Design
for a better
future /

Infrastructure Victoria

ICT Infrastructure Advice for Automated and Zero Emission Vehicles

June 2018

Question today
Imagine tomorrow
Create for the future

Automated and Zero Emission Vehicle Infrastructure Advice
ICT Advice

Infrastructure Victoria

WSP
Level 15, 28 Freshwater Place
Southbank VIC 3006

Tel: +61 3 9861 1111
Fax: +61 3 9861 1144
wsp.com

REV	DATE	DETAILS
1.0	25 May 18	Final draft
1.1	9 June 18	Updated draft, incorporating feedback from Infrastructure for Victoria.
1.2	18 June 2018	Final report – for publication
1.3	27 June 2018	Incorporated key independent reviewer comments

	NAME	DATE	SIGNATURE
Prepared by:	Julien Marr, Wilson Foo, Veronica Dato, Elias Harb, Wayne Glenn, Juan Jimenez & Ben Jensen	27/06/2018	
Reviewed by:	Scott Benjamin	27/06/2018	[signature]
Approved by:	Pascal Felix	27/06/2018	

TABLE OF CONTENTS

GLOSSARY AND ABBREVIATIONS.. IV

EXECUTIVE SUMMARY VII

1 INTRODUCTION 1

1.1 BACKGROUND 1
1.2 PURPOSE 1
1.3 SCOPE AND LIMITATIONS 1
1.4 INTERACTIONS WITH OTHER WORK PACKAGES 3
1.5 VEHICLE DEFINITIONS USED 3
1.6 FUTURE SCENARIOS 4
1.7 REPORT STRUCTURE 5

2 METHODOLOGY 7

2.1 OVERVIEW 7
2.2 SCENARIO EVALUATION 7
2.3 USE CASES 8
2.4 FUNCTIONS 9
2.5 INFRASTRUCTURE ANALYSIS 10
2.6 DETERMINE ENABLERS AND BARRIERS 14
2.7 DATA PROVIDED TO THE CONSULTANT 15

3 SCENARIOS, USE CASES AND FUNCTIONS 16

3.1 SCENARIO EVALUATION 16
3.2 USE CASES 17
3.3 FUNCTIONAL ANALYSIS 23

4 INFRASTRUCTURE ANALYSIS 34

4.1 INTRODUCTION 34
4.2 CELLULAR TOWER COVERAGE 34
4.3 ROADSIDE INFRASTRUCTURE 42
4.4 CENTRAL SUPPORT SYSTEMS 43
4.5 BACKBONE LINKS 46

5 ENABLERS AND BARRIERS 48

5.1 INTRODUCTION 48
5.2 ICT INFRASTRUCTURE 48
5.3 MAPPING INFRASTRUCTURE 49
5.4 CENTRALISED TRAFFIC MANAGEMENT CENTRE 50
5.5 MOBILITY AS A SERVICE ENABLERS AND BARRIERS 51

5.6 MAJOR URBAN INFRASTRUCTURE PLANNING IMPACTS 53
5.7 CROSS-STATE OPPORTUNITIES AND RISKS 54
5.8 DATA COLLECTION, SHARING, PRIVACY AND SECURITY 56
5.9 CYBER SECURITY 59
5.10 OTHER ENABLERS AND BARRIERS 61
5.11 TRIGGERS AND INTERVENTIONS 63

6 KEY FINDINGS 65

6.1 SCENARIOS 65
6.2 USE CASES 65
6.3 FUNCTIONAL ANALYSIS 66
6.4 INFRASTRUCTURE 66
6.5 ENABLERS AND BARRIERS 67
6.6 TRIGGERS AND INTERVENTIONS 68

7 LIMITATIONS 69

7.1 PERMITTED PURPOSE 69
7.2 QUALIFICATIONS AND ASSUMPTIONS 69
7.3 USE AND RELIANCE 69

8 ABOUT WSP 71

BIBLIOGRAPHY 72

LIST OF TABLES

TABLE 1.1 REPORT STRUCTURE 5
TABLE 4.1 BASE LAYER TOWER SUMMARY 34
TABLE 4.2 LGA CELL TOWER REQUIREMENTS 37
TABLE 4.3 NEW CELL TOWER COVERAGE OVERLAP 42
TABLE 5.1 MAJOR URBAN INFRASTRUCTURE PROJECTS – RECOMMENDED PLANNING REQUIREMENTS 53
TABLE 5.2 LIST OF ADDITIONAL ENABLERS AND COMMENTARY 61
TABLE 5.3 LIST OF ADDITIONAL BARRIERS IDENTIFIED WITH COMMENTARY 62

LIST OF FIGURES

FIGURE 1.1 FUTURE SCENARIOS AT A GLANCE 5
FIGURE 2.1 OVERVIEW OF DELIVERABLES STEPS...................................7
FIGURE 3.1 POTENTIAL NETWORK CONNECTIONS BETWEEN END USERS AND INFRASTRUCTURE 24
FIGURE 3.2 NEW MOBILITY – WSP 25
FIGURE 3.3 AV USE OF LOCATIONS TO DETERMINE POSITION – DEVELOPED BY BOSCH (AUSTROADS).................................27
FIGURE 4.1 EXISTING TOWER LOCATIONS AND COVERAGE FOR VICTORIA 36
FIGURE 4.2 ADDITIONAL TOWERS – M AND A CLASS ROADS.................39
FIGURE 4.3 ADDITIONAL TOWERS – B AND C CLASS ROADS 40
FIGURE 4.4 ADDITIONAL TOWERS ON ALL SEALED ROADS...................41
FIGURE 4.5 POTENTIAL CLOUD-BASED - KEY SYSTEM INTERACTIONS 45
FIGURE 5.1 MAAS FEASIBILITY CHECKLIST...52

LIST OF APPENDICES

APPENDIX A ASSUMPTIONS
APPENDIX B SCENARIOS
APPENDIX C USE CASES
APPENDIX D COMMUNICATION NETWORKS FOR CAVS

GLOSSARY AND ABBREVIATIONS

TERM/ABBREVIATION	DEFINITION
3G/4G/5G	Wireless network communications based on 3GPP standards
3GPP	3rd Generation Partnership Project is a mobile communications industry collaboration that organises, develops and manages mobile wireless communications standards
5.9GHz	5.9GHz is the frequency band allocated for C-ITS telecommunication.
5G	Next-generation Radio (NR) communications through telecommunications provider
AV	Automated vehicle
AWS	Amazon Web Services
Backhaul	Telecommunications carriers (NBN, Telstra etc.) high capacity communications links
CAHARV	Connected and Highly Automated Road Vehicles
CAM	Cooperative Awareness Message (C-ITS message)
CAV	Cooperative Automated Vehicle
CAVI	TMR’s Cooperative and Automated Vehicle Initiative
C-ITS	Cooperative ITS
C-V2X	Cellular-Vehicle to Everything. A C-ITS mobile peer to peer telecommunications standard in the 5.9 GHz band being developed by 3GPP group in competition with IEEE802.11p (DSRC, G5)
ConOps	Concept of Operations
COS	Central operation systems
DDoS	Distributed Denial of Service
DENM	Decentralised Environmental Notification Message (C-ITS message)
DMS	Dynamic Message Sign (includes Variable Message Sign)
DEDJTR	Department of Economic Development, Jobs, Transport and Resources
Degraded mode	See ‘Graceful Degradation’
Dominant Road Users	Transportation modes that generally provide a high level of safety for occupants but a low level of safety for Vulnerable Road Users (e.g. cars, trucks)
DSRC	Dedicated short range communications
eCAV	Electric, cooperative and Automated Vehicle
Edge device	Hardware that processes and stores information in a geographically convenient location
ETSI	European Telecommunications Standards Institute
FCV / FCEV	Fuel cell electric vehicle

TERM/ABBREVIATION	DEFINITION
Fog computing	Extending cloud computing to the edge of an enterprise's network
G5	ETSI ITS-G5 / IEEE802.11p telecommunications (Wi-Fi) standard in the 5.9 GHz band; also known in the USA as DSRC
GNSS	Global Navigation Satellite System
Graceful Degradation	Action of a vehicle moving to a conservative driving posture due to restricted information or systems failure.
HAD	Highly automated driving
Highly Automated	Level 4 or 5 (SAE) Vehicle, sometimes called Autonomous
HMI	Human machine interface
ICT	Information and communication technology
IoT	Internet of things
ISO	International organisation for standardisation
ITS	Intelligent transport system
ITS-S	ITS Station
IV	Infrastructure Victoria
IVI	In-Vehicle Information C-ITS Message (includes; In-Vehicle Signage [IVS] & Contextual Speed Message [CSM])
Latency	Delay in time over a communications network
LGA	Local government area
LDM	Local Dynamic Map
LSE	Large-scale emergencies
MaaS	Mobility as a service
MABM	Melbourne Activity-Based Model
MAP	Cooperative ITS message, broadcasting an intersection’s geography/topology
Map tile	Electronic layers of information defined in geographic areas
MNO	Mobile network operator
OBU	On-board (Vehicle) C-ITS unit
O-D	Origin-destination
OEM	Original Equipment Manufacturer
P-ITS-S	Personal ITS Station
PKI	Public Key Infrastructure issues by SCMS
Platooning	Convoy of vehicles (typically freight), usually with one driver in the lead vehicle.

TERM/ABBREVIATION	DEFINITION
QoS	Quality of Service
RIMS	Roadside infrastructure (including Active & Passive) & maintenance sites (including mobile and immobile)
RSU	Roadside C-ITS unit
SAE	Society of Automotive Engineers
SBAS	Satellite based augmentation system
SCMS	Security Credential Management System
SOA	Service orientated architecture
SPaT	Signal Phase and Timing (C-ITS message)
STREAMS	VicRoads's Freeway Management System platform
TFV	Transport for Victoria
TMC	Traffic management centre
V2I	Vehicle-to-infrastructure communication
V2P	C-ITS enabled Vehicle to/from C-ITS enabled personal device
V2V	Vehicle-to-vehicle communication
V2X	V2V, V2I, and vehicle-to-other (including pedestrians, cyclists)
VKT	Vehicle kilometres travelled
VMS	Variable message sign
VSL	Variable speed limit
Vulnerable Road Users	Transportation modes that generally provide a low level of safety for users when interacting with Dominant Road Users (e.g. cyclists and pedestrians). Motorcyclists are also generally categorised at Vulnerable Road Users.
ZEV	Zero emission vehicle

EXECUTIVE SUMMARY

The Special Minister for State asked Infrastructure Victoria to provide advice by October 2018 on the infrastructure needs for introducing automated vehicles (AVs) and zero emission vehicles (ZEVs). In March 2018, Infrastructure Victoria appointed WSP to research and advise on the potential ICT infrastructure needs for implementing AVs and ZEVs, that may:

— Enable the operation of highly automated vehicles (Society of Automotive Engineers (SAE) levels 4 and 5) in Victoria
— Respond to the ownership and market models that may emerge from highly automated vehicles' availability
— Provide for ZEVs as a high proportion of the Victorian fleet.

WSP assessed and analysed impacts on ICT infrastructure of a range of future scenarios developed by Infrastructure Victoria, with the following objectives:

1. Identify the minimum and optimal ICT requirements to enable AVs in a defined range of uptake scenarios, and the gap between existing/planned ICT infrastructure capabilities and usage in Victoria, with all assumptions explicitly identified.
2. Identify enablers, barriers, opportunities and risks of ICT infrastructure in AV uptake scenarios.
3. Provide a summary of infrastructure responses for potential AV uptake scenarios.

Infrastructure Victoria's seven future scenarios include a combination of different times, driving modes, power sources and ownership/market model options. This included two scenarios where the adoption of AVs or ZEVs is not as rapid as some predict: the 'Dead end' scenario, where 'the hype never happened', and 'Slow lane' scenario, where 'man and machine never meet on the road'.

PROCESS

The diagram below outlines the 'top down' process used to consider infrastructure needs. Using the use cases provided, we considered a range of likely use cases and distilled key functions required. These functions help us determine the potential infrastructure needs and barriers and enablers.

We have used a state-of-the art understanding of these technologies from discussions with key contractors and parties involved in current technology trials and deployments to ensure that needs considered are as realistic as possible. There are significant uncertainties around these technologies' future directions. Hence, throughout the report we state key assumptions and validated these with engineering judgement in the absence of formal references.

KEY FINDINGS

We note below what is a minimal or optimal requirement to support AVs.

— **Focus on the key benefits:** AV development's focus and functions are to reduce accidents and make travel safer. The assertion that AVs alone will reduce city traffic congestion has little support. Mobility as a Service (MaaS) and vehicle sharing are more likely to significantly impact road capacity. We have based the ICT infrastructure need on the assumptions made in the MABM which outlined an increase in vehicle throughput in many scenarios. We note that if connected and cooperative AV fleets are better managed, there may be opportunities to improve travel reliability and certainty for end users which are recognised as key end user needs by many road operators in additional to any potential improvements to throughput.

— **Need for radical change in approach to central operation systems:** The nature and role of these systems will change. AVs will become an increasingly important aspect of transport systems, as the operator will need to proactively predict and manage the network (with CAV or shared fleets) via machine learning and eventually artificial intelligence. This is required for an optimal outcome.

— **Roadside ICT infrastructure:** WSP believes the existing roadside ICT infrastructure is adequate for the introduction of AV, provided critical infrastructure is prioritised and traffic signal controllers and tunnels management systems are updated over time to achieve a minimum outcome. A separate study, as technology matures, would be required to confirm this.

— **Optimising vehicles on the network:** WSP recommends an extended industry liaison period before committing to any significant V2X rollout funding. Instrumentation of critical infrastructure such as tunnels and bridges may be considered for funding on a case-by-case basis. In the short-term, we need investment in trials applying 'optimum' technologies so that future benefits are realised and industry and government roles are well understood. Based on today's costs, WSP estimates that, by 2046, the capital expenditure would need to be in the order of magnitude of $40m for the minimum scenario and $205m for the optimum scenario for deployment (2018 dollars)[1].

— **Growing communication network use:** Over the next three years, we estimate average network data speeds will increase from 18.8Mbps to 43.6Mbps. Average traffic per capita per month is estimated to increase from 42.5GB to 125.8GB. At most, the average driver's AV seek to transmit 500MB of data per month (mainly cellular) which is a fraction of the overall network use that **backbone links** will support in the future given expansion of 4K video and other entertainment needs that network providers will seek to support. Therefore, no significant infrastructure cost should be assigned to expanding backbone links for minimum or optimum outcomes. Further sensitivity analysis that modelled growth of traffic per vehicle increased a hundred-fold, provides confidence in this position.

— **Meeting all users' needs, wherever they live:** Cellular tower (current and planned 5G) technical capabilities should suffice. Network breadth of coverage, particularly in rural areas, is an issue. As a minimum, 134 additional **cellular towers** will be needed to cover priority routes (M and A class roads); the order of magnitude estimate would be about $76–109m (2018 dollars). All trips on sealed roads should ideally be covered, making a total of 2098 towers supporting 5G and future communication services; order of magnitude estimate would be about $1.1–1.7b (2018 dollars) for the optimum outcome.

ENABLERS AND BARRIERS

ENABLERS

— **Leadership/stewardship:** Government to lead discussions with industry about central systems needs and integration with third party data providers who are part of the wider CAV ecosystem.

— **Leadership:** Government agencies to promote requirements for supporting future CAV operation in present-day infrastructure design. This will help industry prepare for implementation of CAV related ICT ahead of significant CAV penetration.

— **Leadership/stewardship/governance**: Government to provide a clear assistance framework to ensure data collection requirements (including safety, privacy and security) are clearly understood and incorporated in system designs, i.e. privacy by design.

