking

Parking Layout Efficiency

Automation of light vehicle passenger transport will create a range of opportunities to increase the efficiency of the layout of parking structures. Some gains relate to the application of automated valet functionality. When passengers can be dropped at a remote PU/DO facility, parking layouts can be altered and a higher bay yield is possible, for example:

- **Reduced bay dimensions:** since humans will not be exiting vehicles, the widths of bays can be reduced to the minimum dimensions needed to park the vehicle and the vehicles will be able to park with precision, minimising the depth of bays required. Critical bay dimensions still need to account for columns and manoeuvring, which limits the reduction in footprint
- **Aisles and ramps could become one-way:** increasing the efficiency of space used for vehicle movements into the structure. A minimum aisle width will still be required to allow for the ability of vehicles to manoeuvre in and out of bays
- **Tandem parking arrangements:** AVs forming part of a shared fleet can employ tandem parking arrangements consolidating bays significantly. Since individualised vehicles are not required in such a scenario, vehicles can enter the facility at one end and gradually move forward in a queue until they are called into service again.

Even in structures where valet parking is not employed, some consolidation of parking may be enabled owing to the precise manoeuvrability assumed of AVs.

A typical at-grade parking layout for 100 bays, designed in accordance with Australian Standard 2890.1 (Class 1a) is shown in Figure 77.

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[229] Cranenburgh. N, 2018, '*Electric vehicles could get charged on-the-go with wireless tech'*, Create Engineers Australia

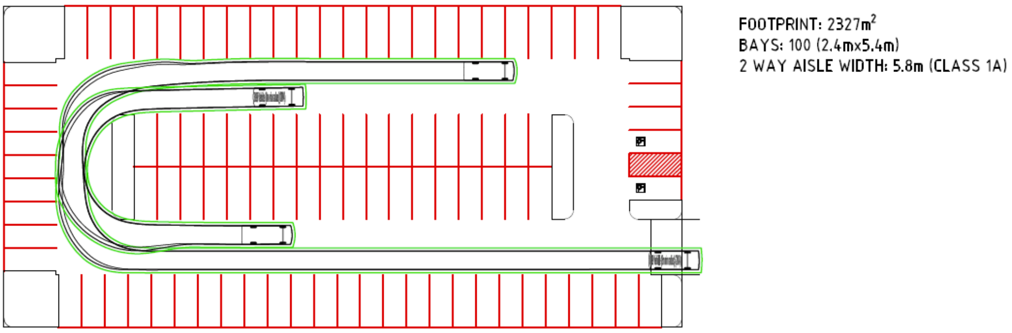

Figure 77: Typical Parking Design for a Module of 100 Parking Bays

Figure 78 shows the layout of a parking structure on the same footprint (2,327m^2) but with bay dimensions, aisle widths and island dimensions optimised to suit AVs. The vehicle movements and turning circles was validated against a B99 car/van design vehicle[230]. An additional nine bays fit inside the layout using the optimised dimensions yielding a 9% efficiency increase.

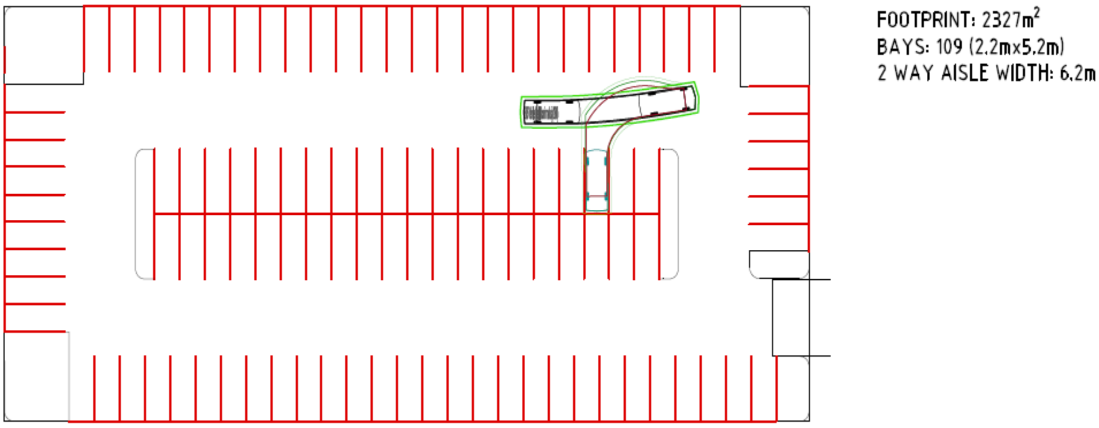

Figure 78: Increased Efficiency Parking Layout

Figure 79 shows the layout of a tandem parking arrangement on the same footprint assuming a scenario of private AV ownership and use whereby each passenger needs to retrieve the same vehicle they arrived in. In addition to the same decreased bay dimensions shown in Figure 78 this arrangement allows vehicles to block each other, to a maximum queue of three vehicles on one side of the aisle and two on the other side (to suit our example).

In order to retrieve a specific vehicle parked in by two other vehicles when its owner summons it, the system would request the maximum of two blocking vehicles to reverse into the aisle, allow the summoned vehicle to depart, and re-park to the deepest bay. This layout fits 155 bays, an increase of 55% from the typical layout shown in Figure 77. The scenario assumes limitations to tolerance for delays associated with vehicles being released and for congestion in aisles. The latter issue will be more acute in short-stay parking areas compared to longer-stay areas.

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[230] Austroads, 2013, Austroads Design Vehicles and Turning Path Templates Guide. National Library of Australia, Sydney NSW

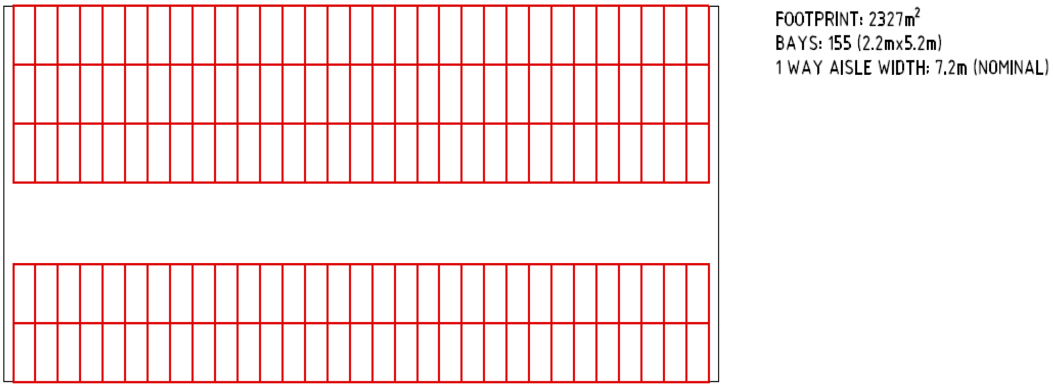

Figure 79: Private AV Fleet Tandem Parking Layout

Figure 80 shows the tandem parking layout possible if the entire vehicle fleet is shared and autonomous. Individual vehicles no longer need to be summoned, enabling vehicles to arrive at the structure at the back of the queue, shuffle forward as other vehicles turn over and exit the structure when they reach the front of the queue and are summoned. When combined with reduced bay dimensions, an additional 95 effective bays can occupy the same footprint – an increase of 95%. The concept of individual bays can disappear in this scenario, as algorithms determine the most efficient space for a new vehicle to park depending on factors such as likely wait time.

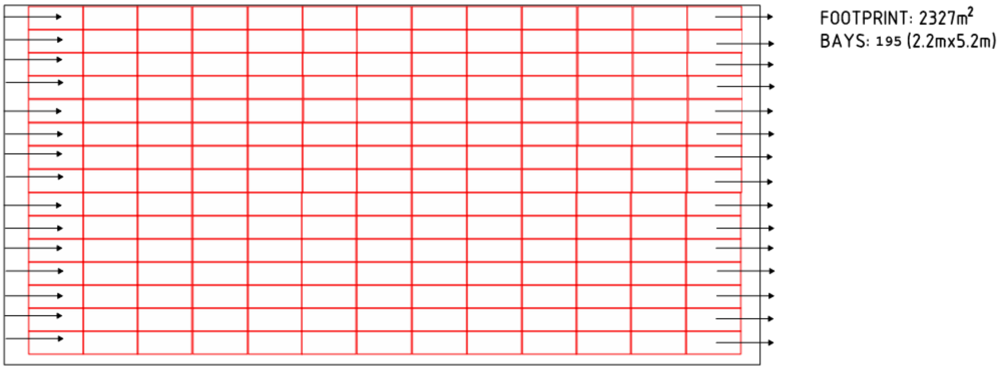

Figure 80: Shared AV Fleet Parking Layout

The various parking layouts described above are summarised in Table 19.

Table 19: Parking Layout Comparison for 2327m^2 Footprint

	Typical layout	**Optimised dimensions**	**Optimised layout and dimensions (including aisle for individual vehicle retrieval)**	**Optimised layout for shared fleet**
Bay width (m)	2.4	2.2	2.2	2.2
Bay length	5.4	5.2	5.2	5.2
Aisle width	5.8	6.2	7.2	-
No. bays	100	109	155	195
Ratio	1.00	1.09	1.55	1.95

Similar studies conducted by others have demonstrated:

- An increase in capacity of up to 20% is possible due solely to adjustments to parking bay dimensions[231]
- Increases in efficiencies for AV tandem parking arrangements varying from 60% to 250% depending on operational tolerances and the types of vehicles assumed (for example ubiquitously smaller vehicles)[232] .

Importantly, no efficiency gains are likely to be possible for parking modules required to cater for mixed parking (both human driven and autonomous vehicles), as these must be able to cater for human drivers according to current parking specifications (unless structures are created which segregate human driven vehicles from their autonomous counterparts). Furthermore, the layouts represent high efficiency without impacts associated with structural columns, plant and other obstructions, which would manifest in decks and basements. Irregular footprints will also affect the efficiency gains possible.

Designing for Resilience

The decrease in off-street parking demand, expected to occur as a result of increasing AV uptake, means much of the parking infrastructure currently being planned, designed and built may no longer be needed in future. It is therefore crucial to not only minimise the amount of parking supplied relative to current demands, but also to make sure new infrastructure that is built is resilient and able to be removed or adapted as needs change.

Changes to parking policy being contemplated by Melbourne City Council would require structured parking above ground to incorporate minimum 3.5 metre floor-to-floor heights, flat floorplates or stacker systems appropriate for future retrofit[233].

More broadly, the following major design elements require consideration in the design of resilient, multi-deck parking structures, which may be converted into residential/commercial uses in future.

Structural Considerations

- Increased floor-to-floor heights from 2.3 metres to 3.5 metres, with corresponding reduced column spacings
- Flat rather than sloped floor-plates
- Structural foundations capable of supporting additional dead and live loadings
- Lower structural foundations to allow for below-grade services
- Reduced floor spans to reduce vibration and deflection

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[231] Transport System Catapult, 2017, *Future Proofing Infrastructure for Connected and Automated Vehicles*, February, Transport Systems Catapult
[232] Nourinejad. M, Bahrami. S, Roorda. M, 2018, *Designing Parking Facilities for Autonomous Vehicles*, January, University of Toronto, Toronto
[233] City of Melbourne, 2018, *Central Melbourne Design Guide*, City of Melbourne, February

- Floor penetrations to allow for adequate stair cases, elevators and other services
- Structural facades enclosing the structure to deal with weather exposure.

Mechanical Considerations

- Air inlets to allow for proper mechanical ventilation for each floor
- Equipment rooms to meet heating and cooling requirements, and service distributions
- Adequate roof space to meet pipework and ductwork requirements.

Electrical Considerations

- Sufficient space to retrofit large transformers required for residential and commercial use
- Lighting space requirements.

Plumbing Considerations

- Storm drains required on roof tops of parking structures
- Removable ground floor slab to accommodate sanitary drainage
- Main supply line capable of supporting pipes and supply system for future water distribution.

Geotechnical Considerations

- Lower foundations of increased strength.

Fire compliance Considerations

- Fire-resistant exterior wall (minimum one-hour fire resistance)
- Separation fire wall/barrier (minimum two-hour fire resistance)
- Automatic fire sprinkler protection and altered branch line configuration
- Elevators for accessible egress
- Sufficient space in service shafts for fire alarm conduit routing
- Accommodation of locations for new exterior egress stairwells or horizontal exits when converted.