[1] Excluding central systems investment

— **Deployment:** Having wide cellular network coverage in rural areas will increase safety and network efficiency. While it is currently difficult to determine an appropriate level for minimal or optimal with respect to rural networks there is a general need for access across all roads for AVs to operate across our network.

— **Technology:** Different uses create different needs for maps, infrastructure, and understanding context. Machine learning and artificial intelligence will help the development of these solutions in both vehicle and centralised traffic management and control systems.

— **Operational Management:** CAVs and MaaS fleets offer the opportunity to significantly improve road operators' ability to manage road operations. Improved operation would be possible though cooperative operation of fleets at a strategic network level eg re-routing around congested routes and incentivisation and pricing to change demand and potentially access to the network in some circumstances. There are also opportunities to assist in other use cases such as queue protection on freeways, improving throughput and reducing the possibility of secondary incidents.

— **Connected, automated, shared, electric:** Interaction with these systems and technologies will result in a varied range of future outcomes. MaaS and ride sharing are the most significant opportunities for increased people throughput in our networks. Fleets of car and or ride-sharing vehicles could speed up CAV use and deployment and increase the overall fleet safety.

BARRIERS

— **No clear winner:** AVs will ultimately be Cooperative AVs (CAVs). To support necessary cooperative messaging, this will require additional ICT infrastructure able to provide low-latency vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), or vehicle-to-other (V2X) cooperative telecommunications of sufficient speed and capacity to make this viable. Currently, the lack of certainty of timescales of availability of new forms of cellular communications like 5G. We recommend agencies consider deployment on a case-by-case basis, which should not be an issue for long-term deployment but could delay early deployment of cooperative systems.

— **Human physiology and psychology:** Any consideration of increased traffic density and throughput, and corresponding decrease in headways and gaps between vehicles, should consider human physiology and psychology. People will not find the trip comfortable or pleasant when they see vehicles within their idea of 'safe buffer zones' (safe distance between vehicles). Rapid acceleration and braking can make people ill, making 'car sickness' a potentially significant barrier to achieving higher throughput.

— **Technology:** Accurate CAV positioning in all locations and situations needs varying degrees of augmentation for safe operation, especially in tunnels, in areas that cannot receive GNSS signals, or where SBAS is unavailable (city high rise areas where canyoning is an issue).

— **Privacy and surveillance:** CAV technologies require tracking of vehicle movements over time. Hence, the public is likely to raise privacy and surveillance concerns. The responsible governments will need to find transparent, open ways to discuss these issues with the public to find acceptable ways to deploy and use these technologies. Government will need to consider the impact of current and proposed legislation in this area.

— **Vulnerable road users:** Any requirement for these people to self-select the technology they use for protection from C-ITS or CAV technologies is likely to be controversial and potentially put VRUs at risk if there is any consideration of using a human machine interface (HMI) for these road users. In addition, privacy and surveillance issues mentioned above are of greater significance for VRUs.

— **Digital Divide:** In a mixed-vehicle environment, passive road infrastructure devices will be needed. WSP would discourage road operators from phasing out roadside variable message signs as this would remove one of the few available means of communicating with non-connected vehicles, and would likely lead to suboptimal network management and disgruntled end users.

TRIGGER POINTS

WSP undertook a high-level review of scenarios (where relevant) and main infrastructure components over their lifespan of policy/strategy, planning, funding, design and implementation and have highlighted a few important triggers and interventions from an ICT infrastructure perspective.

— **Incentives:** Freight companies will identify key intercity routes for AV deployment that will need increased coverage. Planning of this AV deployment must extend to cell tower coverage, possibly with government incentives similar to the blackspot program. A second trigger is making vehicles publicly available which should trigger deployment of cell tower coverage across M and A routes as a minimum.

— **Technology trends and take up:** Roadside V2I devices represent a potential risk to overinvestment in ICT infrastructure due to competing technologies. WSP note that the focus needs to be on cooperative data exchange and not the underlying technology and forms of communication.

— **Leadership:** Government (maybe managed by State, guided by national regulator) should provide centralised, single authorities source of, for road conditions, roadworks and incidents before AVs are made available to the public to ensure vehicles have access to a common set of information. Further to this government should push to encourage sharing of infrastructure related data from all vehicle manufacturers and operators to add to this centralised set of data.

— **Cooperation:** All State governments must work closely together to establish a national regulator for AV with enhanced accountability for the states, before any significant effort is spent on trials, regulations or implementation.

— **Leadership**: It is important for government to instigate and lead the development of centralised road management systems, and consider CAV needs and opportunities. It is important that these systems are in place within the next 2 to 5 years at most, otherwise private industry will develop solutions that are unlikely to result in government agencies managing road operations. Where possible, the government will need to use cooperative models that use common languages and messages. This will require a significant repositioning of platforms like STREAMS and SCATS.

— **Leadership:** Augmentation of satellite positioning needs to be supported with significant trialling (with road operators) of terrestrial augmentation for SBAS. Trialling must occur before deployment of AVs that require support of SBAS to operate optimally to understand the potential benefit of these technology when deploying at scale across our rural road networks.

— **Leadership in Safety:** Vulnerable road users need a holistic technical and policy approach to manage interactions with AVs developed before any AVs are deployed. This will include consideration of safety systems and human centred and ethically consideration. Leadership is needed from government in this area to ensure the best possible outcomes are achieved for the community.

KEY DEFINITIONS TO CONSIDER

There are wide range of definitions outlined throughout this document. It is important to consider the difference between connected and cooperative ITS and very important to understand that cooperative ITS is technology agnostic. Other key definitions to consider is the difference between ride sharing (people in the same car at the same time for part of a trip) and car sharing which is equivalent to short term rental of the vehicles and MaaS which is subscription / payment and benefits scheme set up for a range of mobility options and potential to use to influence traveller behaviour.

1 INTRODUCTION

1.1 BACKGROUND

Victoria's Special Minister for State asked Infrastructure Victoria to provide advice by October 2018 on Victoria's infrastructure needs for introducing automated vehicles (AVs) and zero emission vehicles (ZEVs). In March 2018, Infrastructure Victoria appointed WSP to research the ICT infrastructure needs and advise on:

— Enabling the operation of highly automated vehicles (Society of Automotive Engineers (SAE) levels 4 and 5) in Victoria
— The ownership and market models that may emerge from highly automated vehicles' availability
— Providing for ZEVs as a high proportion of the Victorian fleet.

The advice is to be delivered in two parts[2]:

1 The future scenarios that form the basis of the infrastructure advice (delivered late April 2018, 6 months after the request).
2 A detailed report to Government on the potential infrastructure and land-use requirements for the Part 1 future scenarios, to be delivered late October 2018.

1.2 PURPOSE

Infrastructure Victoria appointed WSP to provide advisory services to assess the ICT infrastructure requirements for implementing automated and zero emission vehicles. Infrastructure Victoria required an understanding of the ICT infrastructure required to support mass rollout of AVs and ZEVs, including data network infrastructure, communications networks, traffic management systems, payment platforms (depending on ownership models), data security, privacy, and cyber security. Infrastructure Victoria required understanding of the minimum and optimal ICT infrastructure levels needed to support greater connectivity associated with AVs.

A requirement was for all materials developed, including this report, to be publicly released on Infrastructure Victoria's website.

1.3 SCOPE AND LIMITATIONS

The project objective is to assess and analyse the ICT impacts and implications of introducing AVs and ZEVs. Specifically, to:

1 Identify the minimum and optimal ICT requirements for enabling AVs in a defined range of uptake scenarios, and the gap between existing and planned ICT infrastructure capabilities and usage in Victoria, with all assumptions explicitly identified.
2 Identify enablers, barriers, opportunities and risks of ICT infrastructure in AV uptake scenarios.
3 Provide a summary of infrastructure responses for potential AV uptake scenarios.

Agreed project deliverables were to include:

— Methodology for assessing work as outlined
— Assumptions for evaluating options
— Data to support recommendations

2 Terms of Refence for Advice from Infrastructure Victoria on automated and zero emission vehicle infrastructure, 25 October 2017

- Analysis or assessment where required
- Advice as requested
- Summary report of minimum and optimal recommended infrastructure, including order of magnitude costs (*this report*).

Specific scope inclusions were to:

- Identify the assumptions made for assessing the gap between current, planned, minimal and optimal ICT infrastructure for the future scenarios (Refer section 1.6).
- Assess the gap between existing, planned, minimal and optimal ICT infrastructure for AVs in urban, regional and rural Victoria.
- Identify enablers and barriers:
  - Identify the likely key ICT technologies' infrastructure requirements for supporting AVs in Victoria (e.g. in-road, roadside, geo-fencing, DSRC, V2X, etc.), and technologies to allow a mixed fleet of AVs, human-driven vehicles, and other road users (e.g. bicycles, pedestrians, motorcycles) to communicate.
  - Assess the minimum and optimal mapping and navigation infrastructure needed to support AVs across Victoria. Estimate the impact various levels of mapping quality and accuracy has on AVs' uptake rate.
  - Summarise enablers and barriers related to data collection, sharing, privacy, and cyber-security concerns related to the operation, management and maintenance of connected AVs in Victoria, and advise on any ICT infrastructure requirements to address these. Provide advice on approaches to data sharing, data integration and data stewardship.
  - Assess the need in Victoria for a centralised data system and/or traffic management system (ITS/CITS) to support AVs and enable the network to respond to changed operational conditions, such as extreme weather, road works, or accidents.
  - Summarise Victoria's MaaS enablers and barriers, including integrated trip planning and payment; integration with current public and private transport; and options for non-technology users, and advise on any ICT infrastructure requirements needed to address these.
  - Provide advice on how key ICT technologies (identified above) might be integrated into planned major urban infrastructure projects in Victoria (e.g. to future-proof projects).
  - Identify the opportunities and risks of standardising key AV-enabling ICT infrastructure technologies across states and manufacturers.
- Summarise infrastructure responses: Recommend minimum and optimal ICT infrastructure in Victoria, by local government area (LGA) where possible, including an order-of-magnitude estimate of costs, sequencing, benefits and risks of infrastructure investments, and risk of obsolescence.

The following limitations apply:

- Some vehicle types are excluded from the scope, specifically:
  - Emerging vehicles including 'drones' (aerial or ground-based)
  - Vehicles operating primarily on private land (e.g. agriculture, mining, industrial or construction machinery)
  - Trains and trams.

This report has been prepared for the benefit of the client (Infrastructure Victoria) and no other party. WSP assumes no responsibility and will not be liable to any other person or organisation for or in relation to any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report (including without limitation matters arising from any negligent act or omission of WSP or for any loss or damage suffered by any other party relying upon the matters dealt with or conclusions expressed in the report). Other parties should not rely upon the report or the accuracy or completeness of any conclusions and should make their own enquiries and obtain independent advice in relation to such matters. For the purposes of this limitations statement, 'conclusions' include statements, opinions, facts, cost estimates, information, conclusions and/or recommendations in the report.

1.4 INTERACTIONS WITH OTHER WORK PACKAGES

This work package received inputs from the following other work packages, with the inputs denoted:

— Transport modelling (KPMG) – MABM base case. Some of these modelling outputs indicated up to 90 per cent increase in the potential traffic throughput. These large increases are conservative for calculating ICT requirements. However, great care needs to be taken with any use of such assumptions. Human aspects (psychological and physiological) need greater consideration, as do the practical and technical.
— International markets (LEK) – information on international trends.

Infrastructure Victoria also provided the future scenarios to be used (refer Section 1.6 Future Scenarios).

1.5 VEHICLE DEFINITIONS USED

There are a range of terms used for vehicles and associated systems. These need to be understood correctly when considering system needs, functionality, and interactions:

— **Automated Vehicles:** For this report, we are referring to highly-automated vehicles (SAE Level 4 or 5)[3].

— **Connected Vehicles:** Vehicles that transmit and receive information via internet connection, and that connect with internal vehicle devices using an in-vehicle wireless access point. The wide range of uses includes satnav and entertainment.

— **Cooperative ITS (C-ITS)[4]:** Automated vehicles are currently and will always be connected to the outside world, to communicate with map providers and/or manufacturers. AVs are connected vehicles. As explained by the European Commission on Mobility and Transport: "In many respects today's vehicles are already connected devices. However, in the very near future they will also interact directly with each other and with the road infrastructure. This interaction is the domain of Cooperative Intelligent Transport Systems (C-ITS), which will allow road users and traffic managers to share information and use it to coordinate their actions. This cooperative element – enabled by digital connectivity between vehicles and between vehicles and transport infrastructure – is expected to significantly improve road safety, traffic efficiency and comfort of driving, by helping the driver to take the right decisions and adapt to the traffic situation. Communication between vehicles, infrastructure and other road users is also crucial to increase the safety of future automated vehicles and their full integration in the overall transport system. Cooperation, connectivity, and automation are not only complementary technologies; they reinforce each other and will over time merge completely."[5]

  We have therefore elected to allocate the Cooperative ITS definition to the well-used C-ITS acronym, as it is cooperation that describes the function that will provide the enhanced mobility benefits. Cooperative Intelligent Transport Systems are: "Systems that can bring new intelligence for vehicles, roadside systems, operators and individuals by creating universally understood communication 'language' allowing vehicles and infrastructure to share information and cooperate in an unlimited range of new applications and services."[6] C-ITS uses a set of standards and protocols to describe how information exchange takes place between C-ITS-equipped vehicles, infrastructure and other road users. There are a number of suites of different C-ITS standards worldwide, including those from the USA, Japan and China. Australia has decided to base their C-ITS standards on the European ETSI suite of standards. The ETSI C-ITS standards and protocols allow safety-critical and traffic management use case applications to be employed, by the exchange of data between vehicles, devices and infrastructure in a robust and timely manner. The ETSI C-ITS standards are a suite of technical and policy standards that are telecommunications

---

3 SAE International Standard J3016 Levels of Driving Automation
4 http://www.austroads.com.au/drivers-vehicles/connected-and-automated-vehicles/overview
5 https://ec.europa.eu/transport/themes/its/c-its_en
6 https://www.its.dot.gov/research_archives/connected_vehicle/pdf/Joint_EU-US_Report.pdf

methodology agnostic. There are currently two telecommunications solutions for C-ITS peer to peer communications. These are sometimes referred to as G5 (an acronym derived from the 5.9Ghz frequency band it uses and based on the IEEE 802.11p standard, or commonly known as DSRC) and C-V2X (an acronym meaning Cellular – Vehicle to Everything, also based around the 5.9Ghz band). This is discussed in greater detail below. Additionally, for use case applications that don't require low latency or peer to peer communications, the 3G/4G and eventually 5G Cellular wide area networks can be used.

— **Cooperative and Automated Vehicle (CAV)[7]:** It is important to reiterate that, while Austroads uses the term Connected and Automated Vehicle, in the interest of clarity within this document, we have assumed that the 'C' in CAV means cooperative and not just connected. It would be reasonable to expect that all new automated vehicles produced from now onwards would be connected vehicles, as indeed are all AVs currently produced. Cooperative Automated Vehicles means that automated vehicles will have, in addition to AV telecommunications channels, one or more C-ITS channels to provide peer-to-peer and non-peer-to-peer information sharing with a common language or protocol to provide safety-related functionality (and other functionalities such as congestion management and traffic condition advice). As discussed above, C-ITS standards for Australia are based on the European ETSI suite of standards and these are still under development, however these do not currently consider AV operation, specifically. The integration of C-ITS operation with AV operation within a vehicle is left up to the vehicle manufacturers and standardisation within the AV environment is largely underdeveloped. Indications are that AV manufacturers are coming to the realisation that satisfactory operation at automation levels 4 and 5 are unlikely to be achieved without incorporating cooperative technologies into the vehicles.