Payment Method

- An automatic method of payment will need to be established if AVs are to be able to drop their passengers and park themselves automatically. These methods could include number plate recognition and e-charging, and V2I communication.

New Refuelling Infrastructure Requirements

Level 1+ electric recharging facilities will be warranted in a future where EVs predominate. Level 1 charging points may be expected as standard in bays provided in residential parking facilities, with the potential for self-installation of charging infrastructure in existing structures as uptake of EVs increases (although there may be legal or body corporate restrictions which impede self-installation in apartment buildings). The latter is anticipated to be specific to individual developments and bodies corporate, rather than commonplace and may require legislation to avoid.

Level 2+ charging points may be expected in off-street short-stay and longer-stay facilities. It will not necessarily be a requirement that charging facilities will need to be provided per bay: rates of supply will be influenced by the charge time of points versus duration-of-stay limits.

To achieve increased layout efficiencies, humans must be removed from parking structures. Off-street structures therefore require a form of charging which does not require human intervention (for example to plug in/switch on). In addition, vehicles may store in tandem and reassign dynamically to release vehicles that are called. This requires a form of charging that is still efficient under these conditions. Wireless induction charging may be the solution (refer to **section 6.3.1.2**). This would be more viable if the lifecycle of the parking surface could be increased. Wireless technology is not as high a priority if AV use is not widespread, as human drivers can manually plug into a charging point.

8.7 Case Studies

Four case study locations were explored to convey differences in the impacts of key variables across different locations. These locations have variable urban characteristics, which affect how they are likely to be impacted by new mobility.

The case study locations are summarised as follows:

1. **Metropolitan/CBD key trip attractor:** located in the city centre area, with high relative transit density
2. **Major Suburban Activity Centre:** located in the middle suburbs, with good transit
3. **Regional City/Town:** located in regional Victoria, with thriving main street
4. **Local/Neighbourhood Activity Centre:** located in the outer suburbs with lower density, and transit.

8.7.1 Metropolitan/CBD – Spencer Street (Melbourne, CBD)

Spencer Street between Collins Street and Bourke Street in the Melbourne CBD, exhibits the following characteristics:

- Spencer Street allows two lanes of traffic in each direction, with a speed limit of 40 km/h

- Runs north-south on the eastern entrance to Southern Cross train station. The station generates a significant amount of pedestrian traffic at the site
- Tram lines run along both Spencer Street the full length of the case study site, and are served by tram stops in the road median within the site
- A taxi rank allowing PU/DO exists on the west side of Spencer Street
- Short-term and PU/DO on-street parking exists on the east side of the road
- A significant proportion of both sides of the road is designated as ‘no stopping’
- The footpath width on the east side of the road is relatively narrow; trees, light poles, parked bicycles and motorcycles, parking meters, and rubbish bins contribute to a narrow effective width for pedestrian traffic
- The kerbside space on the west side of the road is significantly wider and connected to the train station. It is cluttered with information kiosks, bins, bicycle parking, signs, seats, a shared bicycle station, and anti-terrorism bollards.

A cross-section of Spencer Street from the intersection with Collins Street is shown in Figure 81.

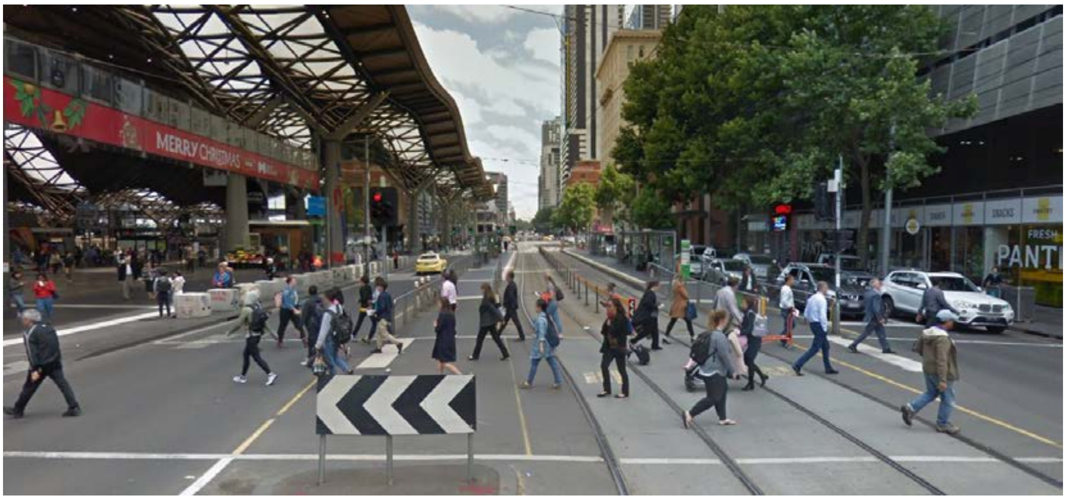


Figure 81: Spencer Street (Google Maps, accessed May 2018)

The widespread implementation of AVs and ZEVs may lead to the following implications for the site:

- The limited supply of kerbside access may inhibit the provision of PU/DO to accommodate expected increases in demand with AVs
- The narrow footpath width adjacent to the east side of the road may reduce the potential to provide above ground charging facilities
- Full uptake of connected AVs may enable AVs and trams to share road space, increasing the amount of kerbside space available.

The issue of limited kerbside access inhibiting future PU/DO provision is likely to impact on CBD environments. It requires a precinct-level evaluation of kerbside availability and definition of PU/DO hubs to serve larger catchments in lieu of all buildings being served by adjacent kerbsides (ubiquitous 400 metre catchment circles would apply).

Alternatively, hubs may be provided off-street depending on land and/or facility availability. Presently, kerbside space is at a premium in many locations and demand, which will ramp up over time, requires immediate contemplation. The time for consideration-led action is now.

FlexKerbs (discussed in **section 4.4.2**) will assist, with the use of technology to permit dynamic allocation of space. These should be prototyped now allowing for changing use between service vehicles, taxis, and so on. Such prototypes should also facilitate data collection regarding supply and demand, and provide the basis for expanding and/or recalibrating the system.

8.7.2 Major Activity Centre - Station Street (Box Hill)

Station Street in Box Hill was chosen to typify a well-defined major activity centre. It exhibits the following characteristics:

- Located approximately 14 km from the Melbourne CBD, in a suburb known for being a major transport hub for Melbourne’s eastern suburbs
- Box Hill train station is located approximately 150 metres to the west of the street
- Box Hill tram interchange is located approximately 100 metres to the west of the street
- A variety of durations of short-stay on-street parking exists on both sides of the road for most of its duration through the core of Box Hill
- The street is generally lined with retail and dining shopfronts
- The street switches between allowing one and two lanes of traffic in each direction, with a speed limit of 40 km/h between 8am – 7pm from Monday to Saturday
- Footpaths are relatively narrow but relatively uncluttered, although the presence of rubbish bins, telephone booths, light poles, signage, and parking meters reduce the effective width in patches on both sides of the street.

A cross-section of Station Street is shown in Figure 82.

Figure 82: Station Street, Box Hill (Google Maps, accessed May 2018)

The widespread implementation of AVs and ZEVs may lead to the following implications for the site:

The high level of competition for kerbside space (for example between retail patrons and service vehicles) lends itself to dynamic kerbside management, allowing the kerb to serve a different mix of functions throughout the day and responding to demand (refer to **section 8.5.1**) such as:

- Higher level of kerbside access compared to Spencer Street example is likely to be easier to cater to increased demand for PU/DO
- The reduction of ticketed on-street parking may significantly affect revenue for local council without appropriate pricing for PU/DO
- The proximity to train and tram stations could enable the implementation of high-turnover PU/DO nodes. Compared to Spencer Street, there are likely to be more transfer trips thereby increasing the feasibility of such a facility.

8.7.3 Regional City/Town – Sturt Street (Ballarat)

Sturt Street in Ballarat was chosen to represent a Regional City/Town. It exhibits the following characteristics:

- Located approximately 120 km from the Melbourne CBD
- Three lanes of westbound traffic and two lanes of eastbound traffic
- The street is located in the central part of Ballarat
- Substantial short-term on-street parking, angled bays are provided on both sides of the westbound lanes and on the north side of the eastbound lanes
- The road is bounded by a mixture of retail and dining shopfronts, some of which utilise the kerbside space for outdoor dining

- In addition to short-term on-street parking, the central medium is used as a park and green space.

A cross-section of Sturt Street is shown in Figure 83.

Figure 83: Sturt Street, Ballarat (Google Maps, accessed May 2018)

The widespread implementation of AVs and ZEVs may lead to the following implications for the site:

- The mix of uses present and competition for kerbside space lend themselves to dynamic kerbside management, allowing the kerb to serve a different mix of functions throughout the day and responding to demand
- Generous road widths and substantial on-street parking create excellent opportunities to meet the increased demand for PU/DO likely with widespread AV uptake
- Reduction to ticketed on-street parking may affect revenue for local council without appropriate fees for PU/DO
- Given the site’s location at the heart of Ballarat, opportunities may be created for Sturt Street to increase footpath widths and act as a community meeting place/pedestrian thoroughfare. These opportunities will need to be reconciled with demands for PU/DO.

8.7.4 Local/Neighbourhood Activity Centre - Springvale Road (Springvale)

Springvale Road in Springvale was chosen to represent a typical neighbourhood centre. It exhibits the following characteristics:

- Located approximately 30 km from the Melbourne CBD
- Two lanes of traffic in both directions, separated by a median, with a 40 km/h speed limit
- Springvale train station is located on the east side of the road

- A variety of durations of short-stay on-street parking exists on both sides of the road
- The street is generally lined with retail and dining shopfronts
- Footpaths are relatively uncluttered, although the presence of rubbish bins, telephone booths, light poles, signage, and parking meters reduce the effective width in some segments on both sides of the street.

A cross-section of Springvale Road is shown in Figure 84.

Figure 84: Springvale Road, Springvale (Google Maps, accessed May 2018)

The widespread implementation of AVs and ZEVs may lead to the following implications for the site:

- Competition for kerbside space (for example between retail patrons and service vehicles) lends itself to dynamic kerbside management, allowing the kerb to serve a different mix of functions throughout the day and respond to demand
- Higher level of kerbside access compared to Spencer Street example is likely to be easier to cater to increased demand for PU/DO, although this is likely to be reduced compared to other location examples, causing less of an issue for temporal management
- The reduction of ticketed on-street parking may affect revenue for local council without appropriate pricing for PU/DO – although this is less of an issue than in the other locations.

8.8 Planning and Management – Focus Areas

The following assessment has been created to understand areas of future focus for the planning and management of parking. The focus could be the development of policy, strategies and targeting further research. The areas of parking that were assessed are:

1. Residential parking supply
2. Long-stay parking supply
3. Short-stay parking supply
4. Kerbside management
5. Stabling facilities

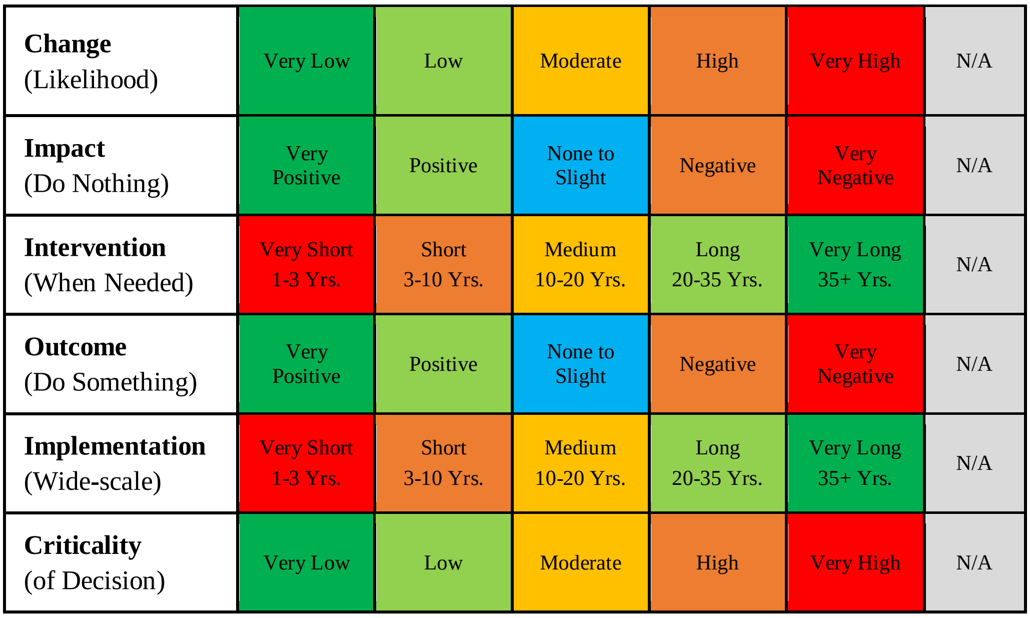
6. Parking area design
7. Parking revenue
8. Refuelling infrastructure.