— **Zero Emission Vehicles (ZEV):** Although not all AVs will be purely battery powered, electric motors will form part of the drive train, or will exclusively propel the vehicle. Plug-in Electric Vehicles (PEVs) will be exclusively propelled by electric motors and will need access to a network of energy provision stations. Each vehicle will need a communications channel for locating suitable energy provision stations and related journey planning to reduce concern with range anxiety and complexity of dealing with a vehicle which has a flat battery on road operation and safety, unless it is a fleet vehicle. Data transfer between these stations, vehicles, manufacturers or fleet operator centres, will happen regardless of the energy source. The vehicle's energy source, whether fossil fuels, electric or hydrogen, has little impact on its ICT infrastructure needs. In their early stages of deployment, not all electric vehicles (EVs) will be highly automated vehicles (AV).

— **Shared Use Vehicles & Mobility as a Service (MaaS):** This is discussed in further detail in Section 5.5 below. These services and solutions will be likely to use Robotaxi solutions in the future. Automated bus solutions operating on fixed, known, low speed routes are likely to be implemented first, favouring urban environments, and gradually servicing more flexible and higher speed routes over time in line with the scenarios promoted by Infrastructure Victoria[8]. There will be some increased need for communication to these vehicles given the need for a flexible route and stops, however this will not be significant in comparison to any other AV in operation.

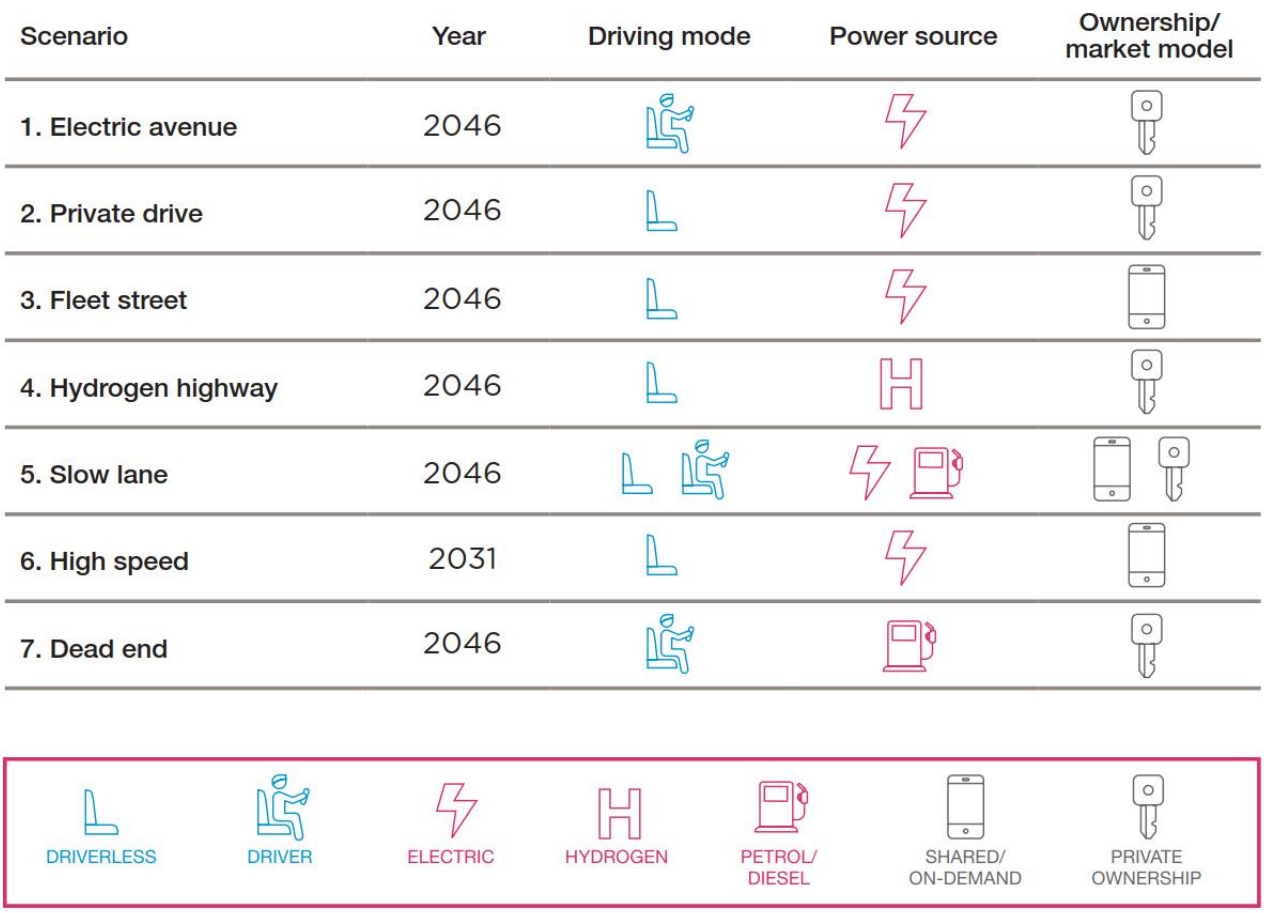
1.6 FUTURE SCENARIOS

In April 2018, Infrastructure Victoria published a report outlining future scenarios for automated and zero emissions vehicles in Victoria[9]. The seven scenarios Infrastructure Victoria identified and presented in Figure 1.1 for contextual information, are:

1 Electric avenue, a world where all cars are electric

7 https://www.qld.gov.au/transport/projects/cavi/cooperative-automated-vehicles
8 http://infrastructurevictoria.com.au/sites/default/files/images/Advice on automated and zero emissions vehicles infrastructure - Future scenarios April 2018.pdf
9 http://www.infrastructurevictoria.com.au/AVadvice

2 Private drive, a world where your car drives you
3 Fleet street, a world where no one owns their own car
4 Hydrogen highway, a world where trucks lead a hydrogen revolution
5 Slow lane, a world where man and machine meet on the road
6 High speed, a world where driverless and electric cars arrive much sooner than we expect
7 Dead end, a world where the hype never happened.



Source: *Infrastructure Victoria, Advice on automated and zero emissions vehicles infrastructure, future scenarios, April 2018*

Figure 1.1 Future scenarios at a glance

1.7 REPORT STRUCTURE

This report is structured as follows:

Table 1.1 Report structure

CHAPTER	TITLE	SUMMARY OF CONTENT
N/A	Executive summary	Overview of the project’s essential outcomes
1	Introduction (this chapter)	Project background, scope, purpose
2	Methodology	How the project was undertaken and key inputs
3	Scenarios, use cases and function	Predict future AV needs and support requirements
4	Infrastructure analysis	Estimate minimum and optimal ICT infrastructure needs, through scenarios where appropriate

CHAPTER	TITLE	SUMMARY OF CONTENT
5	Enablers and barriers	Qualitative assessment of potential enablers and barriers regarding ICT infrastructure
6	Key findings	Summary of the project outcomes and learnings
N/A	Bibliography	

2 METHODOLOGY

2.1 OVERVIEW

Deliverable 1 (define assumptions and project methodology) was completed in the first week with IV guidance. WSP conducted a series of logical steps that built towards an appropriate platform for analysing future ICT infrastructure needs.

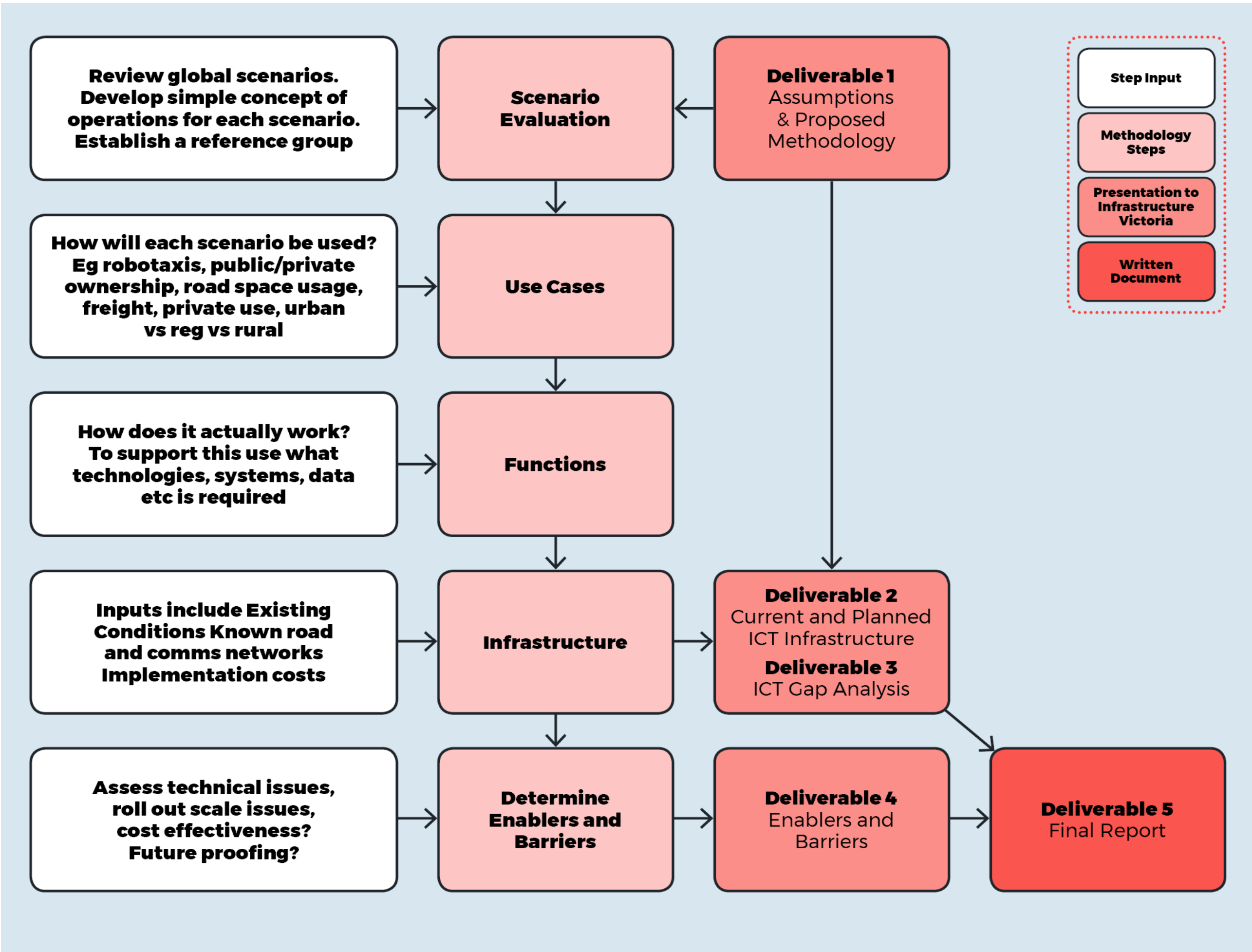


Figure 2.1 Overview of deliverables steps

Key assumptions for each step are included (see Appendix A for full list).

2.2 SCENARIO EVALUATION

WSP developed a high level 'outline of operations'[10] for each of the seven scenarios, covering details such as:

— road usage (e.g. Private Drive scenario could be high volumes; Fleet Street could reduce volumes)
— assumptions (e.g. current trends for growth)
— changes to in-mode usage and freight

[10] 'concept of operations' will not be used in this context to reduce nomenclature confusion with related ICT sectors

— changes to each of the above in the urban, regional and rural contexts
— considerations of how edge cases are managed, such as roadworks and incidents
— impacts on infrastructure over time, and likely take-up rate (e.g. consistent or explosive growth)
— pre-requisites for success (government policy, cultural shifts etc.)

Abstracting operations was a highly qualitative and potentially subjective process. Workshop discussion, attended by WSP and Infrastructure Victoria, enabled a breadth of views to be captured more efficiently. With IV's agreement, we reduced those scenarios with identical outlines of operations from an ICT perspective, and added the outlines to a spreadsheet for comparison. This report contains a detailed summary.

KEY ASSUMPTIONS

Minimum ICT infrastructure investment level focussed on the following:

— Emphasising safe operation over efficiency or economic benefits
— Having the least ICT infrastructure while ensuring safe AV operation on critical Victorian Roads
— Minimising over-investment or technical obsolescence risks
— Ensuring Victoria is not obviously disadvantaged compared to other States or countries.

Optimum level of ICT infrastructure investment focused on the following:

— Emphasising economic benefits, efficient networks, best use of existing assets.
— Promoting a more effective and holistic transport network management approach.
— Ensuring AVs can run optimally over most trip distances
— Ensuring lagging investment does not create missed opportunities.

We have not examined scenarios related to fuel sources that do not impact on ICT infrastructure.

2.3 USE CASES

Before we can deploy infrastructure, we need a strong understanding of who will use it[11] as well as potential and future demand.

WSP developed 'use cases' for each scenario to qualitatively and quantitatively describe how each use case impacts the respective scenario, and its end impact on infrastructure. This approach allowed us to describe and detail the relationships between agents in clear non-technical language. WSP drew on our local and international experience via an internal workshop process to develop the use cases. We gained supporting information from SAE's *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*[12] and Austroads *Assessment of Key Road Operator Actions to Support Automated Vehicles*[13].

KEY ASSUMPTIONS

— A sound reference for use cases is Austroads 'Assessment of Key Road Operator Actions to Support Automated Vehicles'.
— It is acceptable for rural vehicles to run in a 'degraded mode' on rural unsealed roads.
— Vehicle manufacturers will take a strong and direct role in managing AV interactions with centralised trip and map information providers.

---

[11] See WSP – New Mobility Now White Paper (2017)
[12] SAE International J3016-2016
[13] Austroads Research Report AP-R543-17

2.4 FUNCTIONS

We drew on ICT and CAV specialists to determine the ICT Infrastructure functions. We held a workshop to collectively draw on these specialists' knowledge and refine the use cases for functional analysis. Section 3.2 identifies the use cases determined. We used discussions with specialists in WSP and in the wider ICT community, suppliers of CAV, and research papers to gain information from multiple sources on the functional performance of ICT Infrastructure, data usage and use cases to consider.

KEY ASSUMPTIONS

From a functional perspective, many variables come in to play. Assumptions were included to ensure the question can be bounded and an answer can be provided within the limited current understanding of data generation. The key assumption based on data generation is that while CAVs create approximately twenty-five (25) gigabytes per driving hour, only one (1) per cent of this data needs to be shared, based on Tesla maximums[14]. Of this one (1) per cent of data, for every driving hour vehicles immediately share 10 megabytes and receive 10 megabytes. This figure is based on data provided by autonomous vehicle manufacturers and on SAE standards regarding frequency and size of Cooperative Awareness Messages (CAMs) (i.e. 150 bytes sent 10 times per second). Data usage calculations were based on an average of a vehicle driven 1 hour per day and the premise that once data is shared by one vehicle, it does not need to be shared by other vehicles in the same geographical area as they are now aware of the information. In the Tesla example, data per vehicle was 50MB/day[15] on average. In this situation, Tesla is capturing additional information for technology improvements, which explains the average extra daily data. Each vehicle will have its own map provided by a third-party map provider. Map updates will only be sent when an exception occurs (small map updates from centralised systems are passed down as required). At 10MB per hour, there is enough to cover the map information, fleet operators, vehicle manufacturers, V2V, V2P, V2I and V2X required communications. This only covers communication across wireless networks. Communications across wired networks are supported by separate infrastructure mostly already in place.

Data storage is another critical element of the data picture. Once data is shared via the backhaul network, and processed by manufacturers/fleet operators, only 10 per cent will need to be stored for up to a month. This assumption is based on similar data usage by road authorities. It is assumed the stored data is enough to help authorities with any police/legal queries that would be completed within a month, with the information transferred to the requesting organisation. The monthly data can then be compressed, archived to 50 per cent of its original (monthly) size, and stored long-term for up to 20 years.

From a cell tower network perspective, it is assumed that a single tower can provide connections to the maximum number of vehicles the roads can support within its coverage area. WSP assumed MNOs will be financially motivated to meet future demand within the urban environment. This assumption reflects the current black-spot program where government provides additional financial incentive in rural areas, but not in urban environments.

---

14 https://electrek.co/2017/06/14/tesla-autopilot-data-floodgates/

15 https://electrek.co/2017/06/14/tesla-autopilot-data-floodgates/

2.5 INFRASTRUCTURE ANALYSIS

WSP developed a picture of the physical road network for factoring infrastructure requirements based on LGAs. Building on the work completed for understanding the existing ICT infrastructure, and the gap between what exists and what's required, we developed a broad scope of required works and order-of-magnitude cost estimates.

2.5.1 CELLULAR TOWER ANALYSIS SCENARIOS – MINIMAL AND OPTIMAL APPROACH

To assess cell tower infrastructure, we bundled the scenarios into two categories:

- Scenarios involving highly automated vehicles
- Scenarios **not** involving highly automated vehicles
- For the scenarios involving highly automated vehicles (AVs): as a minimum, AV travel requires cellular coverage on roads where AVs are expected to operate in a non-degraded state. The scale of AV rollout will determine the level of investment needed, i.e. if AVs are required to operate in a non-degraded state on M class roads, only M class roads require cellular coverage. The optimal approach to support comprehensive AV rollout would be to ensure complete cellular data coverage on all class M, A, B, C and all sealed roads. This would not include unsealed roads since not all AVs are likely to be able to travel on roads of unknown quality and terrain.
- For the scenarios **not** involving AVs: additional cellular data coverage is not needed and the minimal approach involves no increased or extra cell tower investment.

2.5.2 CELLULAR TOWER ANALYSIS METHODOLOGY

We initially sourced and/or developed the following GIS layers from obtained information, including:

- Roads (including classification)
- Vehicle volumes by road segment
- Crash (accident) history
- Existing cell tower locations (Telstra, Optus and Vodafone)
- Proposed cell tower locations (as part of the Federal Government Mobile Black Spot Program)
- List of all Victoria's rural/regional towns
- VicRoads' field ICT assets (e.g. traffic signals, managed motorway assets, street lighting)

We developed an assumed cell phone tower location map for 2031, using the following assumptions:

- A 5km coverage radius around each tower, based on macrocell base stations implemented using current LTE frequencies; minimal geographical and/or man-made obstructions; and a maximum vehicle density equal to what a single base station within the 5km radius can support. (Note that real-life factors such as weather, terrain, high rise buildings, and trees, will limit cell tower penetration and the area's coverage[16])
- All existing tower locations will remain to 2031 and beyond (current towers)
- Metropolitan Melbourne and regional cities currently have sufficient coverage that will be maintained, and MNOs will have a financial incentive to provide sufficient bandwidth.
- All proposed towers listed in the Mobile Black Spot Program will be constructed and functional by 2031 under the three different funding rounds (Round 1, Round 2 and Priority Locations) (future known towers)

---

16 http://www.mobilenetworkguide.com.au/mobile_base_stations.html

ANALYSIS METHODOLOGY

1 The first assessment compared existing and future towers' coverage using the list of towns from the Department of Planning and Community Development report, *Towns in Time* (2008). We compiled a list of towns with no coverage under the above assumptions.

2 We compared the list of towns with the current mobile coverage map, which showed that all Victorian towns currently have coverage. We assumed a cell tower was located within the town creating a 5km coverage radius (assumed towers).

3 We repeated the analysis with the three cell tower layers (current, future known and assumed) as the future minimum cell tower coverage – the 'future existing coverage'.

4 We determined the additional cell tower investment required to ensure cell tower coverage on all Victorian roads classified M, A, B and C and sealed[17]. (The assessment of unsealed roads was considered out of scope.)

5 The process assumed that roads with higher classifications would receive investment before roads with lower classifications, and higher-classified roads would have full coverage before any investment is made on lower-classified roads.

6 We assessed the number of additional cell towers needed for M class roads based on the existing, future and assumed towers previously outlined. We identified any gaps in coverage along M class roads and placed a tower in that gap, based on the coverage gap length and the (assumed) 5km tower coverage radius.

7 We next assessed A class roads, assuming that all required M class road cell towers would now be constructed. The A class roads assessment therefore incorporated existing, future, assumed and required M class towers. This method was reiterated for B, C, and then sealed roads.

8 The analysis showed the need for a significant number (in the thousands) of new towers, particularly for the C class and sealed roads. To reduce the number of new towers and overlapping coverage, we consolidated all towers within 5km of one another.

Note that our assessment cannot consider the additional cell towers that may be built due to private investment or organic network growth. Commercial confidentiality limits the information available on the size of planned investments or possible tower locations. As such, our results are conservative and represent a scenario with no expected or overlapping private investment.

This analysis also does not consider any potential new road construction or unsealed road upgrades outside the Metropolitan Melbourne area. To support AVs, future road projects should consider assessing cell tower coverage, and enable AV use by including connectivity in future projects' scopes.

Telstra internal documents describe the phase out of 3G HSPA cell towers from 2022 to 2030. 4G cell towers will likely be planned to start phase out from 2030.[18]

2.5.3 PEAK VEHICLE NUMBER METHODOLOGY

KPMG supplied the modelling output results used to calculate the peak vehicle numbers (methodology below). The numbers formed a key input into the ICT infrastructure cost estimate.

— The document 'IV AZEVIA Dashboard 20180515 PRELIMINARY DRAFT v8' outlined the vehicle numbers in 5-minute increments for 'Enroute - private vehicles' and 'Enroute - robotaxis'. The results provided were only for the metropolitan Melbourne model. No equivalent "Dashboard" or vehicle numbers in 5-minute increments results were available for the statewide model. (only the "raw" statewide model output files were available).

---

[17] https://www.data.vic.gov.au/data/dataset/road-network-vicmap-transport

[18] Telstra internal 'Mobile Network Facts' document, dated March 2018.

— The maximum values for both 'Enroute - private vehicles' and 'Enroute - robotaxis' were identified across the provided model results. No figures for any other vehicle classes were available for analysis. It's understood that "private vehicles" included both conventionally-driven vehicles and AVs, while robotaxis referred to shared AVs. The proportion of private AVs, shared AVs and private conventionally driven vehicles were based on the information in the 'Scenario Definitions' tab of the 'IV AZEVIA Dashboard 20180515 PRELIMINARY DRAFT v8' document.

— Analysed the 'Statewide modelling - VITM_Matrices_SA2_2011' and 'Metro Melb - trips_skims_matrices_SA2_2011' model output files to determine the ratio for converting the supplied (metropolitan Melbourne only) figures to statewide figures. Nine different raw output file scenarios (including the Dead end base case) were provided for both metropolitan and statewide results: Dead end, Electric avenue, Fleet street, Fleet street (Low MUTT), Private drive, Private drive (Low MUTT), Private Drive Dead Running, Electric avenue, Slow lane and Slow lane (Low MUTT). No other model output files were provided for any other scenario, and as such, no other scenarios could be analysed.

— The model files gave 'car trip' numbers and 'car time' values (in minutes) for travel between different origins and destinations. The number of trips for each unique origin-destination trip was multiplied by the total time, added to give a total calculated Vehicle Hours Travelled (VHT) for that scenario. (Note that the calculated VHT figures from these raw files do not correspond to the VHT figures provided in the 'IV AZEVIA Dashboard 20180515 PRELIMINARY DRAFT v8' spreadsheet summary. The analysis noted that the statewide results were 'rural/regional only' trips and included no metropolitan trips.)

— We summed the VHT for both metropolitan and statewide results and divided the total statewide and metropolitan VHT over the metropolitan-only VHT to calculate the ratio factor for converting the provided 'Enroute - private vehicles' and 'Enroute - robotaxis' vehicle numbers. We then multiplied the provided 'Enroute - private vehicles' and 'Enroute - robotaxis' metropolitan vehicle numbers by the calculated factor to determine the total peak number of 'Enroute - private vehicles' and 'Enroute - robotaxis' across the state (metropolitan, regional and rural Victoria).

— On 17 May 2018, Infrastructure Victoria supplied (via email) the following data tables to develop freight numbers:

SCENARIO	AUTONOMOUS FREIGHT	CONVENTIONALLY DRIVEN FREIGHT
Dead end	0%	100%
Slow lane	50%	50%
High speed	100%	0%
Electric avenue	0%	100%
Private drive	100%	0%
Fleet street	100%	0%
Hydrogen highway	100%	0%

MOTOR VEHICLE CENSUS[19]			
		% of passenger vehicles	**% of total vehicles**
Light rigid trucks	33,040	0.88%	0.69%
Heavy rigid trucks	81,460	2.17%	1.70%
Articulated trucks	27,472	0.73%	0.57%
Total 'freight'**	141,972	3.79%	2.96%

19 http://www.abs.gov.au/ausstats/abs@.nsf/mf/9309.0

Total passenger vehicles	3,750,484		
Total vehicles*	4,798,097		

- From the information supplied, we assumed total freight percentage 2.96 per cent across all nine assessed scenarios. We did not consider the fluctuations in freight proportions throughout the day and made no changes to the freight percentages based on the time the maximum vehicle number was identified in 'Enroute - private vehicles' and 'Enroute - robotaxis' figures.
- From the figures provided, we calculated a state freight vehicle number based on the split of autonomous and conventionally-driven freight.
- Note that outputs required for calculating vehicle hours travelled (converting metropolitan-only figures to statewide, i.e. metropolitan, regional and rural Victoria) were not available for some scenarios (e.g. Hydrogen highway). These could not be assessed.

2.5.4 ROADSIDE INFRASTRUCTURE

The functional analysis, use cases, and scenario evaluations help us appreciate the roadside infrastructure likely needed for AVs to operate under minimum and optimum requirements.

Building on learnings from the WSP and QLD Main Roads CAVI project, we evaluated options based on safety, efficiency and reliability, and assessed developing trends.

Order of magnitude cost estimates were based on similar infrastructure projects in Victoria over the past five years, drawing on internal WSP experience. Consideration has not been given to land acquisition which may be needed to enable this infrastructure. Ultimately, more accurate costing would require development of preliminary designs on which to base further cost estimates.

KEY ASSUMPTIONS

Traffic Signals and other active roadside infrastructure currently use telecommunication links to central operators with sufficient spare capacity for V2I devices.

Installation costs of V2I devices on traffic signals and lane use gantries is similar to 2018 pricing.

2.5.5 CENTRAL SUPPORT SYSTEMS

After discussions with IV and internal software architects, we also consulted in a series of workshops with 'informed stakeholders' and leading cloud service and network hardware providers to discuss how each organisation would approach:

- Requirements and preferences of Victorian ICT infrastructure
- Functional interactions/systems (diagrams of)

We also reviewed VicRoads' internal proposed TMC/internal systems strategic plan for ICT infrastructure impacts.

Discussions with the leading cloud service and network hardware providers helped inform order of magnitude cost estimates.

ASSUMPTIONS

See 2.4 – Functions

2.5.6 BACKBONE LINKS

WSP engaged NBN and Telstra to discuss[20] strategic and infrastructure planning around potential impacts of high AV data flows and Quality of Service (QoS) requirements.

Next, we examined how these backbone links operate, and the maximum data flows that cell towers generate, and we predicted the measures and infrastructure improvements likely to be needed.

ASSUMPTIONS

No data beyond what is generated and requested by vehicles and roadside infrastructure.

2.6 DETERMINE ENABLERS AND BARRIERS

We prioritised the enablers and barriers identified in the IV document – mapping, security, privacy, use of shared vehicles and MaaS, and operational and maintenance support.

Over two detailed workshops, we identified and discussed additional enablers and barriers.

2.6.1 ICT INFRASTRUCTURE

Based on local and international experience, as well as previous project determinations, WSP developed detailed qualitative descriptions of ICT infrastructure requirements.

2.6.2 MAPPING INFRASTRUCTURE

WSP assessed the mapping and navigation infrastructure (minimum and optimal) to support a variety of AVs within a variety of scenarios. We supplemented existing infrastructure to match, where feasible, the basic systems used overseas (such as Satellite-Based Augmentation Systems) and investigated how one might create accurate ‘street maps’ that include land use and road layout.

2.6.3 CENTRALISED TRAFFIC MANAGEMENT SYSTEMS TO SUPPORT AVS

A centralised traffic management centre (TMC) that is apolitical and serves economic and the public’s best interests is critical to making best use of the available limited road assets in an AV future. Modern TMCs coordinate across transport modes, virtually or physically.

There are three key interrelated functions of a modern TMC:

- Network monitoring
- Incident management
- Proactive and dynamic demand management.

We also investigated recent agnostic VicRoads developments in this space (i.e. broader than roads) such as proactive congestion management, integrated network planning including roadworks / event management.

2.6.4 IMPLICATIONS OF MOBILITY AS A SERVICE INFRASTRUCTURE

Drawing on local and international colleagues’ learnings, we summarised enablers and barriers related to MaaS in Victoria, including integrated trip planning and payment, integration with current public and private transport, and options for non-technology users. We provided advice on the necessary infrastructure requirements for addressing them.

[20] WSP had limited access to technical information or infrastructure planning data for developing strategic cost estimates.

2.6.5 MAJOR URBAN INFRASTRUCTURE PLANNING IMPACTS

Based on the roadside infrastructure device requirements and internal WSP major projects experience, we produced recommendations for supporting roadside infrastructure.

2.6.6 CROSS-STATE OPPORTUNITIES AND RISKS

WSP compiled the following list of key cross-state issues, drawing on recent Austroads, road authorities, and international projects:

- Open Traffic Data agreements
- C-ITS Standards interpretation for national implementation
- Flexible C-ITS Central Operation System platform development for national implementation
- Integration of C-ITS Central Operation System into National ITS Architecture
- Database development for C-ITS I2X messaging
- Next generation Incident Management System
- Next generation Traffic Management System and Centre
- Data warehousing
- Geo-Relevant C-ITS Message Brokerage function
- Security Credential Management System
- GNSS terrestrial augmentation.

2.6.7 DATA COLLECTION, SHARING, PRIVACY AND SECURITY

To analyse the various data-collection requirements for facilitating AV adoption in Victoria, WSP invited input from various industry experts including Cisco and AWS (Amazon). WSP collated their input, as well as insights provided by ITS and global digital consulting businesses. Most discussions focussed on cloud and fog computing and its relevance to the AV rollout.

2.6.8 OTHER ENABLERS AND BARRIERS

We compiled an initial list of enablers and barriers from similar reports and research papers on the topic, and discussed these in an internal WSP workshop with key staff. We expanded on the highlighted workshop outputs for this document.

2.7 DATA PROVIDED TO THE CONSULTANT

WSP received the following information from Infrastructure Victoria:

- Future scenarios April 2018 – Advice on automated and zero emissions vehicles infrastructure
- Strategic modelling of network use by KPMG.

WSP obtained the following information from stakeholders to determine or support our findings:

- VicRoads (roadside devices, road network hierarchy)
- ACMA (cell tower locations).