8.8.1 Assessment Methodology

The following assessment methodology was used in a workshop to assess the areas above:

- **Likelihood of change:** what do we believe the likelihood of change occurring is going to be?
- **Impact:** assuming no interventions are made by government, what is the magnitude of impact from an economic, environmental, and social perspective?
- **Intervention:** when and within what timeframe is an intervention likely to be needed?
- **Outcome:** assuming the right intervention was made by government, what is the magnitude of the outcome from an economic, environmental and social perspective?
- **Implementation:** when is the intervention likely to result in wide-scale benefits or mitigate possible dis-benefits?
- **Criticality:** what is the critical nature of making the right intervention at the right time?

Figure 85 below shows how the six key considerations are assessed using a five-point scale, or N/A if no information is available or too much uncertainty.



Change (Likelihood)	Very Low	Low	Moderate	High	Very High	N/A
Impact (Do Nothing)	Very Positive	Positive	None to Slight	Negative	Very Negative	N/A
Intervention (When Needed)	Very Short 1-3 Yrs.	Short 3-10 Yrs.	Medium 10-20 Yrs.	Long 20-35 Yrs.	Very Long 35+ Yrs.	N/A
Outcome (Do Something)	Very Positive	Positive	None to Slight	Negative	Very Negative	N/A
Implementation (Wide-scale)	Very Short 1-3 Yrs.	Short 3-10 Yrs.	Medium 10-20 Yrs.	Long 20-35 Yrs.	Very Long 35+ Yrs.	N/A
Criticality (of Decision)	Very Low	Low	Moderate	High	Very High	N/A

Figure 85: Six Key Considerations

Figure 86 below presents the outcomes of the assessment. It is clear that the outcome of taking action across each of the variables is significant and positive. This is not a detailed analysis but rather a consistent way to discuss and understand key issues, ideas and concepts.

	Potential Focus Areas							
	Residential parking supply	**Long-stay parking supply**	**Short-stay parking supply**	**Kerbside management**	**Stabling facilities**	**Parking area design**	**Parking revenue**	**Refuelling infrastructure.**
Change	Very High	Very High	Very High	Very High	Moderate	High	Very High	High
Impact	Negative	Very negative	Negative	Very negative	Negative	Very negative	Very negative	Negative
Intervention	Very Short 1-3 years	Short 3-10 years	Short 3-10 years	Very Short 1-3 years	Medium 10-20 years	Very Short 1-3 years	Short 3-10 years	Very Short 1-3 years
Outcome	Very Positive	Very Positive	Very Positive	Very Positive	Very Positive	Very Positive	Very Positive	Very Positive
Implementation	Long 20-35 Yrs.	Medium 10-20 Yrs.	Medium 10-20 Yrs.	Short 3-10 Yrs.	Medium 10-20 Yrs.	Long 20-35 Yrs.	Medium 10-20 Yrs.	Short 3-10 Yrs.
Criticality	High	Very High	High	Very High	High	Very High	Very High	High

Figure 86: Focus Area Assessment

8.9 Findings

8.9.1 General Findings

- Loading bays and parking (off-street and on-street) will become subject to new demands as shared mobility and vehicle automation result in a substantial increase in kerbside drop-offs.
- There is then a potential for vehicles to be reassigned to serve other trips. The size and layout of bays are subject to change depending on structural requirements, vehicle fleet characteristics and uptake of electric drive systems.
- A likelihood of significant decrease in total parking demand, with changes in demand for specific land uses dependant on the level of uptake of shared on-demand services.
- The drop in demand is expected to lead to decreased parking revenue, especially in activity centres and CBDs, as well as private operators including airports and entertainment centres. Alternate revenue opportunities may arise through kerbside access charges.
- Demand for stabling facilities will increase with a rise in uptake of ride-hailing, micro-transit and other shared mobility services, which may increase dramatically with AV uptake.
- A significant increase in kerbside access demand is expected with the uptake of AVs. Kerbside pick-up/drop-off facilities are expected to become a common arrival/departure point, and significant competition for kerbside access is likely to result.
- The widespread uptake of EVs would require the integration of charging facilities into parking facilities.

8.9.2 On-Street Parking Findings

- The shift in demand to kerbside PU/DO from longer dwell times is likely to yield substantial space savings at or near destinations.
- The high level of competition for kerbside access will necessitate dynamic management from government, especially in denser centres and on main streets. Defining restrictions will be key, using the appropriate pricing tools and ensuring measures are adjustable to daily demands. Government's urban data policies should include capture of demand and usage statistics; the analysis of this data is crucial to enabling dynamic kerbside management.
- Kerbside management should also be integrated with overall transport strategy for core urban areas and this should focus on higher capacity public transport and active transport as the primary modes for access.
- Opportunities will be created to define PU/DO nodes at block/sub-precinct levels as a means of managing kerbside access across centres in lieu of a more disaggregated policy of supply and management.

- The widespread uptake of EVs may require on-street parking bays, however this will be dependent on the level of autonomy present in the network, distance travelled per vehicle and the dwell times.

8.9.3 Off-Street Parking Findings

The anticipated decrease in parking demand would enable a decrease in parking supply, which must be reflected and embedded in policy (e.g. elimination of minimum parking supply rates and requirements for future proofing). The most significant decreases in demand, and therefore supply, are likely to occur in high-density, high-value urban areas.

Should shared, on-demand, integrated mobility predominate in the future, residential parking demand may decrease substantially, enabling reduced supply through removing parking minimums and/or setting appropriate maximums.

The widespread uptake of AVs will create a range of opportunities to increase the efficiency of the layout of parking structures. Such opportunities will be limited, while a mix of human driven and autonomous vehicle demand remains. Potential areas of change under widespread AV uptake include:

- Reduced bay dimensions
- One-way aisles and ramps
- Tandem parking arrangements (for shared fleets).

The expected decrease in parking demand means much of the parking infrastructure being used, planned, designed and built today may no longer be needed in future. As such, resilience should be designed into all new parking structures, to ensure they can be removed or adapted as needs change. A suite of structural, mechanical, electrical, plumbing, geotechnical, and fire resistance considerations are provided in this document to enable future retrofit.

Adaptive reuse opportunities will be created, should the expected decrease in demand for parking eventuate, with a suite of potential associated benefits. Reuse opportunities may occur at the following locations, depending on the mobility mix present:

- Off-street parking structures, e.g. multi-deck parking
- Land occupied by on-street and off-street parking
- Residential parking (i.e. parking garages).

The widespread uptake of EVs warrants the inclusion of charging facilities into off-street parking infrastructure. Rates of supply will be influenced by the charge time of points versus duration-of-stay limits. A form of charging which does not require manual operation will be needed in off-street structures if AVs prevail, enabling realisation of layout efficiencies. Slow charging (e.g. Level 1 AC) may be expected as standard in bays provided in residential parking facilities.

9 Strategic Priority Actions

9.1 Context

In reflecting on this study's findings and recommendations the project team has developed nine strategic priority actions from a transport engineering perspective. Any of these actions could be pursued by Victoria in preparing for an AV and ZEV future. Due to the uncertainty and rapid change, the project team utilised a concept from the US Military called VUCA[234] that is used to help make sense of constantly changing challenges. Figure 87 below outlines the concept - on the left are elements of a fast changing and challenging environment, and on the right are the fundamentals required to meet this challenging environment.

Figure 87: VUCA Concept

The following points highlight the nine strategic priority actions which were generated by the project team (each are detailed further in this section):

Vision

- Responsibility and Governance
- Community and Stakeholder Engagement

Understanding

- Cooperation with Other Jurisdictions
- Readiness and Testing

Clarity

- Movement and Place
- Outcome Led Design

Adaptability

- Real Options Analysis
- Road Standards and Guidelines
- Funding Mechanisms

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[234] Leadership in a VUCA world, 2018, https://www.impactinternational.com/blog/2012/01/leadership-vuca-world

9.2 Vision

9.2.1 Responsibility and Governance

In June 2016, TfV was established as the statutory office responsible for the planning and coordination of all transport systems in Victoria. Therefore, TfV is best placed to oversee and drive Victoria's future strategy for AVs and ZEVs. However, any strategy for AVs and ZEVs should be developed under a long-term transport master plan (Vision) for the State, which Victoria does not have publicly available. It is acknowledged that long-term transport planning is discussed within Plan Melbourne and the Victorian Infrastructure Plan. To put the plan into action strategies and frameworks, such as Movement and Place, would be used to deliver the outcomes set by the long-term master plan. AVs and ZEVs would be seen as key delivery mechanisms within the strategies and frameworks. In order to significantly reduce the risk and uncertainty of future proofing, retrofitting or building new infrastructure for AVs and ZEVs.

The current Transport for NSW (TfNSW) and Roads and Marine Services (RMS) arrangement provides a possible model for Victoria to follow due to similarities in government structure. Importantly, TfNSW takes the overall lead in planning, including developing a long-term master plan, and has recently created a future transport strategy called: '*Future Transport 2056 Strategy*'[235]. Figure 88 below illustrates what the relationship between TfV and key stakeholders could look like – adopted from Austroads[236].

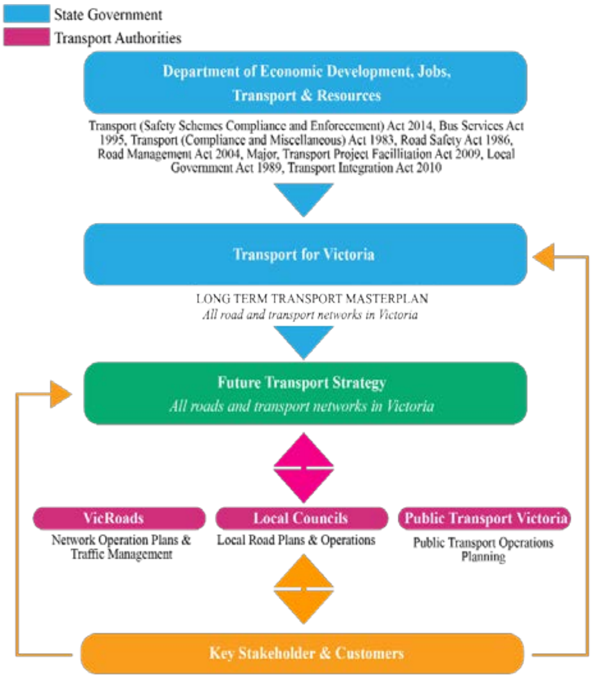

Figure 88: Example of Possible Relationship Between TfV and Key Stakeholders

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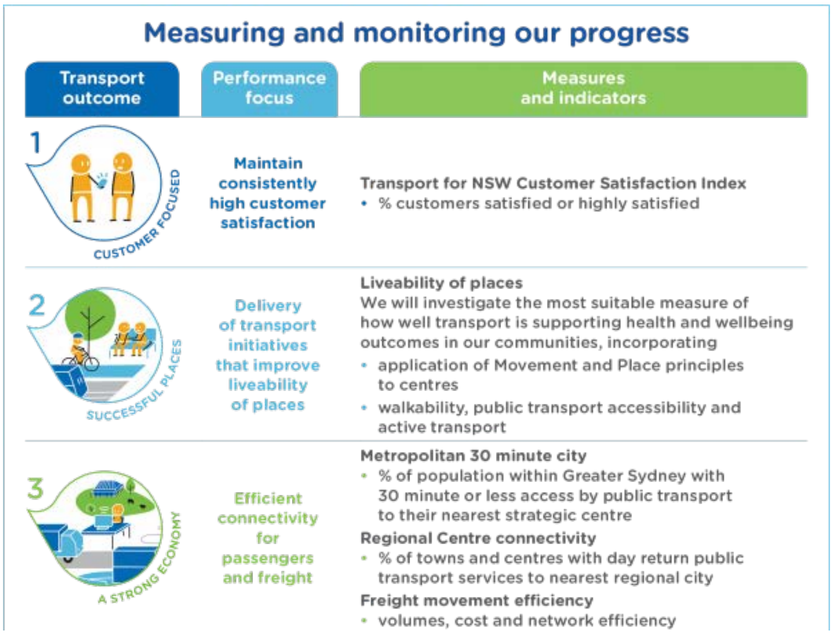
[235] Future Transport Strategy 2056, TfNSW, https://future.transport.nsw.gov.au/

[236] Austroads, 2017, Current Practice and Developments in Concept of Operations across Road Agencies in Australia and New Zealand https://www.onlinepublications.austroads.com.au/items/AP-R553-17

With TfV taking leadership and responsibility for future mobility planning, appropriate governance and performance reporting could be put in place to monitor Victoria’s journey towards an automated and zero emissions future. Figure 89 highlights an example of the performance measures and indicators selected for the NSW Future Transport Strategy. They provide a framework for monitoring and reporting on how their activities are contributing to the six state-wide future transport outcomes.