…did we receive any cost information from any external source…?

3 SCENARIOS, USE CASES AND FUNCTIONS

3.1 SCENARIO EVALUATION

IV provided seven scenarios based on various vehicle types, fleet composition, take-up rates and energy sources. Electric non-AV, ZEV and hydrogen scenarios either do not require additional ICT infrastructure, or have the same requirements as another scenario. These assumptions are explained in Appendix B.

This process reduced the effective number of scenarios from seven to the following five:

— Private drive (very high private AV use)
— Fleet street (very high shared AV use)
— Slow lane (slow AV take up rate)
— High speed (fast AV take up rate)
— Dead end (Base case, no AV, effective over-investment risks).

To evaluate each scenario, we considered a range of factors based on their likelihood of affecting government's ICT investment and rollout. The following factors were assessed, and presented for discussion in a workshop with IV on 5 April 2018.

1 Physical road network use:

 a Private drive highest, Fleet street moderate, Slow lane and Dead end similar levels to today. High speed would have rapid uptake and moderate-to-high use
 b High variability across road use scenarios, therefore high risk to government getting investment wrong, particularly by underinvesting. Need to carefully assess potential impacts.

2 Road pricing model

 a Consistent across all scenarios. Minimum scenario has no road pricing; optimum scenario has road pricing.

3 Data use per vehicle

 a Generally moderate-to-high impact, apart from Dead end where there is no change
 b Reinforce the need to assess future bandwidth requirements to support big data, IoT, etc. Present across most scenarios.

4 Mode-use changes (such as public vs private)

 a ICT will need to support a range of scenarios. The key risk associated with a significant increase in pedestrians and cyclists is catering for pedestrians and cyclists in scenarios requiring communication between ICT systems.

5 Urban-, regional- and rural-specific impacts

 a Take up in rural and regional centres will lag take up in metropolitan Melbourne/Geelong – a continual issue
 b Include a broad range of factors when assessing future regional ICT investment to promote uptake of AV services.

6 Management of edge cases e.g. roadworks, low quality road infrastructure and incidents

 a All scenarios require an authoritative single-source database and/or current road and ICT infrastructure availability
 b Key issue(s) to be considered

7 Mapping and positioning

- **a** All scenarios will require, as a minimum, lane level accuracy
- **b** Key area(s) of investment

8 Impacts on centralised ICT support infrastructure

- **a** Will range from low to high
- **b** As with road use assessment, the high variability across scenarios represents a high risk of government getting the investment wrong (including underinvestment). Need to carefully assess potential impacts.

9 Impacts of ICT infrastructure changes on safety

- **a** All scenarios will enter a phase where there is a mix of different transport modes and technologies. This represents the biggest risk for slow lane due to the prolonged uptake presence of unconnected vehicles in the fleet
- **b** Challenges of marrying up ICT requirements with other government policies, i.e. Vision Zero and Safe Systems
- **c** Identifying what's needed to ensure Vision Zero/Safe System with the future mix of technologies
- **d** Key risks from impacts will need integration across road safety and AV rollout planning

Refer to Appendix B for detailed analysis.

Beyond the specified scenarios, IV and WSP discussed the definitions of minimum and optimum infrastructure investment, and established the following:

Minimum level of ICT infrastructure investment:

- Emphasises safe operation over efficiency or economic benefits
- Provides minimum possible ICT infrastructure to still ensure safe AV operation on critical Victorian roads
- Minimises all over-investment or technical obsolescence risks
- Ensures Victoria is not disadvantaged compared with other states or countries.

Optimum level of ICT infrastructure investment incorporates the minimum levels, while:

- Emphasising economic benefits, networks efficiencies, and best use of existing assets.
- Promoting a more effective and holistic transport network management approach.
- Ensuring vehicles can run optimally for most trip distances
- Ensuring opportunities are not missed due to lagging investment.

3.2 USE CASES

This process provided clarity in working through each user's requirements with most of the learnings detailed in Appendix C.

The following use cases are not intended to completely represent interactions between users and infrastructure, but to illustrate examples of likely interactions, and capture these within each functional scenario.

3.2.1 PRIVATE USE VEHICLES (SAE LEVEL 4 OR 5)

'Private use' refers to an AV that is owned, leased or rented for full private use. It might be owned by a family or leased from a corporation and used to run errands, take children to care or sports practice, take the family away for a weekend or holiday. It might be owned by a business for site visits, ad hoc deliveries, client meetings, and take one or more employees home at night.

The vehicle is classified as having a Level 4 or 5 SAE automation. For assessing ICT infrastructure requirements, the vehicle fuel source has minimal impact beyond the availability of charging/refuelling stations and the vehicle providing directions.

Communications combine Wi-Fi at a base station, cellular while moving and interacting locally with nearby vehicles, and active infrastructure (V2V, likely DSRC or C-V2X or similar 2046 technology).

Its location accuracy will be appropriate for allowing the vehicle to quickly find itself within a digital map.

INTERSECTION SCENARIOS

As a vehicle approaches an intersection, the vehicle's electronic map (downloaded that morning) communicates the intersection's physical layout. A 3rd party map provider (probably included in the vehicle manufacturer's service) provides information layers and map updates in 2km tiles, including this intersection. The map reports some permanent works with a left lane closure on this intersection's departure side, which the vehicle starts planning to avoid by moving to the right lane.

As the vehicle approaches the intersection, it uses V2V communication and wider locating sensors to interact with other vehicles and adjust speed and position. It notes any changes in expected landmarks (e.g. traffic signs), and reports them back to the map provider.

The traffic signals 'message' the vehicle over DSRC, informing it of signal phasing. The vehicle calculates time needed to get through the green phase, finds it is unable to safely do so and starts decelerating for the red phase. On-board image recognition confirms the information provided. (If the traffic signals are not transmitting over DSRC, the vehicle may be able to access less-timely information through the cellular network and will likely gracefully degrade to a more conservative driving posture.)

The vehicle registers a green light and starts entering the intersection, but a vehicle travelling on the cross road runs the red light. The vehicle and others register this dangerous action, transmit the information to the traffic signals V2I, whereupon all vehicles at the intersection are alerted and respond.

BETWEEN INTERSECTIONS SCENARIOS

The vehicle progressing on a pre-determined route gets information in 2km tiles that carry[21]:

- Road geometry, a 3-dimensional vector map of curves, alignments and intersections used to calculate appropriate speeds
- Lane designation and dimensions, including preferred lanes for smooth travelling and making intersection decisions
- Route landmarks such as poles, signs and structures to help the vehicle locating itself on the road network
- Layers of information such as incidents, roadworks and other vehicles.

The vehicle registers that a traffic sign is not located within the map as expected and notifies its 3rd party mapping company. When enough vehicles confirm the change in the digital landscape, the mapping company will update the map accordingly.

A car crash has occurred in the right lane a kilometre up the road. The vehicles involved transmit alerts via V2V and V2X; the Central Operation System has also detected issues (alerts, congestion etc.) and sends information via cellular network to mapping companies or other data mapping services.

Emergency roadworks are set up. Despite not being scheduled in the network database that morning, they are automatically registered as they are set up. Traffic management vehicles have mandatory V2V capability to transmit information about the roadworks (recommended speed, closed lanes, etc.). The vehicle travels in a conservative posture through the construction site.

An ambulance has pulled into the left lane to run into a house. Its automatically-configured V2V device informs all nearby AVs of its location and the closed lane, so that all vehicles behave appropriately as they approach the ambulance.

---

21 Discussions with HERE Maps May 2018.

NETWORK SCENARIOS

While at its home or business base station, the vehicle is connected via high speed WiFi internet. It routinely updates a digital map with that day's conditions, incidents and roadworks (likely provided and curated by a 3rd party provider and managed by the vehicle's OEM).

Centralised systems provide up-to-date information on the chosen route. The car processes that information, detects delays and determines a more efficient route. (In an optimal scenario, a centralised authority may be more proactive in encouraging or discouraging routes. This will have minimal ICT infrastructure impact.)

Road pricing is likely to be through either C-ITS or as an additional service provided by the vehicle's OEM. This will use data available through the cloud networks.

SCENARIO-SPECIFIC

High Speed – potential issues involve ensuring policy, regulation and supporting ICT infrastructure is operational in time.

Rural context (in general) – private vehicles will most likely need to run in a 'degraded' state on road network links not covered by cellular networks.

3.2.2 NON-COOPERATIVE VEHICLES (LEVEL 3 OR BELOW)

Non-cooperative vehicles could operate with a cellular connection that provides trip information related to incidents, travel time and route selection.

Industry opinion is divided on whether these vehicles may have to retrofit a device that allows them a limited level of integration with AVs and the wider network. There is little research on this, and what exists is not strong.

Non-cooperative or low-level connected vehicles will be observed and reported on by existing road infrastructure (e.g. vehicle detectors) and connected vehicles. The infrastructure and other vehicles would report to connected vehicles on incidents or at-risk behaviour.

SCENARIO-SPECIFIC

This vehicle type is only relevant in the context of the 'Dead end' and 'Slow lane' scenarios. The vehicle will likely use centralised systems similar to today's small-scale implementation.

3.2.3 PUBLIC TRANSPORT (BUS ONLY, PUBLICLY OPERATED)

From an ICT infrastructure perspective, public transport will be automated and interact like AVs. There may be some additional connectivity with pedestrian and other end users. This vehicle type may rely on LIDAR for fine positioning around bus stops, but are unlikely to need additional locational accuracy.

INTERSECTION SCENARIO

V2I connectivity is more likely to give buses priority green-time at intersections, particularly in the Fleet street scenario.

SCENARIO-SPECIFIC

Rural context (in general) – desktop review of rural public transport routes appears to be limited to inter-town trips on M, A or B class roads or within the town boundary themselves. Both scenarios would need to be covered by the proposed minimum level of cellular network coverage. This has safety and efficiency benefits.

3.2.4 SHARED FLEET SERVICES

As with public transport, shared fleet services may have slightly-increased centralised connectivity for optimised customer service. This would be predominantly privately-owned and managed.

SCENARIO-SPECIFIC

Rural context – market size will likely mean Private drive and Slow lane scenarios will need additional shared fleet services.

3.2.5 FREIGHT

This user includes long and short distance freight and potentially freight platoons.

Most AV freight usage, from an ICT infrastructure perspective, is similar to that of AVs. There is a potential for a small increase based on fleet management or other optimisation tools that could be developed.

NETWORK

While there is some debate over platooning, whereby several vehicles (usually trucks) travel in close succession, it does not appear to impact ICT infrastructure.

SCENARIO-SPECIFIC

Freight vehicles within the rural context would benefit from increased cellular coverage. It would improve responsiveness to late changes (e.g. immediate re-routing to pick up a package), and increase awareness and response to incidents on the vehicle's planned route. From a desktop survey, Victorian principal freight routes[22] are limited to M, A and B class roads.

3.2.6 MOTORCYCLISTS

Motorcycles connected with V2V or V2X or V2I capability would connect similarly to AVs. Based on current policy and industry attitudes towards safety, any system will be passive to minimise potential rider distractions. ICT infrastructure impact is likely minimal. This assumption is based on recent experience implementing the Australian Integrated Multimodal Ecosystem trial.

3.2.7 CYCLISTS & PEDESTRIANS

In an optimal scenario, cyclists and pedestrians would passively broadcast their location and planned route so AVs could adjust their behaviour to provide maximum protection. We assume that, in scenarios with high proportions of AV use, cyclists on key road transit routes would choose to opt into some form of passive integration.

Pedestrians would also be protected from anonymised monitoring (by passing vehicles), or when they are near roadside C-ITS infrastructure.

INTERSECTION SCENARIOS

Some current V2I field devices (Cohda) track Wi-Fi signals and relay that information to local connected vehicles. The ICT infrastructure impact is minimal. However, it would be desirable to prioritise ensuring roads with high levels of vulnerable road users (cyclists and pedestrians) have V2I integration in the minimal case, in addition to the critical metropolitan and regional intersection traffic signals that the minimal scenario would see implemented.

---

[22] http://maps.infrastructure.gov.au/KeyFreightRoute/index.html

SCENARIO-SPECIFIC

In the optimal scenario, additional image recognition or other methods could help detect pedestrians or cyclists. This would be particularly beneficial in areas with poor safety records for vulnerable road users.

3.2.8 EMERGENCY SERVICES VEHICLES

Emergency vehicles generally interact with infrastructure the same as normal AVs, but traffic signals and other vehicles are sent stronger directions to prioritise emergency services vehicles and ensure their unfettered access.

SCENARIO-SPECIFIC

Using V2I or cellular network-controlling infrastructure such as traffic signals, other vehicles are made aware of a fire engine travelling north on Sydney Road, Brunswick towards its Coburg destination. Emergency services highly prioritise this. The network then creates a priority traffic signal route. In the future, vehicles on a freeway without emergency lanes may be forced out of a lane to provide access.

A fire engine must turn west earlier than expected due to congestion that wasn't freed in time. As it approaches traffic signals, they respond through DSRC/V2I and give the fire engine priority.

Within the Slow lane scenario, a fleet with higher percentage of non-connected vehicles will have a negative impact on emergency vehicles' ability to proactively move through traffic.

3.2.9 CENTRAL OPERATORS

Transportation network management styles follow different philosophies moulded by tangibles such as government policy, long-term land use planning, or agnostic public funding (or lack of), and intangibles such as public perception or culture. In Victoria, the road network has been strongly managed with technology with world-leading results[23]. We have assumed this proactive network management approach is maintained.

Proactive network management includes authority to control and optimise the network, including traffic signals, ramp control signals and lane control signs usually reacting to incidents, road works, or congestion.

Many organisations, public and private, will need various levels of access to the information generated or required by AVs.

With modern cloud-based database technologies (such as federated databases) sharing relevant information, it is now relatively straightforward to balance usability with security and privacy. Complications will mostly revolve around authorisation and definitions of 3rd party data versus 'official' data.

SCENARIO-SPECIFIC

For the minimal scenario, central operators will likely continue the current policy of proactively managing critical road network links (freeways and metropolitan Melbourne's approximately 15 arterials) and continue taking a more passive role on the low-volume network links.

For the optimal scenario, operators will likely expand their proactive network management to incorporate the rest of Melbourne and Geelong's arterial network. Increased funding will be needed mostly for control system features, such as incident detection, with machine learning and operators to optimise and manage the network.

A cloud database environment's flexibility strongly supports the scenarios whereby we assess extremes of either fleet or private vehicle usage, to reduce the risk of overinvestment and lagging user demand.

[23] Motorway Design Volume Guide December 2017 – VicRoads

The reduced level of vehicle information available to network operators and unrealised safety benefits means that Slow lane, compared to other scenarios, will need a higher resourcing level to manage the complex mix of vehicle types over a longer period.

3.2.10 ACTIVE ROADSIDE INFRASTRUCTURE

Active roadside infrastructure is any active on-road vehicle control system, such as (permanent or temporary) traffic signals, lane control signs or variable speed signs. Ideally, AVs travelling near active roadside infrastructure will be able to communicate and understand the critical information provided. A vehicle travelling towards a traffic signal queries the signal's current and planned phasing (red, amber or green). It does this via cellular network to the traffic signal control system, or directly via a V2I device.

INTERSECTION

Traffic Signals control all Victoria's critical high-capacity arterial intersections. A direct V2I device solution for critical sites would provide a minimal optimisation level. Optimal coverage would come from increasing the rollout of V2I devices to also cover all intersections and locations with poor vulnerable road user safety records.

BETWEEN INTERSECTIONS

Lane Use Management and Variable Speed Limit signs would benefit less from V2I devices. Speed zone control and lane conditions (closed, merge, or no change) are not modified fast or often and could easily be communicated via cellular network. These devices are invariably installed in locations with cellular network connection, either from urbanisation or because existing electronic speed signs use cellular communication.

SCENARIO-SPECIFIC

There is a significant over-investment risk for the 'Slow lane' and 'Dead end' scenarios. It is difficult at this stage to even determine the protocol Australian V2I devices will use, with DSRC and C-V2X the current main challengers. No state wants to be the Betamax Video of AVs. WSP recommends an extended industry liaison period before committing to any V2I rollout funding.

3.2.11 PASSIVE ROADSIDE INFRASTRUCTURE

Passive roadside infrastructure includes traditional ITS devices that provide information to road users, such as travel time, incidents, roadworks and alternative route conditions. These will obviously be replaced in the future by integrated information customised to each end user.

However, in a mixed vehicle environment these devices will be needed longer than is currently planned. Removing one of the few available options for communicating with non-connected vehicles will likely lead to suboptimal network management and disgruntled end users.

SCENARIO SPECIFIC

The Slow lane scenario will require a longer period for devices to be built and maintained, particularly with an average 10-year life span. The High-speed scenario will have the opposite effect.

3.2.12 ROADWORK SITES

For roadworkers and the public, roadworks (or any temporary activity impacting normal road use) represent one of the highest risk work and transport environments.

Current controls include physical protection (bollards, flashing signs and trucks) and route planning information (Google maps and advanced electronic message signs).

The State already operates, in one format or another, an integrated and resilient system of registering and managing roadworks linked to mapping systems. However, work is needed to ensure traffic control companies comply. An automated traffic management system for vehicles entering and leaving a proposed work zone could create further efficiencies.

Linking the roadworks to the map tile is reasonable for the minimal scenario. A more direct onsite interaction would confirm accuracy and assure compliance. This could be achieved by attaching V2I devices to traffic control devices or truck mounted attenuators that provide vehicles nearby with positioning and status information. It would involve mandating the cost to traffic management companies, likely to be less than $5,000 per vehicle[24], which government could subsidise.

Having a wide cellular network coverage in rural areas will increase safety and network efficiency by enabling increased awareness between vehicles and roadwork sites and allowing vehicles to operate optimally (as opposed to operating in a degraded mode and relying on V2I interactions).

INTERSECTION SCENARIO

A V2I device that is integrated with traffic signals has an updated lane availability schematic due (for example) to construction on the north approach. The vehicle changes lanes and reduces speed to avoid the roadworks.

BETWEEN INTERSECTIONS

As you travel along a network link between intersections, the map updates the tile (via the cellular network) with emergency roadworks in the left lane. Your map updates and the car safely merges into the right lane. The vehicle changes lanes and reduces speed, avoiding the roadworks.

3.2.13 LARGE SCALE EMERGENCIES

Emergencies could include bushfires, floods or terrorism. As a minimum, road network operators would rapidly and efficiently inform road users of risks on planned routes. Optimally, operators would wish to electronically ‘close’ network routes or intersections, and force AVs to use other routes without having to send often over-stretched emergency services to maintain a blockade or detour.

The strongest enabler for proactively managing such large-scale emergencies is cellular network coverage and capacity.

3.3 FUNCTIONAL ANALYSIS

We describe how each use case operates technically, the data generated, the ICT infrastructure required and technology needed.

3.3.1 NETWORK CONNECTIONS

Figure 3.1 depicts the functional analysis showing most of the use cases for ICT infrastructure, the physical relationships between each, and the communication connection needed to enable CAVs in the year 2031 and beyond. This will rely on multiple communication networks operating in the same geographical space, possessing different functionality, and providing a combined and cohesive communication system to enable AVs. See Functional Analysis – 3.3 for a detailed functional analysis of each use case.

24 Based on implementation cost of similar roadwork site management technologies (break in FM/UHF radio systems)

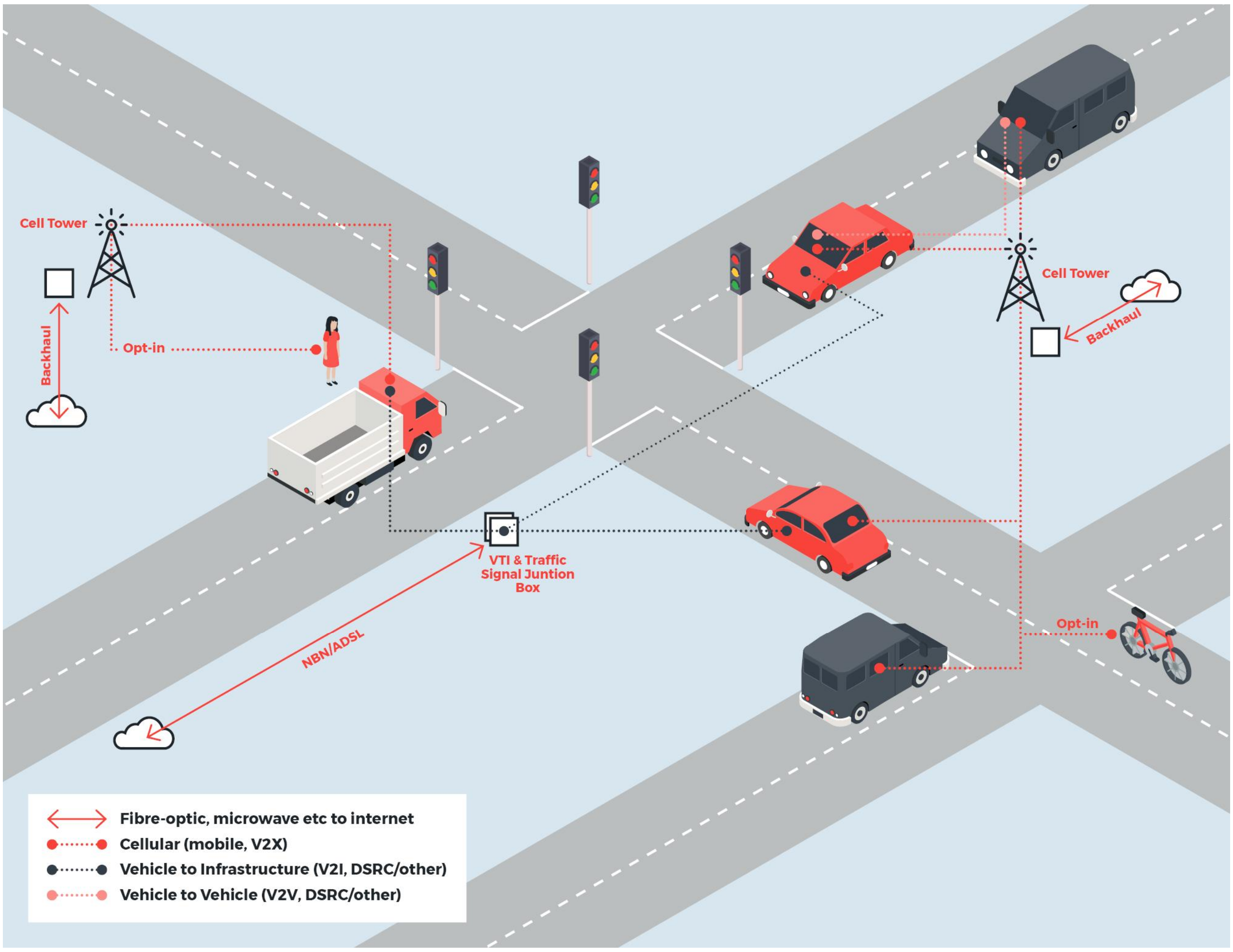


Figure 3.1 Potential network connections between end users and infrastructure

3.3.2 CONNECTED, COOPERATIVE, ELECTRIC AND HIGHLY AUTOMATED ROAD VEHICLE INTERACTIONS

Further to Section 1.5 – Vehicle Definitions, we need to consider the interaction between elements of 'New Mobility' and how best to implement solutions and maximise the benefits for future communities. Key elements include Connected and Automated Vehicles (CAV), Electric Vehicles (EV), connected vehicle communications, road and transport pricing models, Mobility as a Service (MaaS) and vehicle sharing outlined in Figure 3.2.

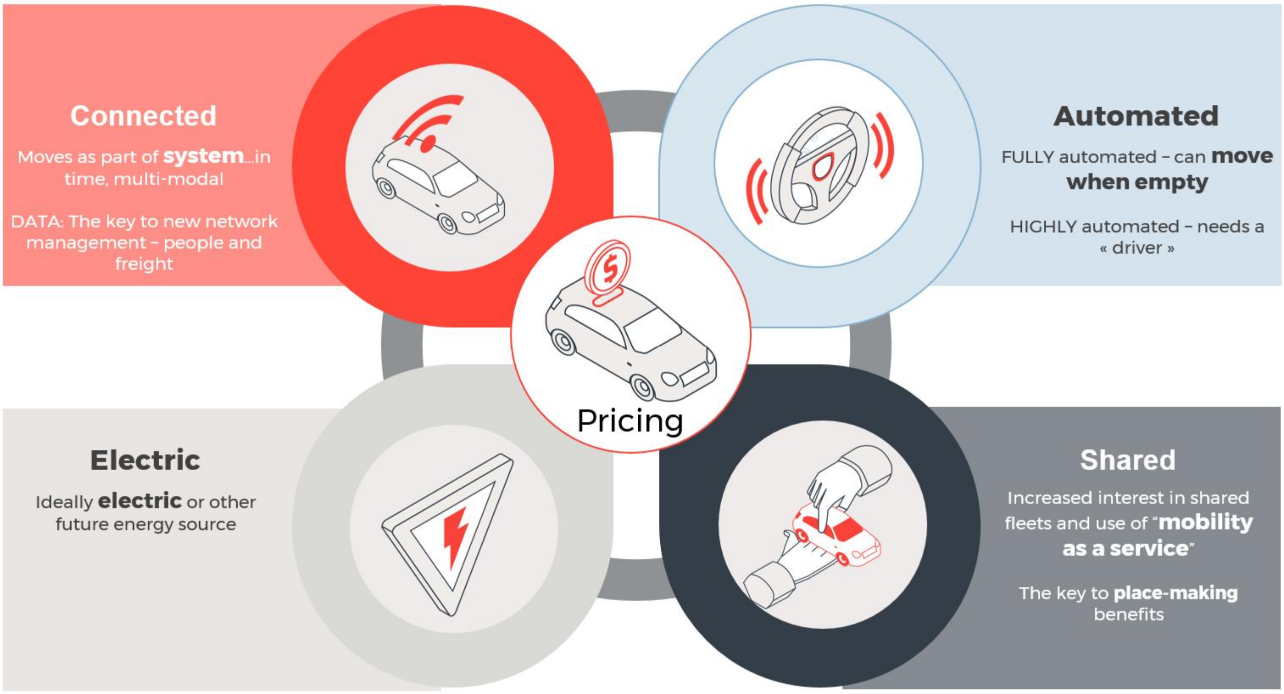


Figure 3.2 New Mobility – WSP

This diagram's central pillar relates to business models and understanding of use needs and how best to influence behaviour changes. This isn't just about road pricing or road user charging. With the right information and incentives, we have an opportunity to influence user behaviour over time. Business models offer an opportunity to unlock the technology benefits sooner, e.g. if car sharing and MaaS are successful, there will be fewer privately-owned vehicles and more fleet vehicles. These will turnover sooner and adopt higher levels of automation, which can lead to earlier AV-related safety benefits.

KEY FUNCTIONS TO SUPPORT ZEVS AND AVS

Comnmunication and Positioning are the two key digital infrastructure functions needed for supporting ZEVs, AVs and other related system deployments. The needs of each will be determined by use case, and can be considered in two broad categories:

SAFEY CRITICAL

— Low latency: Subsecond safety systems such as peer-to-peer information being shared as part of cooperative systems
— Higher latency: non-real-time activities where data transfer within a few seconds (as a minimum) would be acceptable. Examples include providing information on upcoming roadworks or road surface condition.

NON SAFETY CRITICAL.

— These are all higher latency activities – non-immediate and non-safety-critical aspects of vehicle operation. Examples include mapping data updates and vehicle performance or condition logs.

COMMUNICATION

CAVs will need a range of ICT technologies and supporting infrastructure to be able to communicate with:

— Mobile Network Operator (MNO) towers
— Roadside infrastructure such as Traffic Signal Controllers and Tunnel systems (V2I)
— Other vehicles including motorbikes, freight vehicles and light rail and devices carried by people (V2V, V2P).

For safety, CAVs will all need to be connected to the outside world for communication with the vehicle manufacturer/mapping provider and possibly fleet operator via MNO telecommunications towers as a minimum. (See

Section 4.2) At a minimum the existing MNO telecommunication towers can provide this connectivity. However, CAV operation will be limited to the existing coverage areas (i.e. limited in rural areas). Optimally, additional MNO telecommunication towers are installed to ensure sufficient coverage on all sealed roads, urban or rural.

For safety-critical, low-latency functions, 5.9GHz DSRC or C-V2X peer-to-peer telecommunications are the only suitable current communication technologies being investigated. CAVs do not rely on V2V communication to operate, with V2V providing additional efficiency benefits, effectively allowing vehicles to 'see' around corners. We expect the need to incorporate ICT Infrastructure at intersections, tunnels, bridges and other critical infrastructure as a minimum. Optimal implementation would provide V2I connectivity at all road network locations. Adding V2V technology will further increase efficiency.

Additional analysis can be found in Appendix D - Communication networks for CAVS.

NAVIGATION AND POSITIONING

Identifying vehicle locations on our networks is crucial for network operation both at a network level (movement and place) and at a micro level (the vehicle's lane, and distance from other vehicles, pedestrians etc.). This topic is still developing with increasing literature and discussion on the subject (refer to Austroads AP-R431-13 for additional information). When considering CAV positioning systems, accuracy describes navigation performance requirements, but there is far more to discuss.

CAV positioning will need to consider not only accuracy but also integrity, continuity, availability, timeliness and interoperability[25], and not only horizontally (what lane) but also vertically (altitude to determine carriageways, stacked underpasses and overpasses, and compromised GNSS signals). CAVs also require an internal clock synchronised with the Central Operation System and all other CAV clocks nearby. Current thinking is that CAVs will use the common GNSS clock to synchronise their internal clock, highlighting the GNSS signal's importance to CAV operation.

The level of positioning accuracy and timeliness required for CAV operation will vary, determined by the application, the level and type of augmentation or alternative navigation methods employed, and the situation (i.e. location and external factors such as block or lost GNSS signals). Austroads AP-R431-13 provides guidance on the initial requirements for positioning accuracy and timeliness based on the application type. CAV operation requires minimum positioning accuracy of 0.7m or better for a "Where-in-lane-level" accuracy with 95% confidence and 0.01 – 0.1 second latency. Depending on the application, the Research prototype indicates CAVs may require higher positioning accuracy to one of three levels: road-level (sub-metre), lane-level (decimetre) and where-in-lane-level (centimetre). To achieve this under all circumstances, CAVs will need to employ a hybrid approach to navigation within the vehicle. It will combine GNSS with Satellite Based Augmentation Systems (SBAS) and other terrestrial-based augmentation systems, as well as positioning information from vehicle sensors and roadside telecommunications infrastructure.

Based on Austroads AP-R431-13, optimum positioning accuracy is therefore in the centimetre range. Funding announced in the (May 2018) Federal Budget[26] will help create a more accurate satellite-based positional navigation and timing capability to enhance the current GPS capability. This funding will deliver positioning accuracy of three to five centimetres in regional and metropolitan areas with mobile phone coverage, and up to 10 centimetres elsewhere.