Measuring and monitoring our progress

Transport outcome	Performance focus	Measures and indicators
1 CUSTOMER FOCUSED	Maintain consistently high customer satisfaction	Transport for NSW Customer Satisfaction Index • % customers satisfied or highly satisfied
2 SUCCESSFUL PLACES	Delivery of transport initiatives that improve liveability of places	Liveability of places We will investigate the most suitable measure of how well transport is supporting health and wellbeing outcomes in our communities, incorporating • application of Movement and Place principles to centres • walkability, public transport accessibility and active transport
3 A STRONG ECONOMY	Efficient connectivity for passengers and freight	Metropolitan 30 minute city • % of population within Greater Sydney with 30 minute or less access by public transport to their nearest strategic centre Regional Centre connectivity • % of towns and centres with day return public transport services to nearest regional city Freight movement efficiency • volumes, cost and network efficiency

Figure 89: Example of NSW Future Transport Strategy Performance Outcomes

9.2.2 Community, Industry and Stakeholder Engagement

IV is applauded for its approach to community, industry and stakeholder engagement for this program. It is potentially the most important aspect of preparing and enabling an AV and ZEV future. The time is right to begin engaging with the Victorian community regarding the transport future they want/need, and regarding how infrastructure should respond to this changing landscape.

An important part of developing a future transport strategy will be engaging with industry and academia. A highly effective example of this is the recently launched ‘Roads for the Future’[237] initiative by the UK National Infrastructure Commission, Highways England and Innovate UK. This initiative brought together industry, government and academia to look at a series of use cases to prepare UK’s road network for the future.

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[237] National Infrastructure Commission, 2018 https://www.nic.org.uk/our-work/roads-for-the-future/

9.3 Understanding

9.3.1 Consistency and Cooperation with Other Jurisdictions

At a recent 'Transforming Transport' summit, speakers from VicRoads, NTC and ITS Australia discussed a variety of topics[238] including:

- If there are variations in road infrastructure and laws surrounding road rules across different states, it can impede the development of some road technologies such as automated vehicles
- Road infrastructure needs to be nationally consistent for technology and intelligent transport systems to be able to function appropriately
- The role for technology and intelligent transport systems needs to be consistent, it needs to be built on the same rules and standards, so that we develop a consistent infrastructure
- Chief Executive of ITS Australia Susan Harris stated: *"We need consistency… so when we bring cars in that can talk to our traffic lights and our intersections, and cars that can read our signs, we know that our cars and the road infrastructure will interact in a consistent way across Australia."*

It is strongly accepted that Australia does not want to repeat the rail gauge issues experienced when states set their own standards, resulting in a system that was not interoperable. Enormous cost has been incurred to achieve a standardised national network.

Through TfV taking leadership and responsibility for future mobility planning, it will be important that a coordinated and consistent approach is taken to engagement with other jurisdictions and the Federal Government. Maintaining and building collaborative relationships with Austroads and NTC will ensure Victoria is standardising and harmonising its approach to design, build, operate and maintain its infrastructure.

Working in partnership with other jurisdictions goes beyond consistency, it will enable Australia to effectively trial, understand and develop emerging technologies by not burdening one state or territory with the cost of doing this. It will allow lessons learnt to be shared and our understanding to evolve, providing more certainty to make decisions and possible changes to the road network. A good example would be research into impacts and benefits from heavy vehicle platooning on Australian roads - this would be a costly exercise that has national implications, therefore such research would be better to be undertaken through Austroads.

9.3.2 Readiness and Trialling

While it is expected that Victoria will work closely with other jurisdictions, it will be important to continue to trial AV technology on our road network. Initial

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[238] https://infrastructuremagazine.com.au/2017/11/21/a-nationally-consistent-approach-to-infrastructure/

findings from the Victorian CAV trials[239] has demonstrated the benefits of understanding how this technology interacts with Victoria's road network. Secondly, preparing and running trials will help to get Victoria ready for the use of AVs on the network. Readiness can be thought of in four broad ways: Asset, Operational, Organisational and Customer/User, the following points highlight key elements for each readiness area.

Asset Readiness

- Establish a link between AV technology requirements and asset readiness
- Deliver and maintain assets fit for purpose
- Understand resourcing and cost requirements to have assets fit for purpose.

Operational Readiness

- Understand the realistic and practical steps required for road operations to gain the productivity benefits from AVs
- What are impacts of AVs on road operations, roadworks and safety
- Establish a concept of operations (refer to **section 7.2.1**) to maintain pace with technology developments.

Organisational Readiness

- Understand how the development of AVs and ZEVs will influence how long-term planning is undertaken
- Establish the internal changes required to government organisations to enable and support AVs and ZEVs
- Skill development and education of people working within the transport field
- Understand how key stakeholders can be utilised to help prepare.

Customers/User Readiness

- Explore the attitudes of customers, adoption and acceptance of AVs
- Behavioural change and travel demand management.

9.4 Clarity

9.4.1 Movement and Place

As discussed in **section 4,** the Austroads '*Guide to Traffic Management Part 4: Network Management*' (GT4) was updated in late-2016 with a particular focus on the 'Movement and Place' (M&P) concept for network management. The Austroads research report *'Assessment of Key Road Operator Actions to Support*

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[239] https://cAVs.transurban.com/content/dam/cAVs/documents/victorian-trials-report.pdf

Automated Vehicles'[240] also highlighted the need for jurisdictions to adopt a more holistic planning framework like M&P in preparing for an AV future.

The framework reflects the fact that a more integrated approach to the operation and planning of the transport system is best practice. Since the release of the updated GT4, two Australasian transport authorities have released their own versions of the M&P frameworks: Transport for NSW and Auckland Transport.

Victoria has not formally released an official M&P framework however VicRoads has stated:

'*M&P has emerged out of the SmartRoads framework by placing a renewed focus on the value of place to the State's economy and liveability. The current structure of the framework in Victoria has been placed into four 'modules' including:*

- *Network classification*
- *Performance assessment*
- *Toolbox*
- *Option assessment.*

The framework is very much in the early stages and no cohesive strategy has been released publicly. It is expected that the evolution of the framework going forward will need to bring together a framework that can be used equally by urban designers, planners through to traffic engineer.'[241]

Through Arup's AV trial programs in Australia and in the UK, an issue raised by vehicle manufacturers is that governments should have a clear indication as to how AVs should operate – and this should include consideration of the value communities have in their places and streets. A comprehensive M&P framework could go a long way to achieving this. The recently released Roads and Streets Framework (RASF) and the Transport Design Manual (TDM) by Auckland Transport provides a good case study for Victoria to consider in developing their own framework[242].

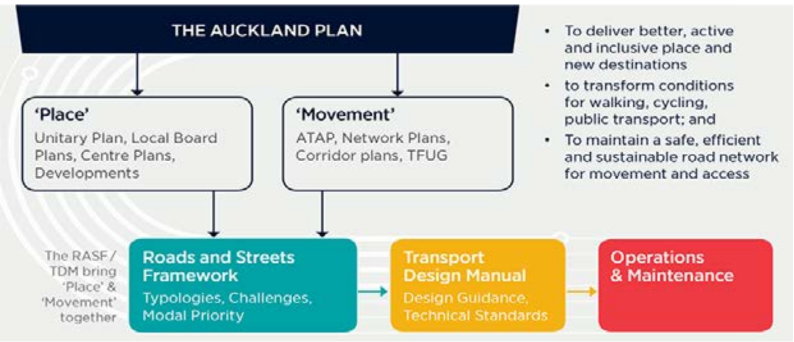

Figure 90: Auckland Transport - Roads and Streets Framework

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[240] Austroads, 2017, Assessment of Key Road Operator Actions to Support Automated Vehicles https://www.onlinepublications.austroads.com.au/items/AP-R543-17

[241] VicRoads, 2018, Movement and Place https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/smartroads

[242] Auckland Transport, 2018, Roads and Streets Framework and the Transport Design Manual https://at.govt.nz/about-us/manuals-guidelines/roads-and-streets-framework-and-the-transport-design-manual/

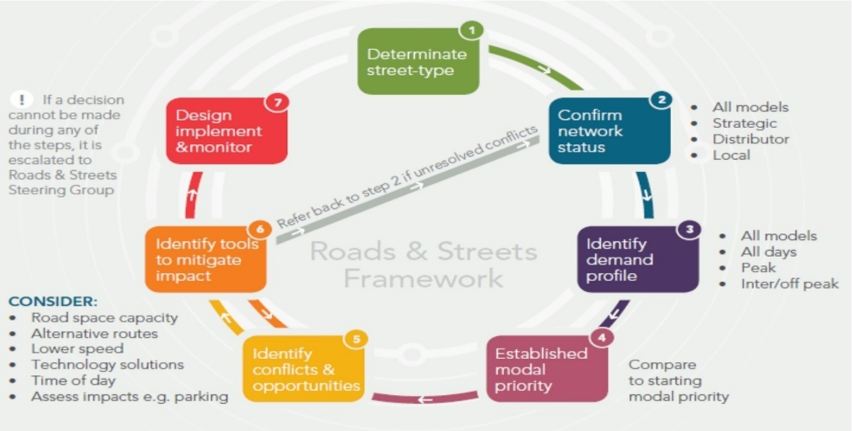

Figure 91: Auckland Transport - Roads and Streets Framework

It is also noted that a core fundamental to TfNSW's future transport strategy is meeting the needs of both Movement and Place. Figure 92 below highlights the Movement and Place matrix which TfNSW are using to inform their future transport planning and engineering:

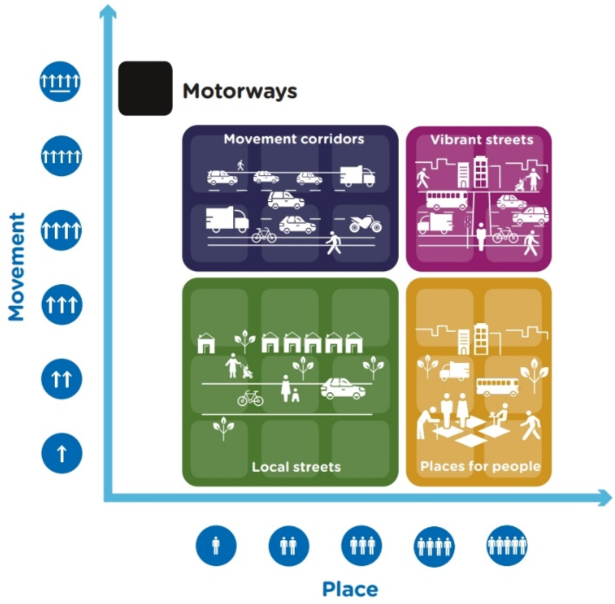

Figure 92: TfNSW Movement and Place Framework

9.4.2 Outcome Led Design

Outcome led design challenges new thinking around the planning, design and delivery of roads and streets, which is especially important to take up the opportunities of AVs and ZEVs, while mitigating potential challenges.

An outcome led design approach for roads and streets draws together human-centred design principles, and more holistic design considerations than current practice. It brings them to the forefront of decision making process throughout all phases of transport engineering, from planning through to design and delivery. It helps to translate strategic objectives into tangible design objectives, easily understood by multiple disciplines including planners, designers and engineers.

Roads and streets need to be designed practically having regard to the unique needs of each contextual design environment and the particularities of place. In order to enable this, flexible design approaches are needed which may not meet current design standards.

Outcome led design draws from Performance Based Practical Design (PBPD) which is a decision-making process developed by the US Federal Highway Administration (FHWA). As defined by FHWA, *PBPD can be articulated as modifying a traditional design approach to a 'design up' approach where transportation decision makers exercise engineering judgment to build up the improvements from existing conditions to meet both project and system objectives. PBPD uses appropriate performance-analysis tools, considers both short and long-term project and system goals while addressing project purpose and need.* It is a rational decision-making process that allows informed engineering judgment at the planning and preliminary design stages of a project[243].

The shift towards outcome led design will require changes to current practices that are used to plan, design and construct roads. It will require a more holistic, joined-up process, with cross-discipline working from policy development through to detailed design.

From Arup's collective experience working in the road planning and design space, and from our initial research, it appears that best practice outcome led design is supported by four key pillars (see Figure 93 below):

- Outcomes
- Indicators
- Interventions
- Metrics.

Figure 93: Outcome Led Design (Source: Arup)

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[243] Federal Highway Administration, 2017, Performance Based Practical Design https://www.fhwa.dot.gov/design/pbpd/documents/hif17026.pdf

9.5 Adaptability

9.5.1 Real Options Analysis

The Victorian Department of Treasury and Finance has recently released their guide to assist practitioners in considering and managing the potential effects of uncertainty on infrastructure investment development and delivery. In particular, the guide highlights the use of real options analysis, to better manage investments significantly impacted by uncertainty. Though we are starting to build a picture of how AVs and ZEVs might look in the future, there *are* a lot of uncertainties on what the impacts will be, and therefore it will be important to consider this in road infrastructure planning today. Figure 94 below illustrates the value of building in flexibility to decision making where uncertainties exist.

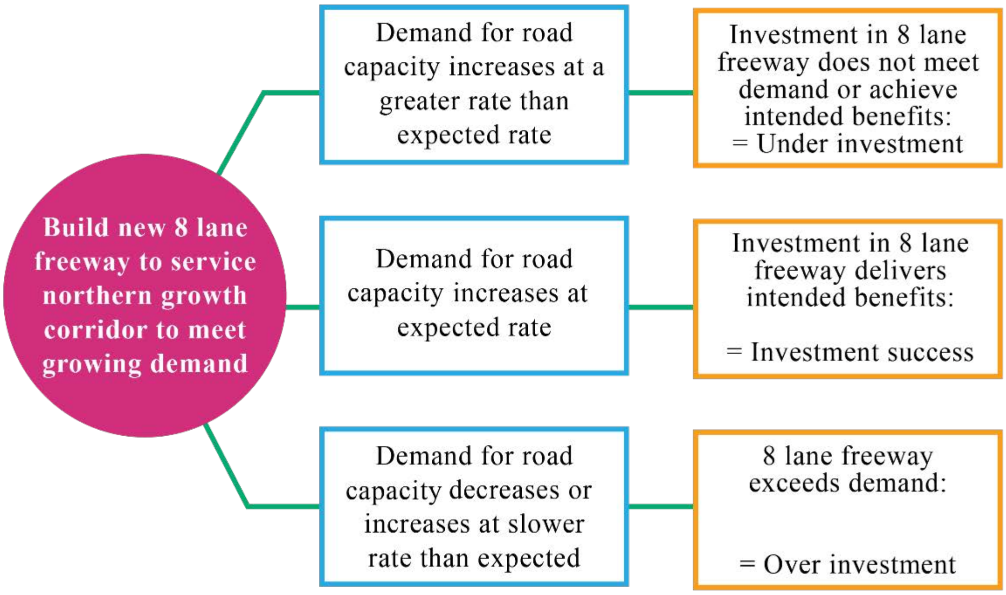

Figure 94: Dealing with Uncertainty (Source: Department of Treasury and Finance)

Real options analysis builds flexibility into the planning process, allowing investments to adapt to uncertainty. It enables investments to be structured to encompass flexibility at future milestone stages. Figure 95 illustrates how real options analysis compares to traditional cost benefit analysis thinking. A practical example of real options analysis is the reserving of land for a new road corridor, it would be an over investment to build the road from day one, and if the traffic demands never eventuate then the road reservation can be sold. In considering AVs or ZEVs in future road projects a real options analysis may assist planners and engineers to create a ‘no regrets’ investment strategy.

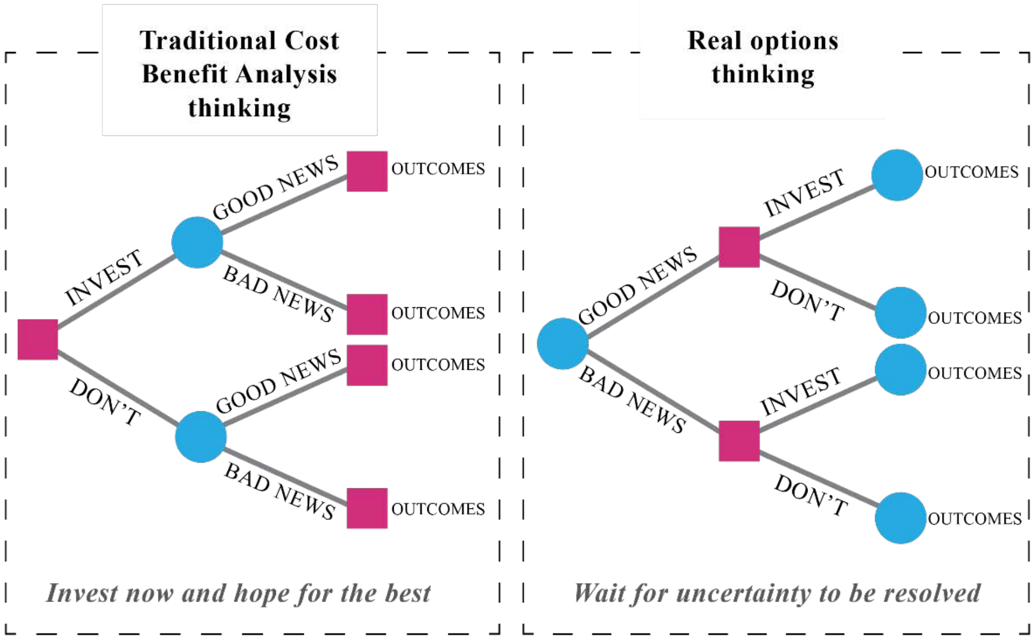

Figure 95: Decision Tree CBA Versus Real Options

9.5.2 Adaptable Road Standards and Guidance

VicRoads outlines various traffic engineering documents on their website[244] to provide practitioners involved in traffic engineering, road design and road safety with the nominated guidance and standards used by VicRoads. Their website states:

'VicRoads and all other state road authorities are working towards greater consistency in how road networks are managed across Australia. In order to achieve this, the Austroads Guide to Traffic Management and Australian Standards relating to traffic management have been adopted to assist in providing consistency and harmonisation across all jurisdictions. This agreement means that these Austroads Guides and Australian Standards are the primary technical references.'

However, with the rapid and evolving nature of AVs and ZEVs, there is a risk that guides and standards will not keep pace with the change. One concept put forward by the project team is to consider moving guidelines - like Austroads - into an online only 'wiki' platform. A wiki is a website on which users collaboratively modify content, such as Wikipedia. A wiki is created without any defined owner, and wikis have little implicit structure, allowing structure to emerge according to the needs of the users[245]. This would be a substantial change and need further investigation into the pros and cons of moving towards a free user created website, including how content would be added, reviewed and approved.

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[244] VicRoads, 2018, Traffic Engineering https://www.vicroads.vic.gov.au/business-and-industry/technical-publications/traffic-engineering

[245] Wiki, 2018, https://en.wikipedia.org/wiki/Wiki

9.5.3 Infrastructure Funding

To provide innovative alternatives to business as usual transport solutions, decision makers globally are actively seeking new ways to fund and finance transport related projects. AVs in particular may require governments to explore new funding models such as increased user fees (e.g. road pricing or parking levies), increased property taxes, land value capture (e.g. tax increment financing or increased land and property values) and public private partnerships (private sector funding). However, some of these methods may be hard to justify and depend heavily on the cost-benefit ratio identified within the business case. Therefore, upgrading or building new digital and physical infrastructure for AVs and ZEVs is likely to require a different method of evaluation and funding models.

If AVs require additional infrastructure and/or ZEVs are not charged current fuel excise, then road user pricing or other related policy measures will need to be considered to ensure that all users are paying their fair share. Alternatively, if road user pricing is not put in place, there may be a lack of funding to encourage and enable the safe and efficient operation of AVs on the road network.

Appendix A

Case Study: Preparing for Change – Highways England

A1 Delivering Infrastructure

Many elements of road building have not evolved substantially in decades. As new technologies emerge there will be great opportunities to modernise the design, construction and maintenance methods used within transportation. In the future owners will be challenged to create assets which are increasingly resilient, easy to maintain, adaptable and more efficient to construct. Figure 96 highlights the possible future design, construction and maintenance of the Strategic Road Network (SRN).

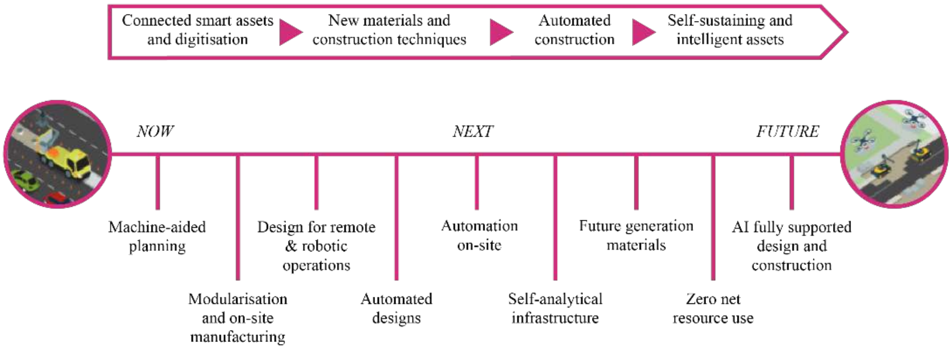

Figure 96: Possible Future Design, Construction and Maintenance of the SRN

A2 Connected and Autonomous Vehicles

Connected and autonomous travel will be one of the most significant and potentially disruptive changes in mobility. Connected systems promise integrated, reliable and safer travel, whilst autonomy could realise radically altered environments and increased productivity. Both technologies have widespread implications for current assets and provide new capabilities and opportunities for both users and authorities. Figure 97 highlights some of the key areas which will enable Highways England to realise the advantages from future vehicle technologies.

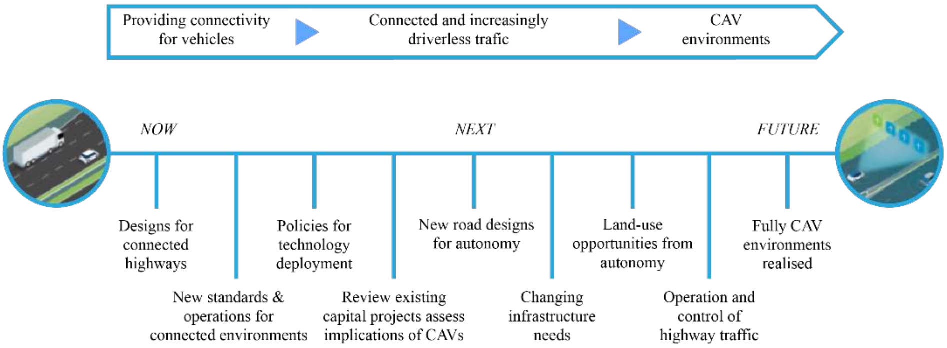

Figure 97: Key Areas to Realise Advantages from Future Vehicle Technologies

A3 Customer Mobility

The way users travel, both on and off the highway network, will transform. Ownership models for vehicles are changing, as are approaches to mobility. Traditional and disruptive entities are progressively positioning themselves as providers of mobility services, and transport systems are increasingly interacting across modes. In this emerging environment, transport owners will be expected to adapt to meet these evolving mobility demands, enabling seamless journeys for their users. Figure 98 highlights how Highways England is planning to support the transformation of its customers' journeys.