Figure 3.3 outlines an example of an in-vehicle hybrid approach to achieving enhanced positioning accuracy for an AV. The diagram shows a process within the vehicle, referred to as localisation, which relies on vision-based sensors and global positioning systems to provide enhanced positioning.

---

25 Austroads AP-R431-13

26 https://www.businessinsider.com.au/federal-government-2018-gps-accuracy-2018-5

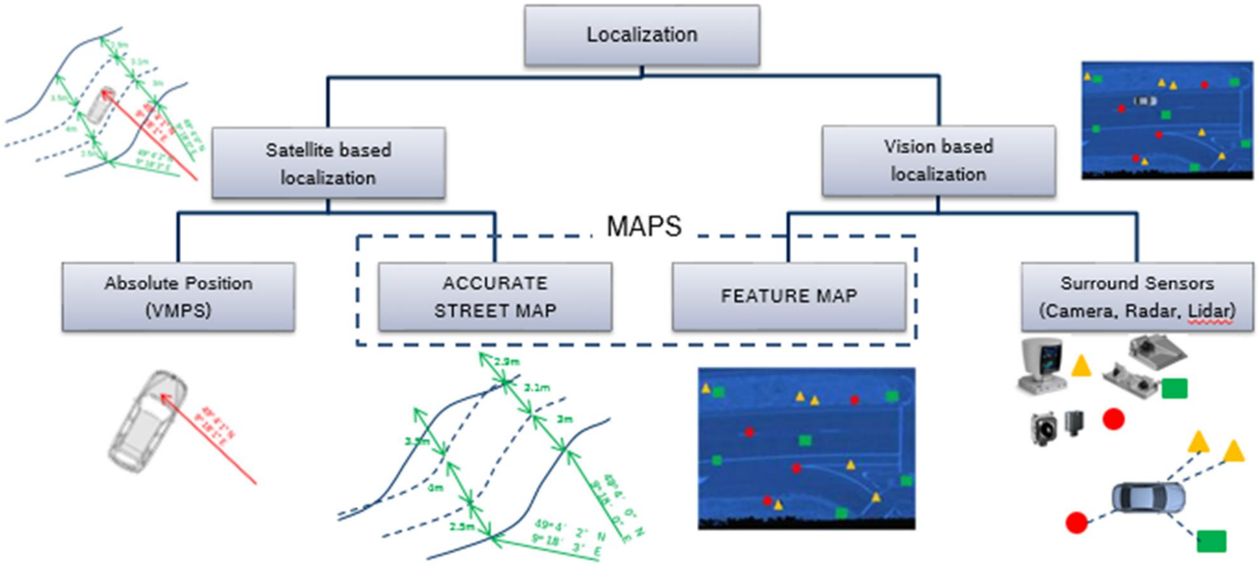


Figure 3.3 AV use of locations to determine position – Developed by Bosch (Austroads)[27]

Additional positioning augmentation will be needed in special situations, such as in-tunnel environments where GNSS as a primary positioning source is not viable. In this case, they will need positioning from other sources such as C-ITS RSUs, cellular, Bluetooth or Wi-Fi telecommunications infrastructure to augment the AV's on-board sensors, and provide adequate lane-level positioning for highly automated operations. Among the potential solutions currently being trialled, are:

— Waze & Bluvision – several trials are currently underway, each using special bluetooth beacon technology for positioning in a tunnel environment. It currently only works with the Waze App but will likely work with Google navigation[28].

— U-Blox – has embedded the cellular positioning technology CellLocate® into several of its 2G, 3G and 4G modules. The technology uses the CellLocate® service to provide the modem with a location estimate, based on its observations of the surrounding cellular base-station signals. This helps the GNSS receiver and provides an approximate fall-back positioning solution, where no other is available. However, the CellLocate® service is not in widespread use in GNSS devices[29].

— Ultimately 5.9Ghz C-ITS Roadside and Vehicle communications will also become part of the positioning mix to provide the required accuracy in tunnel environments (or other situations where GNSS signals are not available or are inaccurate). Codha Wireless is currently trailing a proprietary 5.9GHz V2X-Locate solution based on their Roadside C-ITS units[30].

3.3.3 VULNERABLE ROAD USERS

Vulnerable Road Users (VRUs) include pedestrians and cyclists. VRUs could communicate with Level 4/5 CAVs by opting to share their mobile phone information via apps operating in conjunction with the C-ITS environment. This information is expected to include location and general status and will be sub kilobyte (kB) throughput. It would be transmitted using the MNO wireless 3GPP telecommunication networks and could incorporate 5.9Ghz DSRC. VRU information could be shared with Level 4/5 CAVs through the MNO network and potentially relayed through V2V networks to ensure Level 4/5 CAVs are aware of the VRUs' travel direction, speed and location. Level 4/5 CAVs could

27 https://wiscav.org/wp-content/uploads/2017/05/Austroads-Road_Agencies_Support_for_AVs.pdf
28 www.blog.nordicsemi.com
29 https://www.u-blox.com/en/celllocate-enhance-gnss-positioning-indoors-0
30 http://www.cohdawireless.com/updates/press-releases/world-first-cohda-system-beats-gps-blackspots/

also detect VRUs through their on-board sensors, but this relies on the VRUs being within sensor range. VRUs who are sharing their information will allow the Level 4/5 CAV systems to plan and determine when and where they might encounter a VRU. VRUs will not require any extra ICT Infrastructure to what's available or provided for Level 4/5 CAVs, but they will need improved location technology, such as that for Level 4/5 CAVs. VRU trials have been happening throughout the world to understand how V2P and Vehicle-to-Cyclist (V2C) communications can function. In Australia, research is conducted by companies such as Telstra and Cohda Wireless[31].

3.3.4 DISCONNECTED AND HUMAN-DRIVEN VEHICLES

The introduction of Level 4/5 CAVs will be phased. There will be times where Level 4/5 CAVs will be sharing the road with non-cooperative and non-automated or low-level automated vehicles. There may even be a scenario where Level 4/5 CAV technology never progresses to the mission-critical capability it needs for success. To allow for Level 4/5 CAVs, ICT Infrastructure would not need to develop further than what low-level CAVs require. Network speeds, bandwidth and technology will not need to develop, other than to provide sufficient bandwidth for vehicle passengers to use their mobile phones. C-ITS RSUs will not be needed and neither will mission-critical MNO wireless networks. GNSS is still likely to improve, as its advantages stretch across many industries. While non-cooperative and non-automated or low-level automated vehicles remain on the road, today's roadside traffic management infrastructure will need to remain operational.

3.3.5 ROADSIDE INFRASTRUCTURE (ACTIVE & PASSIVE) & MAINTENANCE SITES

Roadside Infrastructure (active and passive) and Maintenance Sites (RIMS) (mobile and immobile) will be crucial elements of the ICT Infrastructure to enable Level 4/5 CAVs.

RSUs will be positioned at critical points in the road network including traffic control signals, intersections and tunnels. RSUs may be implemented in two forms: active RSUs that plan and co-ordinate navigation of a certain area, and passive RSUs that act as a repeater to ensure an area's road users receive certain messages. Roadwork and Maintenance sites (mobile or fixed) can also act as temporary RSUs. They can provide information on their location and any road network changes they are causing, and may also act as repeaters to ensure road users in the surrounding area are receiving messages from others. RIMS will be able to share their locations and possibly help other vehicles determine their locations based on the RIMS' set location.

RIMS will use G5 (or DSRC)/C-V2X to communicate wirelessly with Level 4/5 CAVs, and will have backhaul connections via wired or wireless connections to the greater network. As to data creation, RIMS will repeat and share information provided by other road users, operators, and vehicle manufacturers, but will produce very little of their own data. The exception is the maintenance site case where they will share their locations and road changes data. RIMS will create minimal data that's included within the expected data figures for Level 4/5 CAVs.

RSU Stations will be needed at locations such as signalised traffic intersections. They will monitor (V2I) messages from C-ITS equipped vehicles and other mobile V2X devices moving through the intersection. They will send (I2X) Signal Phase and Timing (SPaT) information as well as intersection MAP and other information to C-ITS equipped vehicles and mobile V2X devices also approaching and moving through the intersection. This infrastructure will enable safety applications, such as Red Light Ahead warnings to approaching vehicles, Red Light Violation warnings to vehicles at risk, and Vulnerable Road User Crossing warnings (and the like). (Some of these Roadside C-ITS applications will become less important when non-CAV vehicles are no longer on the roads. When all vehicles are connected and operating cooperatively, they will talk directly with others nearby).

To provide the desired safety benefits, low-latency V2I and I2X telecommunications will be needed between Roadside C-ITS Stations, CAVs and mobile V2X devices. Supporting this operation will need direct peer-to-peer telecommunications via DSRC or C-V2X. The infrastructure needed at each intersection includes one or more C-ITS RSUs interfacing with the intersection's Traffic Signal Controller and associated supporting infrastructure.

Trials in V2I technology are happening around the world, and are testing several alternative RSU solutions.

---

[31] http://www.cohdawireless.com/updates/press-releases/telstra-and-cohda-wireless-successfully-trial-v2i-technology-over-4g/

3.3.6 CENTRAL OPERATION SYSTEMS AND LARGE-SCALE EMERGENCIES

AVs may reduce accidents and make travel safer, but alone they will not reduce city traffic congestion. Indeed, in their early deployment stages, AVs are likely to increase traffic congestion due to extra vehicles making trips into the city to drop passengers off or pick them up, or to parking locations outside the city. Central Operation Systems will be needed.

Central Operation Systems (COS) and Large Scale Emergencies (LSE) will communicate with each other to share critical information. The COS will then communicate with Level 4/5 CAVs about the LSE. LSEs such as natural disasters and acts of terrorism will need Central Operations Systems to coordinate with Emergency Services Vehicles to create unobstructed routes, detours and vehicle rerouting, and change signal phasing and timing to minimise vehicle obstructions. The COS will also gather information on the LSE and transmit this via the MNO network to roadside infrastructure, pedestrians and cyclists. The roadside infrastructure will then repeat this information to Level 4/5 CAVs, telling them the emergency-related actions to take. The information will be transmitted within regular communication messages between all road users, and captured within the transmit data values (see 3.3.7 – Data Creation and Sharing for CAVs). To facilitate this, the ICT Infrastructure will need mission-critical wired and wireless communications. The COS will likely receive LSE information through a wired connection via fibre or satellite network.

When there is no LSE, the COS's function remains the same. However, rather than transmitting emergency information, the COS will transmit traffic data, incidents, road pricing, mapping updates and scheduled road works. Messages transmitted will contain status data, positioning information updates, security certificate information and vehicle-specific messages. The COS will primarily use a wired fibre optic telecommunications network to receive information from third party mapping providers, vehicle manufacturers, security management systems, fleet operators and public transport operators. The COS will then transmit this information to roadside infrastructure and other road users through a mission-critical MNO wireless network, implementing QoS. The data sent across the wireless network will also be transmitted within the regular communication messages sent and received between all road users, and captured within the transmit data values (see 3.3.7 – Data Creation and Sharing for CAVs). Wired network transmissions will have little impact on the wired networks' bandwidth which will have sufficient capacity from 2031 onwards. With this wealth of knowledge, the COS will be able to control, authorise and optimise the network, and will likely move to future demand prediction and planning through machine learning and artificial intelligence.

3.3.7 DATA CREATION AND SHARING FOR CAVS

Data creation and transmission is crucial for CAV implementation. The tables below calculate the estimated data transmission totals for different driving scenarios, to indicate the total data generated on the network, data stored per month and stored per year.

Private Drive Scenario

Vehicle Types	Total Data Generated PV/PH (GB) {a}	Data Shared PV/PH (MB) {b}	Max # of vehicles per day (provided by MABM (State & Metro)) {c}	Data shared immediately (GB/hour) [V2I] {b*c*.001}={d}	Delayed data transferred to the third party (manufacturer/ operator) centralised systems (GB/hour) {c*(a*1%)}={e}	Max data transferred to vehicles (GB/hour) [I2V] {b*c*.001}={d}	TOTAL data generated on the network (TB/day) {(d+e+d)/1000}={f}	Data Stored (TB/month) {10%*f*30}={g}	Data stored (TB/year) {g*12*50%}
Private CAVs	25	10	643647	6436	160912	6436	174	521	3128
AV Freight	25	10	19633	196	9817	196	10	31	184
						TOTALS	**184**	**552**	**3312**

Note:
1. Vehicles drive an average 1 hour per day.
2. 1% for {e} is based on Tesla data download rates.

Fleet Street Scenario

Vehicle Types	Total Data Generated PV/PH (GB) {a}	Data Shared PV/PH (MB) {b}	Max # of vehicles per day (provided by MABM (State & Metro)) {c}	Data shared immediately (GB/hour) [V2I] {b*c*.001}={d}	Delayed data transferred to the third party (manufacturer/operator) centralised systems (GB/hour) {c*(a*1%)}={e}	Max data transferred to vehicles (GB/hour) [I2V] {b*c*.001}={d}	TOTAL data generated on the network (TB/day) {(d+e+d)/1000}={f}	Data Stored (TB/month) {10%*f*30}={g}	Data stored (TB/year) {g*12*50%}
Shared CAVs	25	10	413224	4132	206612	4132	215	645	3868
AV Freight	25	10	12605	126	6303	126	7	20	118
						TOTALS	221	664	3986

Note:
1. Vehicles drive an average 1 hour per day.
2. 1% for {e} is based on Tesla data download rates.

Hydrogen Highway Scenario

Vehicle Types	Total Data Generated PV/PH (GB) {a}	Data Shared PV/PH (MB) {b}	Max # of vehicles per day (provided by MABM (Metro Only)) {c}	Data shared immediately (GB/hour) [V2I] {b*c*.001}={d}	Delayed data transferred to the third party (manufacturer/ operator) centralised systems (GB/hour) {c*(a*1%)}={e}	Max data transferred to vehicles (GB/hour) [I2V] {b*c*.001}={d}	TOTAL data generated on the network (TB/day) {(d+e+d)/1000}={f}	Data Stored (TB/month) {10%*f*30}={g}	Data stored (TB/year) {g*12*50%}
Private CAVs	25	10	601511	6015	150378	6015	162	487	2923
AV Freight	25	10	18348	183	9174	183	10	29	172
						TOTALS	172	516	3095

Note:
1. Vehicles drive an average 1 hour per day.
2. 1% for {e} is based on Tesla data download rates.
3. Hydrogen Highway values based on Maximum Private vehicle (metro only) multiplied by a Conversion Factor of 1.476 (max conversion factor used in MABM spreadsheet), AV freight calculated by Total Freight %/(1-(Total Freight %))*Maximum Private Vehicle (Metro Only)*AV Freight percentage.

Slow Lane Scenario

Vehicle Types	Total Data Generated PV/PH (GB) {a}	Data Shared PV/PH (MB) {b}	Max # of vehicles per day (provided by MABM (State & Metro)) {c}	Data shared immediately (GB/hour) [V2I] {b*c*.001}={d}	Delayed data transferred to the third party (manufacturer/operator) centralised systems (GB/hour) {c*(a*1%)}={e}	Max data transferred to vehicles (GB/hour) [I2V] {b*c*.001}={d}	TOTAL data generated on the network (TB/day) {(d+e+d)/1000}={f}	Data Stored (TB/month) {10%*f*30}={g}	Data stored (TB/year) {g*12*50%}
Shared CAVs	25	10	191817	1918	95909	1918	100	299	1795
Private CDVs	5	0	282951	0	0	0	0	0	0
AV Freight	25	10	7241	72	3621	72	4	11	68
Non-AV Freight	25	0	7241	0	0	0	0	0	0
						TOTALS	104	311	1863

Note:
1. Vehicles drive an average 1 hour per day.
2. 1% for {e} is based on Tesla data download rates.