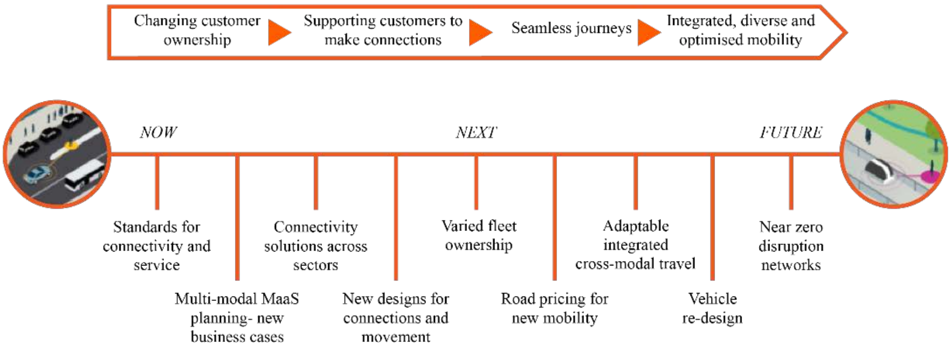

Figure 98: How Highways England Plans to Support Journey Transformation

A4 Vehicle Energy

Around the globe authorities are pushing for reductions in emissions and improved air quality. Key to achieving these goals will be supporting the transition away from conventional powertrains to clean zero emission fleets. Successfully realising this ambition will require policy, strategic direction and investment in alternative power sources and networks. Figure 99 highlights how the electrification of transport may take place.

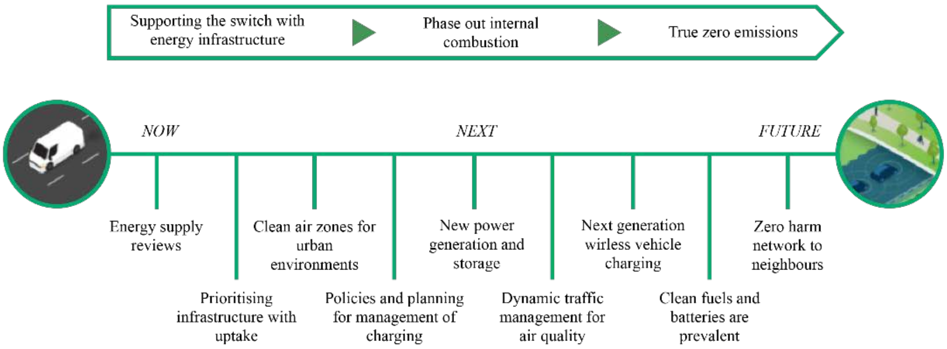

Figure 99: How the Electrification of Transport May Take Place

A5 Transport Operations

The emphasis on highways operations in the future will shift, roads will become increasingly linked via telecoms networks and connected assets, with raised customer expectations. This will bring new operating pressures to authorities, but also opportunities to greatly reduce the disruption caused by maintenance, weather and incidents on their networks. Figure 100 highlights how Highways England plans to deliver efficient customer-focussed operations, in response to the changing mobility landscape.

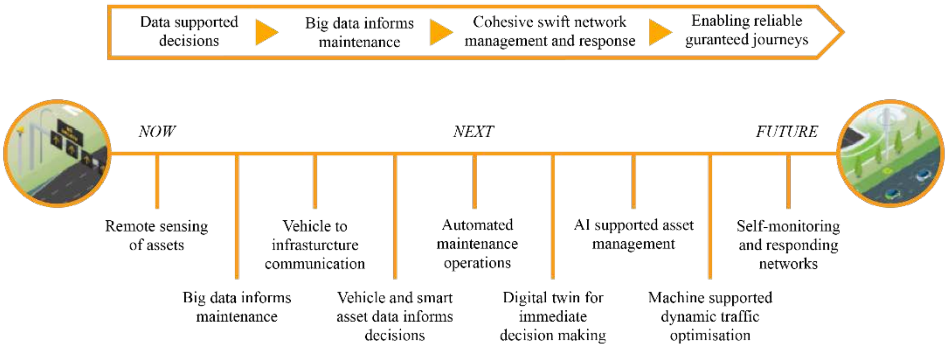

Figure 100: Highways England Plan for Efficient Customer-focussed Operations

Appendix B

Parking and Land-Use Matrix

Scenario		Key variables (IV)	Defining assumptions	Web of impacts	Decreases overall parking demand	Creates opportunities for parking land reuse	Decreases residential parking demand	Decreases commuter parking demand	Decreases recreational/ retail parking demand	Increases kerbside access demand	Creates opportunities for increased parking layout efficiency	Decreased parking-related revenue	Increased requirements for stabling facilities	New refuelling infrastructure requirements	Questions	Land use implications
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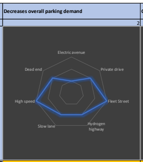
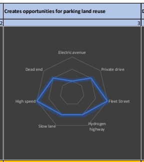
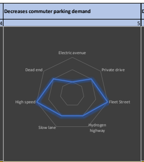
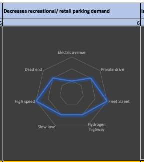
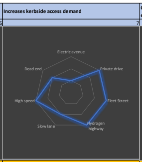
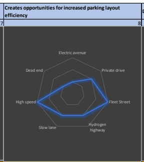
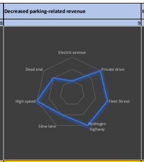
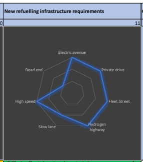
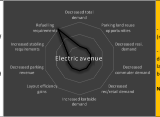
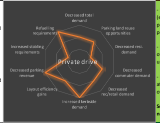
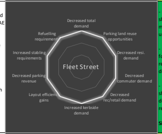
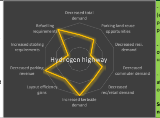
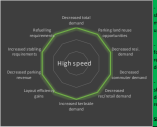
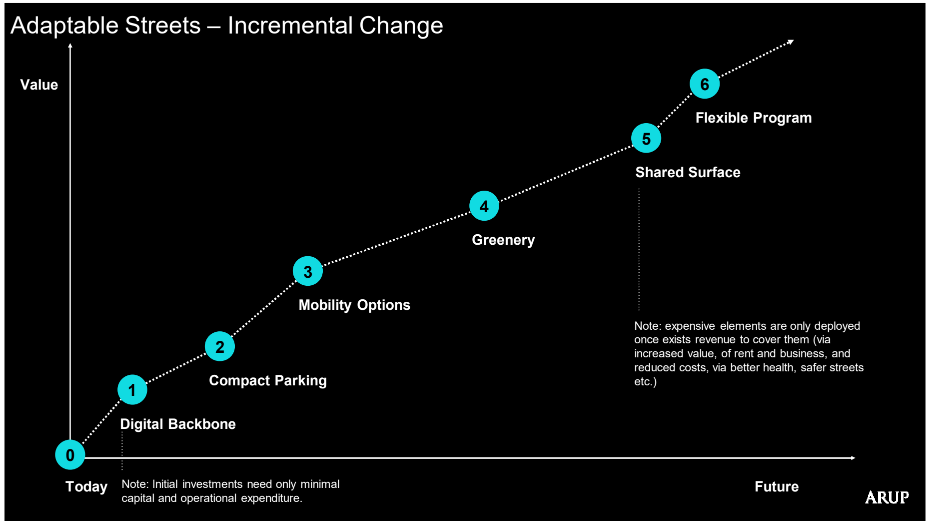
																
Electric avenue	1	- 2046 - Non-driverless - Electric - Private ownership - Single occupancy	- No growth in ride-hailing (BAU with respect for current market penetration of MaaS) - 100% of vehicles are electric - No additional uptake of MaaS compared to BAU. Vast majority of population retains private ownership		- No opportunity to decrease residential parking demand (no change to rates of private vehicle ownership) - No opportunity to decrease parking demand at destination end of trip, due to lack of increased MaaS and lack of driverless mobility (no change to current travel behaviour) **No decrease in overall parking demand**	- Lack of opportunity to reduce parking leads to no current parking becoming redundant **No opportunities for parking land reuse**	- No opportunity to decrease residential parking demand (no change to rates of private vehicle ownership) **No decrease in residential parking demand**	- No opportunity to decrease commuter parking demand (no change to rates of private vehicle ownership and use for commutes) **No decrease in commuter parking demand**	- No opportunity to decrease recreational/retail parking demand (no change to rates of private vehicle ownership and use for these trip purposes) **No decrease in recreational/ retail parking demand**	- No increased use of shared mobility services and deployment of driverless vehicles leads to no additional kerbside demand **No increase in kerbside access demand**	- No change to current demand for parking and no deployment of driverless vehicles means no opportunities for improving parking layout efficiency **No opportunities to increase parking layout efficiency created**	- No change to current demand for parking and no deployment of driverless vehicles means negligible impacts on parking demand and therefore revenue generation **No decrease in parking-related revenue**	- No increased use of shared mobility services and deployment of driverless vehicles leads to no new demand for stabling facilities **No increased requirements for stabling facilities**	- Differing fleet charging characteristics means a range of recharging options need to be provided - EV charging infrastructure needed at home, work, retail locations - Some induction charging infrastructure built into transport network e.g. at intersections - Petrol fuel stations obsolete and removed - Vehicles able to be used as home batteries (charged by rooftop solar panels) - Charging infrastructure needed at stabling/ parking facilities	- How does energy supply and demand differ between an autonomous/ non-autonomous vehicle scenario? - How would the servicing requirements of charging infrastructure affect the performance and serviceability of parking infrastructure it is located within? - How does parking structure design (at-grade, decked, basement) need to change to incorporate charging?	- Decreased emissions and noise leads to improved amenity of urban space near traffic - Lack of change to overall vehicular trips made, VKT generally and demand for parking present no new opportunities for adaptive reuse of parking areas nor for streetscape reclamation projects
Private drive	2	- 2046 - Driverless - Electric - Private ownership - Single occupancy	- 100% of vehicles are electric, connected (to each other and to infrastructure) and SAE Level 5 driverless - Range of EVs is equivalent to the range of traditional petrol/ diesel vehicle - No additional uptake of MaaS compared to BAU. Vast majority of population retains private ownership		- No opportunity to decrease residential parking demand (either no change to rates of private vehicle ownership or potential for additional ownership among members of the population who are unable to drive themselves) - Decreased demand for parking at destination end (some owners will choose to send their vehicle home/ elsewhere upon arriving) - No additional opportunities to decrease parking demand at origin or destination through MaaS, due to private ownership model **Some decrease in overall parking demand, but limited to non-residential parking**	- Some opportunities to reduce parking demand at the destination end of trips reduces the amount of parking land needed at non-residential land uses **Some opportunities for parking land reuse**	- Potential for increased private vehicle ownership owing to increased independent mobility potential - Possibility of increased independent mobility and vehicle ownership to be offset by more efficient use of vehicles among members of the same household **Vehicle ownership and therefore residential parking demand is similar to BAU**	- Some commuter parking still required, but proportion of commuters will choose to be dropped off and send their vehicle home/ elsewhere to park/ charge/ serve family members **Some decrease in commuter parking demand**	- Majority of travellers will choose to be dropped off as close to destination entrance as possible, although some will still use on-site parking and/ or charging (particularly for shorter trips) **Some decrease in recreational/ retail parking demand**	- Kerbside PUDO becomes the prevalent arrival/ departure facility for land uses other than residential - Users will opt to be dropped off at PUDO located at destination entrance where possible - On-street parking demand also increases for shorter trips (where it is not worth sending the vehicle elsewhere) - Private passenger vehicles compete with service vehicles (e.g. white vans) and surface running public transport for limited kerbside space **Significant increase in kerbside access demand**	- CAVs are able to park with a higher level of efficiency compared to human drivers enabling some degree of efficiency in parking design compared to BAU - Design efficiencies enabled by the removal of need for car doors to open when parked - Private ownership restricts extent to which more efficient layouts can be considered, owing to need to limit vehicle call-up time - Lower tolerance in high-turnover parking areas for call-up delays and policy decisions assumed to limit the VKT and manoeuvring required for vehicles to 'free' themselves from tandem bays **Modest opportunities for increased parking layout**	- Commuters and recreational/retail travellers incentivised to avoid parking their vehicles to not have to pay for parking. CAVs can be directed to circle the block, or reassign to free parking elsewhere/home until called **Significant decrease to parking-related revenue generation**	- No shared operation means no stabling requirements for vehicle fleets - Stabling assessed independently of kerbside demand and demand management requirements **No increased requirements for stabling facilities**	- Differing fleet charging characteristics means a range of recharging options need to be provided - EV charging infrastructure needed at home, work, retail locations - Some induction charging infrastructure built into transport network e.g. at intersections - Petrol fuel stations obsolete and removed - Vehicles able to be used as home batteries (charged by rooftop solar panels) **Significant refuelling infrastructure requirements**	- Application of congestion charge or pay-by-km charge on CAV use to mitigate reassignment and circulating behaviour - Pay-by-distance scheme may offset reduced parking revenue; however, receipts may be by different stakeholder	independent mobility and reduced value of time while in-vehicle - Some opportunity for adaptive retrofit of parking structures, but more likely in suburban locations - Decreased emissions and noise leads to improved amenity of urban space near traffic (particularly ports, industrial) - Streetscape impacts arising from kerbside demands - If PUDO nodes are designated to manage origins/destinations, the locations of these could be leveraged to activate certain areas
Fleet Street	3	- 2046 - Driverless - Electric - Shared, on-demand services - Multiple occupancy	- 100% of vehicles are electric, connected (to each other and infrastructure) and SAE Level 5 driverless - Range of EVs is equivalent to the range of traditional petrol/ diesel vehicles - 100% of vehicles on the network are part of AMoD service - AMoD services are fully integrated with public transport in one MaaS ecosystem - Number of passenger fleet vehicles reduced		- Large decrease in residential parking demand; uptake of shared mobility services replaces private ownership, meaning no traditional residential parking is needed (pick-up/ drop-off and short-term on-street only) - Large decrease in destination trip-end parking demand; as for residential, only PUDO and short-term on-street required (for trips where the amount of time spent at destination is very small) - Increase in vehicle stabling facilities required; due to the shared operation of vehicles, these can be located out of dense urban centres and are insignificant compared to the reduction in traditional parking **Significant decrease in overall parking demand**	- Land previously used for residential parking (garages etc.) is able to be used for other uses (AirBnB/ home gym/ office/ bedroom) - New houses are built without parking garages, enabling increased density of population without any reduction in living floorspace from today's levels - Significant infill opportunities created by decrease in destination trip-end parking demand. This is particularly significant in urban cores and high-density activity centres, where infill represents up to 30% of total land area - A lot of current parking infrastructure must be demolished as it is unsuitable for retrofit to future uses **Significant opportunities for parking land reuse**	- Private ownership replaced by shared MoD; residents are able to order a vehicle to pick them up from their home/ from a designated pick-up site in relative proximity - The need for private residential parking is reduced drastically(only exceptions are work vehicles like trade vans with personal tools inside, although these may also be shared and could either be parked in longer-term on-street parking or inside a secure external facility and summoned) **Significant decrease in residential parking demand**	- Commuters choosing to travel by vehicle are dropped at their place of work utilising PUDO, either at the entrance or at the nearest drop-off node. Vehicles then continue on to serve other users or assign to a suburban stabling area **Significant decrease in commuter parking demand**	- Travellers choosing to travel by vehicle are dropped at their destination utilising PUDO, either at the entrance or nearest drop-off node. Vehicles then continue on to serve other users - No exclusive-use off-street parking is required at recreational/ retail destinations **Significant decrease in recreational/ retail parking demand**	- Kerbside PUDO becomes the prevalent arrival/ departure facility for vehicle trips associated with all land uses - PUDO facilities are located as close as possible to end destinations to meet convenience expectations. This leads to signficant redesignation of kerbside areas in activity centres and downtowns, especially and creates competition with service vehicles and surface running public transport **Significant increase in kerbside access demand**	- CAVs are able to park with a higher level of efficiency compared to human drivers enabling some degree of efficiency in parking design compared to BAU - Design efficiencies enabled by the removal of need for car doors to open when parked - More efficient bay and module designs are possible, taking advantage of tandem configurations, as specific vehicles do not have to be available on-demand - Efficient design criteria relate to stabling areas given the reduction in requirements for private and exclusive use parking **Significant opportunities for increased parking layout efficiency where stabling is needed**	- Significant drop in parking demand leads to significant reduction in parking revenue - While stabling areas will be needed, these are likely to be in suburban areas where reduced fees can be levied - Transfer of fee receipts between stakeholders (e.g. potential for reduced local government parking provision and charging) **Significant reduction in parking revenue anticipated**	- The entirety of the vehicle fleet consists of shared, on-demand vehicles; these require stabling areas - Stabling facilities needed both for vehicles waiting for their next trip and for vehicles in need of charging - Vehicles in high-density areas likely to mainly use stabling facilities on outskirts of area; efficient management of routes required to ensure congestion is minimised in peak times (vehicles in need of charging could be allocated to trips ending close to charge points) **Significant increase in requirements for stabling facilities**	- EV charging infrastructure need to be co-located with stabling areas - Some charging infrastructure built into transport network e.g. at intersections - Petrol fuel stations obsolete and removed **Significant refuelling infrastructure requirements**	- How best to manage the placement of depots/ stabling facilities used for vehicle charging and storage? (Opportunity is created to locate facilities outside of high-value, dense urban centres, but there is potential to negatively impact the area chosen) - How many fleet providers are in the mobility eco-system? Does government policy require sharing of stabling facilities or does each fleet provider have their own, adding to how many sites are developed for this purpose? - How are PUDO facilities managed? Is it "free-for-all" or are there nodes? (transit hubs?) - Is there potential for fees-for-use of PUDO? - How does PUDO interact with service vehicle access and surface public transport? Are facilities controlled by time-	- Infill opportunities created, particularly in CBDs (~30% of CBD land area currently just parking) - Parking depots/ stabling and charging facilities able to be located outside high-value, dense urban activity centres - Removal of off-street parking and shift to PUDO facilities changes the way humans interact with the built environment and current viability of land for certain uses (e.g. retail may become viable in a location it was not previously, due to an increase in people walking past as the nearest drop-off point for a major attractor takes them past the shopfront) - If PUDO nodes are designated to manage origins/destinations, the locations of these could be leveraged to activate certain areas
Hydrogen highway	4	- 2046 - Driverless - Hydrogen - Private ownership - Single occupancy	- 100% of vehicles are hydrogen-fuelled, connected (to each other and infrastructure) and SAE Level 5 driverless - Range of hydrogen-powered vehicles equivalent to the range of traditional petrol/ diesel vehicle - No additional uptake of MaaS compared to BAU. Vast majority of population retains private ownership		- No opportunity to decrease residential parking demand (either no change to rates of private vehicle ownership or potential for additional ownership among members of the population who are unable to drive themselves) - Decreased demand for parking at destination end (some owners will choose to send their vehicle home/ elsewhere upon arriving) - No additional opportunities to decrease parking demand at origin or destination through MaaS, due to private ownership model **Some decrease in overall parking demand, but limited to non-residential parking**	- Some opportunities to reduce parking demand at the destination end of trips reduces the amount of parking land needed at non-residential land uses **Some opportunities for parking land reuse**	- Potential for increased private vehicle ownership owing to increased independent mobility potential - Possibility of increased independent mobility and vehicle ownership to be offset by more efficient use of vehicles among members of the same household **Vehicle ownership and therefore residential parking demand is similar to BAU**	- Some commuter parking still required, but proportion of commuters will choose to be dropped off and send their vehicle home/ elsewhere to park/ charge/ serve family members **Some decrease in commuter parking demand**	- Majority of travellers will choose to be dropped off as close to destination entrance as possible, although some will still use on-site parking and/ or charging (particularly for shorter trips) **Some decrease in recreational/ retail parking demand**	- Kerbside PUDO becomes the prevalent arrival/ departure facility for land uses other than residential - Users will opt to be dropped off at PUDO located at destination entrance where possible - On-street parking demand also increases for shorter trips (where it is not worth sending the vehicle elsewhere) - Private passenger vehicles compete with service vehicles (e.g. white vans) for limited kerbside space **Significant increase in kerbside access demand**	- CAVs are able to park with a higher level of efficiency compared to human drivers enabling some degree of efficiency in parking design compared to BAU - Design efficiencies enabled by the removal of need for car doors to open when parked - Private ownership restricts extent to which more efficient layouts can be considered, owing to need to limit vehicle call-up time - Lower tolerance in high-turnover parking areas for call-up delays and policy decisions assumed to limit the VKT and manoeuvring required for vehicles to 'free' themselves from tandem bays	- Commuters and recreational/retail travellers incentivised to avoid parking their vehicles to not have to pay for parking. CAVs can be directed to circle the block, or reassign to free parking elsewhere/home until called **Significant decrease to parking-related revenue generation**	- No shared operation means no stabling requirements for vehicle fleets - Stabling assessed independently of kerbside demand and demand management requirements **No increased requirements for stabling facilities**	- Hydrogen charging infrastructure needed at home, work, retail locations - Petrol fuel stations obsolete and removed **Significant refuelling infrastructure requirements**	- Application of congestion charge or pay-by-km charge on CAV use to mitigate reassignment and circulating behaviour - Pay-by-distance scheme may offset reduced parking revenue; however, receipts may be by different stakeholder	- Potential for increased sprawl owing to increased independent mobility and reduced value of time while in-vehicle - Some opportunity for adaptive retrofit of parking structures, but more likely in suburban locations - Decreased emissions and noise leads to improved amenity of urban space near traffic (particularly ports, industrial) - Significant impacts on streetscapes owing to kerbside operations
Slow lane	5	- 2046 - Non-driverless + driverless - Electric + petrol/ diesel - Shared, on-demand services + private ownership - Multiple occupancy + single occupancy	- 50/50 split between human-driven and autonomous vehicle use - Driverless vehicles are both privately owned and available as MaaS - Driverless vehicles are electric, connected (to each other, with limited connectivity to infrastructure), and SAE Level 5 - Range of EVs is equivalent to the range traditional petrol/ diesel vehicle - Ride hailing, pooling and car sharing services are automated		- Private owners of conventional and driverless vehicles limit the opportunity to decrease residential parking demand - Shared driverless mobility service users do not require residential parking; homes without parking therefore represent a proportionate (small) share of the market (on-street parking still common e.g. for visitors) - Shared driverless mobility services users do not require parking at the destination trip-end - Privately-owned conventional vehicles require parking at trip destinations; privately-owned CAVs require some parking at destinations but at a lower rate than traditional vehicles **Some decrease in overall parking demand**	- Opportunities for parking land reuse stem from the drop in destination trip-end parking needed caused by the uptake of shared services and, to a lesser extent, private driverless vehicles **Some opportunities for parking land reuse**	- Privately-owned conventional vehicles and CAVs do not allow for a decrease in residential parking - Driverless mobility adds more users to the network (elderly, disabled etc.) - The uptake of shared mobility services via driverless fleet reduce residential parking demand but this is does not allow wholesale revision to parking standards **No/ nominal decrease in residential parking demand**	- A small decrease in commuter parking demand occurs as the result of shared driverless mobility services dropping users off - Commuter parking is still required for drivers of conventional vehicles, and to a lesser extent, private AV users **Some decrease in commuter parking demand**	- A small decrease in recreational/ retail parking demand occurs as the result of shared driverless mobility services dropping users off - Parking is still required for drivers of conventional vehicles, and to a lesser extent, private AV users **Some decrease in recreational/ retail parking demand**	- Increase in kerbside access demand stemming from uptake of shared fleets and private AV users - Private and shared passenger vehicles compete with service vehicles (e.g. white vans) and surface running public transport for limited kerbside space **Some increase in kerbside access demand**	- Mixing of conventional vehicles and CAVs limits ability for increased efficiency of parking layouts - Some AV-only car parks/ stabling areas exist and allow for increased efficiency; these are limited compared to locations shared with human-driven cars **Some opportunities for increased parking layout efficiency**	- Relative uptick in demand for PUDO and reduced demand for parking by users of shared services and some private CAV owners reduces parking revenues - Some requirements for stabling may lead to transfer of receipts between stakeholders **Some reduction in parking-related revenue**	- Uptake of driverless shared services leads to requirement for some stabling areas **Some increase in requirements for stabling facilities**	- EV charging infrastructure needed at home, work, retail locations. Difficulties for developers and parking operators to gauge demands for particular charging infrastructure: particularly for residential - Some charging infrastructure built into transport network e.g. at intersections - Petrol fuel stations less common - EVs able to be used as home batteries (charged by rooftop solar panels) **Moderate refuelling infrastructure requirements**	- Application of congestion charge or pay-by-km charge on CAV use to mitigate reassignment and circulating behaviour - Pay-by-distance scheme may offset reduced parking revenue; however, receipts may be by different stakeholder - May be a petrol-power price premium to encourage EV uptake - Some parking areas may need to be designed and designated for EVs, exclusively; all residential bays may be required to be recharging enabled	- Potential for increased sprawl owing to increased independent mobility and reduced value of time while in-vehicle, for CAV users - Limited opportunity for adaptive retrofit of parking structures; limited opportunities to make parking structures more efficient owing to mixing of fleet - Some decreases to emissions and noise leading to improved amenity of urban space near traffic (particularly ports, industrial) - Some streetscape impacts arising from kerbside demands
High speed	6	- 2031 - Driverless - Electric - Shared, on-demand services - Multiple occupancy	- 100% of vehicles are electric, connected (to each other and infrastructure) and SAE Level 5 driverless - Range of EVs is equivalent to the range of traditional petrol/ diesel vehicles - 100% of vehicles on the network are part of AMoD service - AMoD services are fully integrated with public transport (MaaS) - Number of vehicles (and VKT, congestion) reduced massively		- Large decrease in residential parking demand; uptake of shared mobility services replaces private ownership, meaning no traditional residential parking is needed (pick-up/ drop-off and short-term on-street only) - Large decrease in destination trip-end parking demand; as for residential, only PUDO and short-term on-street required (for trips where the amount of time spent at destination is very small) - Increase in vehicle stabling facilities required; due to the shared operation of vehicles, these can be located out of dense urban centres and are insignificant compared to the reduction in traditional parking **Significant decrease in overall parking demand**	- Land previously used for residential parking (garages etc.) is able to be used for other uses (AirBnB/ home gym/ office/ bedroom) - New houses are built without parking garages, enabling increased density of population without any reduction in living floorspace from today's levels - Significant infill opportunities created by decrease in destination trip-end parking demand. This is particularly significant in urban cores and high-density activity centres, where infill represents up to 30% of total land area - A lot of current parking infrastructure must be demolished as it is unsuitable for retrofit to future uses **Significant opportunities for parking land reuse**	- Private ownership replaced by shared MoD; residents are able to order a vehicle to pick them up from their home/ from a designated pick-up site in relative proximity - The need for private residential parking is reduced drastically(only exceptions are work vehicles like trade vans with personal tools inside, although these may also be shared and could either be parked in longer-term on-street parking or inside a secure external facility and summoned) **Significant decrease in residential parking demand**	- Commuters choosing to travel by vehicle are dropped at their place of work utilising PUDO, either at the entrance or at the nearest drop-off node. Vehicles then continue on to serve other users or assign to a suburban stabling area **Significant decrease in commuter parking demand**	- Travellers choosing to travel by vehicle are dropped at their destination utilising PUDO, either at the entrance or nearest drop-off node. Vehicles then continue on to serve other users - No exclusive-use off-street parking is required at recreational/ retail destinations **Significant decrease in recreational/ retail parking demand**	- Kerbside PUDO becomes the prevalent arrival/ departure facility for vehicle trips associated with all land uses - PUDO facilities are located as close as possible to end destinations to meet convenience expectations. This leads to signficant redesignation of kerbside areas in activity centres and downtowns, especially and creates competition with service vehicles and surface running public transport **Significant increase in kerbside access demand**	- CAVs are able to park with a higher level of efficiency compared to human drivers enabling some degree of efficiency in parking design compared to BAU - Design efficiencies enabled by the removal of need for car doors to open when parked - More efficient bay and module designs are possible, taking advantage of tandem configurations, as specific vehicles do not have to be available on-demand - Efficient design criteria relate to stabling areas given the reduction in requirements for private and exclusive use parking **Significant opportunities for increased parking layout efficiency where stabling is needed**	- Significant drop in parking demand leads to significant reduction in parking revenue - While stabling areas will be needed, these are likely to be in suburban areas where reduced fees can be levied - Transfer of fee receipts between stakeholders (e.g. potential for reduced local government parking provision and charging) **Significant reduction in parking revenue anticipated**	- The entirety of the vehicle fleet consists of shared, on-demand vehicles; these require stabling areas - Stabling facilities needed both for vehicles waiting for their next trip and for vehicles in need of charging - Vehicles in high-density areas likely to mainly use stabling facilities on outskirts of area; efficient management of routes required to ensure congestion is minimised in peak times (vehicles in need of charging could be allocated to trips ending close to charge points) **Significant increase in requirements for stabling facilities**	- EV charging infrastructure need to be co-located with stabling areas - Some charging infrastructure built into transport network e.g. at intersections - Petrol fuel stations obsolete and removed **Significant refuelling infrastructure requirements**	- How best to manage the placement of depots/ stabling facilities used for vehicle charging and storage? (Opportunity is created to locate facilities outside of high-value, dense urban centres, but there is potential to negatively impact the area chosen) - How many fleet providers are in the mobility eco-system? Does government policy require sharing of stabling facilities or does each fleet provider have their own, adding to how many sites are developed for this purpose? - How are PUDO facilities managed? Is it "free-for-all" or are there nodes? (transit hubs?) - Is there potential for fees-for-use of PUDO? - How does PUDO interact with service vehicle access and surface public transport? Are facilities controlled by time-	- Infill opportunities created, particularly in CBDs (~30% of CBD land area currently just parking) - Parking depots/ stabling and charging facilities able to be located outside high-value, dense urban activity centres - Removal of off-street parking and shift to PUDO facilities changes the way humans interact with the built environment and current viability of land for certain uses (e.g. retail may become viable in a location it was not previously, due to an increase in people walking past as the nearest drop-off point for a major attractor takes them past the shopfront) - If PUDO nodes are designated to manage origins/destinations, the locations of these could be leveraged to activate certain areas
Dead end	7	- 2046 - Non-driverless - Petrol/ diesel - Shared, on-demand services and private ownership - Multiple occupancy and single occupancy	- No driverless vehicles are present on network - No additional penetration into market of non-fossil fuel vehicles compared to BAU - MaaS maintains growth trajectory but retains a modest share of the passenger transport market		- Limited opportunity to decrease residential parking demand excepting from some increase in uptake of MaaS; however, this is likely to be more evident in urban rather than suburban locations and be associated with households giving up a second vehicle rather than all vehicles - Slight decrease in demand for parking at destination end stemming from the minor growth seen in MaaS **Some decrease in overall parking demand**	- The limited opportunities to reduce parking demand at the destination end of trips may reduce the amount of parking needed at non-residential uses **Some opportunities for parking land reuse**	- Some increased availability and uptake of MaaS permits some reduction in residential parking demand, but this will be geographically-variable - Lack of deployment of CAVs may mean that there is no counter-balancing demand for parking associated with new independent mobility (e.g. Scenario 4) **Limited decrease to residential parking demand**	- Growth in MaaS may reduce commuter parking demand while increasing demand for PUDO - Effects anticipated to be geographically variable **Some decrease in commuter parking demand**	- Growth in MaaS may reduce recreational/ retail parking demand while increase demand for PUDO - Effects anticipated to be geographically variable **Some decrease in recreational/ retail parking demand**	- Increase in kerbside access demand resulting from MaaS uptake - Effects anticipated to be geographically variable **Some increase in kerbside access demand**	- No change compared to BAU owing to conventional vehicles remaining the norm **No opportunities for increased parking layout efficiency**	- Relative uptick in demand for PUDO associated with MaaS uptake reducing demand for parking and therefore parking receipts **Some reduction in parking-related revenue**	- Relative uptick in MaaS but nominal anticipated change to current MaaS business models - Potential added demand for stabling areas for car sharing services but ride hailing companies anticipated to continue to employ driver-partners who use their own vehicles **No/ nominal in increase to requirements for stabling facilities**	- No change to current refuelling infrastructure requirements **No refuelling infrastructure requirements**	- Will uptake of MaaS be sufficient to make a substantive difference to variables including parking supply (and associated policy), kerbside operations, vehicle ownership (at least, for non-downtown dwellers), and streetscape design criteria?	- Nominal impacts on travel behaviour and land use compared to status quo

3	🟧	No change to present
2	🟩	Minor swing in the affirmative
1	🟩	Major swing in the affirmative

Appendix C

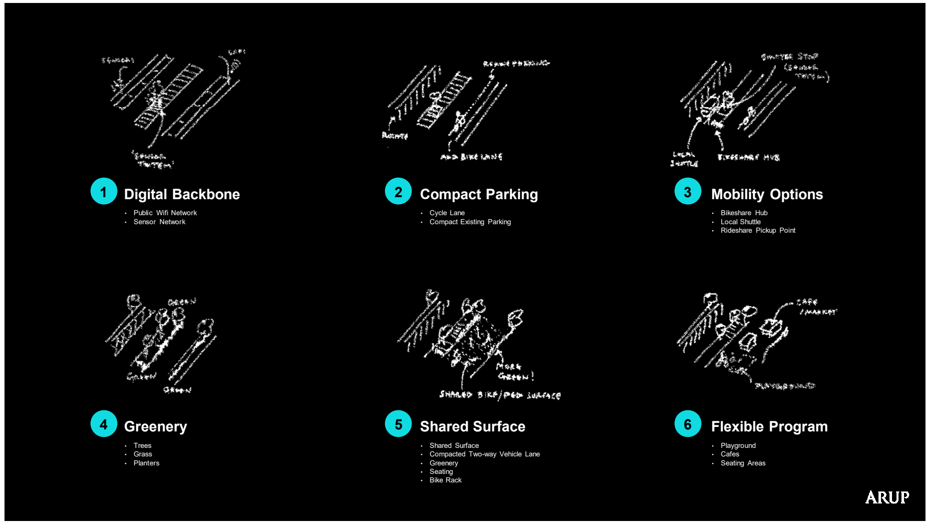
Adaptable Street Visualisations



Adaptable Streets – Incremental Change

Note: Initial investments need only minimal capital and operational expenditure.

Note: expensive elements are only deployed once exists revenue to cover them (via increased value, of rent and business, and reduced costs, via better health, safer streets etc.)



1 Digital Backbone

- Public Wifi Network
- Sensor Network

2 Compact Parking

- Cycle Lane
- Compact Existing Parking

3 Mobility Options

- Bikeshare Hub
- Local Shuttle
- Rideshare Pickup Point

4 Greenery

- Trees
- Grass
- Planters

5 Shared Surface

- Shared Surface
- Compacted Two-way Vehicle Lane
- Greenery
- Seating
- Bike Rack

6 Flexible Program

- Playground
- Cafes
- Seating Areas


Compact Parking
ROTATED & COMPACTED PARKING
CYCLE LANE
ARUP


Mobility Options
LOCAL SHUTTLE
RIDESHARE PICKUP POINT
5
BIKESHARE HUB
WAITING BENCH
ARUP


Greenery
TREES
5
GRASS
PLANTERS
ARUP


Shared Surface
GREENERY
5
BIKE RACK
SHARED SURFACE
SEATING
ARUP


Flexible Program
CAFE
CAFE
PLAYGROUND
ARUP


All Iterations
TREES
LOCAL SHUTTLE
GREENERY
PUBLIC WIFI
WIFI & SENSOR TOTEM
CAFE
CAFE
RIDESHARE PICKUP POINT
BIKE RACK
PLAYGROUND
BIKESHARE HUB
PLANTERS
SHARED SURFACE
SEATING
WAITING BENCH
GRASS
ARUP


Future
CAFE
ARUP