High Speed Scenario

Vehicle Types	Total Data Generated PV/PH (GB) {a}	Data Shared PV/PH (MB) {b}	Max # of vehicles per day (provided by MABM (State & Metro)) {c}	Data shared immediately (GB/hour) [V2I] {b*c*.001}={d}	Delayed data transferred to the third party (manufacturer/operator) centralised systems (GB/hour) {c*(a*1%)}={e}	Max data transferred to vehicles (GB/hour) [I2V] {b*c*.001}={d}	TOTAL data generated on the network (TB/day) {(d+e+d)/1000}={f}	Data Stored (TB/month) {10%*f*30}={g}	Data stored (TB/year) {g*12*50%}
Shared CAVs	25	10	413224	4132	206612	4132	215	645	3868
AV Freight	25	10	12605	126	6303	126	7	20	118
						TOTALS	**221**	**664**	**3986**

Note:
1. Vehicles drive an average 1 hour per day.
2. 1% for {e} is based on Tesla data download rates.
3. High Speed Scenario based on Fleet Street numbers.

Dead End Scenario

Vehicle Types	Total Data Generated PV/PH (GB) {a}	Data Shared PV/PH (MB) {b}	Max # of vehicles per day (provided by MABM (State & Metro)) {c}	Data shared immediately (GB/hour) [V2I] {b*c*.001}={d}	Delayed data transferred to the third party (manufacturer/operator) centralised systems (GB/hour) {c*(a*1%)}={e}	Max data transferred to vehicles (GB/hour) [I2V] {b*c*.001}={d}	TOTAL data generated on the network (TB/day) {(d+e+d)/1000}={f}	Data Stored (TB/month) {10%*f*30}={g}	Data stored (TB/year) {g*12*50%}
Private CAVs	5	0	694799	0	0	0	0	0	0
Non-AV Freight	5	0	21193	0	0	0	0	0	0
						TOTALS	**0**	**0**	**0**

Note:
1. Vehicles drive an average 1 hour per day.
2. 1% for {e} is based on Tesla data download rates.

Electric Avenue 'non-connected' Scenario

Vehicle Types	Total Data Generated PV/PH (GB) {a}	Data Shared PV/PH (MB) {b}	Max # of vehicles per day (provided by MABM (State & Metro)) {c}	Data shared immediately (GB/hour) [V2I] {b*c*.001} ={d}	Delayed data transferred to the third party (manufacturer/operator) centralised systems (GB/hour) {c*(a*1%)} ={e}	Max data transferred to vehicles (GB/hour) [I2V] {b*c*.001} ={d}	TOTAL data generated on the network (TB/day) {(d+e+d)/1000} ={f}	Data Stored (TB/month) {10%*f*30} ={g}	Data stored (TB/year) {g*12*50%}
Private CAVs	5	0	686017	0	0	0	0	0	0
Non-AV Freight	5	0	20925	0	0	0	0	0	0
						TOTALS	**0**	**0**	**0**

Note:
1. Vehicles drive an average 1 hour per day.
2. 1% for {e} is based on Tesla data download rates.

CAVs will generate more than 20 GB data per hour, through sensors, cameras and other technology[32]. However, most of this data does not need to be shared. Rather, the vehicle will process much within the vehicle, i.e. edge computing. A portion of this data will be processed and become information for sharing[33].

Two sets of information will be formed. The first set is low-priority information that can be shared after it is processed. Most of this information will ideally be shared when vehicles return to base, either through a home/business wired or Wi-Fi connection. This low-priority information will primarily provide manufacturers and vehicle operators with vehicle status data, non-safety-critical messages, and vehicle information. ICT Infrastructure that can transmit this information exists today in most homes and businesses, and after the NBN and 5G rollouts, it will be more widespread with greater capacity than today. Ideally this information will have access to a low-latency, high capacity network, high priority information needs. The second set of shareable information will be high-priority and (often) safety-critical information that must be shared with other vehicles, roadside infrastructure and manufacturers/fleet operators. This high-priority information is likely to have the largest impact on ICT Infrastructure required. From MNO communications links to roadside infrastructure links down to V2V and Vehicle to Pedestrian (V2P) wireless links, several mission-critical wireless networks will be needed for different purposes to ensure safe, effective and efficient CAV operation. High-priority information will likely include changed travel conditions, incidents, emergencies, 'unsafe' changes (compared to the vehicle's stored digital map), vehicle direction, speed and on-board systems status.

We expect Level 4/5 CAVs to access high priority information around 10MB/hr/vehicle for data uploads and the same for data downloads, and to require low-latency wireless networks. This is based on the combined data transmission across all communication networks including with vehicle manufacturers' head offices, mapping system providers, manufacturers' dedicated battery recharge stations, other vehicles, roadside infrastructure and infotainment. Most data transmission (i.e. low-priority information) is not safety-critical and does not require low-latency telecommunications. Hence, very little will need to be in real time, which should lessen the cellular load. Making sure wireless networks are capable and configured with Quality of Service (QoS) protocol is a key element of CAVs' successful implementation. QoS will allow network operators to prioritise messages from different user groups (or other information types) to ensure safety-critical information gets top priority and reaches its target audience. QoS has the capability to control jitter, provide dedicated bandwidth, and set latency to reduce chances of data loss or message duplication. With QoS implementation, however, systems are subjected to delayed information from low-priority users/information providers. This is tolerable in a safety-critical system as it is crucial the high-priority information is not held up. QoS is implemented within 3GPP technologies as well as DSRC and C-V2X, allowing the network operator to determine the requirements and priority levels of different types of data (e.g. voice, video, text).

Numerous trials have shown that DSRC has shortcomings: C-V2X is still emerging but appears to address some or all. DSRC is a rebranding of the old 802.11a standard and would need upgrading to accommodate true CAV operation's expected message densities. Examples of DSRC improvements include increased Basic Safety Message (BSM) verifications, better alert latency, and improved coverage range[34]. C-V2X has the benefit of being based on 3GPP, which industry is interested in because it is part of the roadmap to 5G connectivity; it leverages the comprehensive coverage of secure and well-established LTE networks; enables highly reliable, real-time communication at high speeds and in high-density traffic; and supports both short-range and long-range transmissions between vehicles and roadside infrastructure[35].

The density of AVs in a geographical area will determine the density of additional cellular towers. In a city environment with high-traffic density, reaching the required telecommunications density to accommodate all vehicles would need extra cellular base stations. For full scale AV rollout, only 5G cellular technologies can provide the density and low

---

32 https://semiengineering.com/data-issues-grow-for-cars/

33 https://www.tuxera.com/blog/autonomous-cars-300-tb-of-data-per-year/

34 http://www.electronicdesign.com/automotive/dsrc-vs-c-v2x-looking-impress-regulators

35 https://www.gsma.com/iot/wp-content/uploads/2017/12/C-2VX-Enabling-Intelligent-Transport_2.pdf

latency those areas need. That means supplying, installing and maintaining additional cellular base station infrastructure and extra backhaul telecommunications into the wider network.

Cellular coverage is currently patchy in some rural areas (outside cities and towns). Providing these areas with the resilience needed to operate CAVs in the future, will likely involve mobile satellite telecommunications as an integral component of the 5G ecosystem. This would allow advisory messaging in environments with high accident rates or are subject to extreme weather conditions, bush fires or flooding. Satellite could also provide backhaul for remote cell towers in rural areas, as in the 3GPP Initiative underway to incorporate satellite functionality into the 5G Standards. It will make the 5G network available to remote users directly via satellite[36]. Reaching the necessary capacity and coverage would need considerable extra infrastructure investment and further investigation into a 5G Satellite network's latency capabilities. Nonetheless, until the 3GPP 5G standard (i.e. Release 15 and Release 16) are officially released, standard-compliant equipment cannot be manufactured. Release 15 is due in the second half of 2018[37].

Section 5.6 covers analysis of major urban infrastructure planning. One opportunity is to include innovation funds in projects requiring innovation KPIs to be met before funds are released. Alternatively, trials can be built into projects during testing and commissioning phases, to identify how the new technology integrates with the existing system.

The ICT infrastructure and vehicle technology required to ensure CAVs can drive on our roads will need national and, in some cases, international standardisation. Vehicle manufacturers must agree on compatible standards to ensure businesses and consumers have options. In many countries, lack of rail standardisation forced operators to change train carriages at state or national borders because of incompatible standards. We cannot allow this with ICT infrastructure as it would create a dysfunctional system where certain AV models can only function in certain countries, states or even cities. Creating independent and incompatible ecosystems (state or national) that limits business and consumers' vehicle choices is a suboptimal solution that will prohibit a unified highly automated vehicle network. Standardisation is crucial if CAVs are to be fast tracked into our lives.

---

36 http://www.3gpp.org/news-events/3gpp-news/1933-sat_ntn

37 http://www.3gpp.org/specifications/67-releases

4 INFRASTRUCTURE ANALYSIS

4.1 INTRODUCTION

WSP used each vehicle type's use cases and functions to determine the ICT infrastructure that needs to be assessed before it can support AV deployment:

— **Cellular Tower Coverage:** Capacity relies on sufficient Backbone Links to Central Support Systems
— **Roadside Infrastructure:** Supported by Central Support Systems and Backbone Links
— **Central Support Systems:** A variety of control, monitoring and operational systems
— **Backbone Links:** Mostly provided by NBN and Telstra.

4.2 CELLULAR TOWER COVERAGE

As detailed in 3.3 – Functional Analysis, cellular tower coverage is an important AV enabler. With it, vehicles operate optimally, understand and respond to roadworks, other vehicles, and road conditions.

The results of the cellular coverage gap analysis are presented below. The analysis mapped Victoria's existing cellular data coverage and made assumptions to develop future new coverage and identify areas of no coverage on M, A, B, C class and sealed roads. From this, we calculated the number of towers and amount of investment required to ensure complete cellular data coverage on all Victorian M, A, B, C class and sealed roads.

To determine the 'future existing coverage' (i.e. the 2031 assumed future network coverage), we assessed the coverage along road corridors, excluding the general cellular land coverage. This section's results should be considered in this context.

4.2.1 FUTURE EXISTING COVERAGE

The 'future existing coverage' comprises three components:

1. 'Current towers' – coverage based on 2018 mobile phone tower locations
2. 'Future known towers' – coverage based on towers slated for funding under the Mobile Black Spot Program
3. 'Assumed towers' – coverage that assumes all Victorian regional and rural towns will have cell phone coverage.

Table 4.1 summarises the 'future existing coverage' tower numbers. Figure 4.1 shows the current Victorian coverage map.

Table 4.1 Base layer tower summary

CELL TOWER TYPES	NUMBER OF TOWERS
Cell Tower Telstra	2752
Cell Tower Optus	2436
Cell Tower Vodafone	1712
Mobile Black Spot Program (Priority Round)	19
Mobile Black Spot Program (Round 1)	110
Mobile Black Spot Program (Round 2)	30
Additional Regional Towns Assumed Towers	30
TOTAL	**7089**

The ‘future existing coverage’ statistics are:

- 7089 cell towers are assumed to be constructed and operational by 2031
- A total length of 87,652km of M, A, B, C class and sealed roads will have coverage
- A total area of 78,266km^2 will have coverage in Victoria
- These assume that the towers have a 5km coverage radius or “buffer” as outlined in Section 2.5.2.

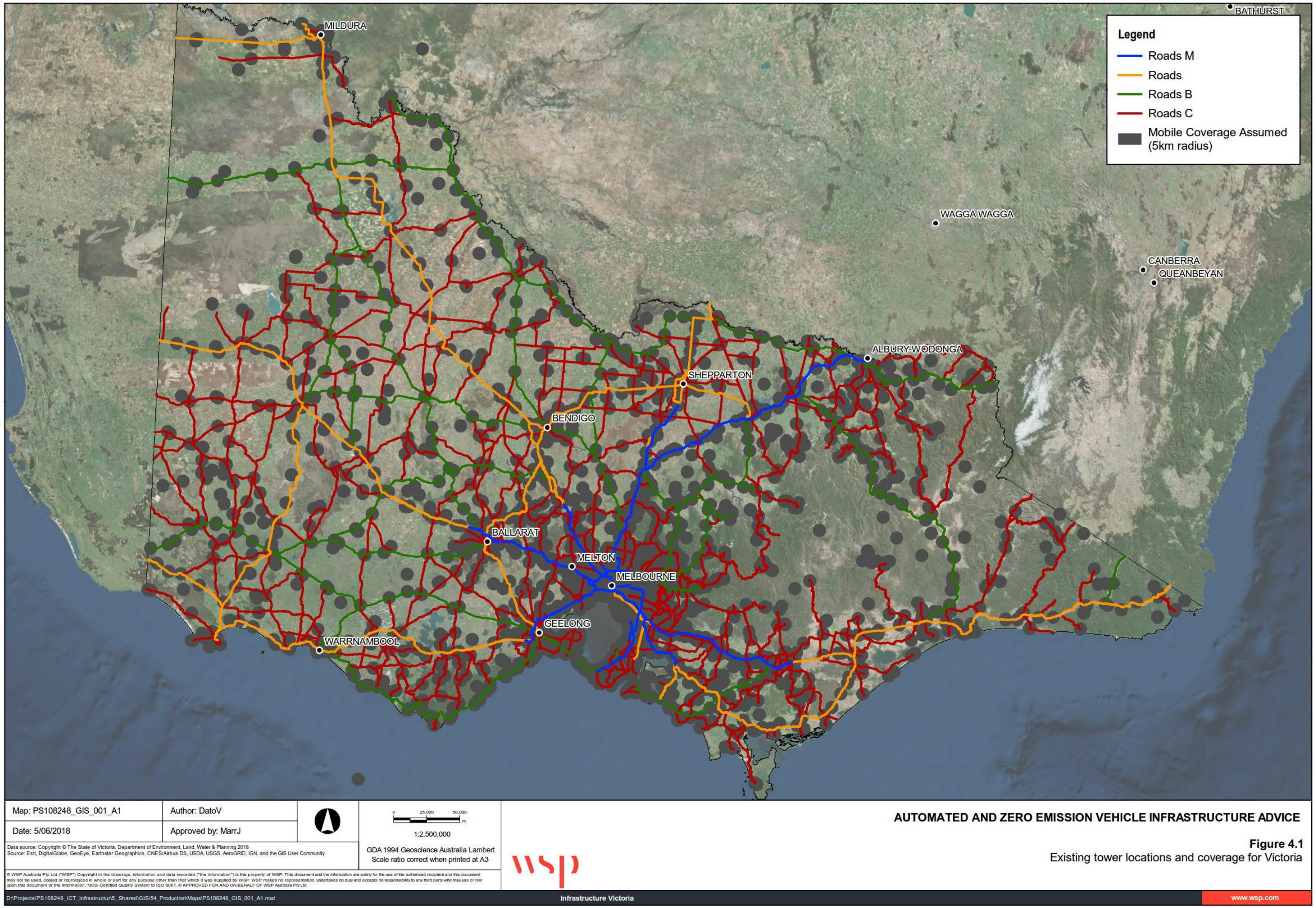


Figure 4.1 Existing tower locations and coverage for Victoria

4.2.2 MISSING COVERAGE

Table 4.2 summarises the cell towers required based on LGAs. The towers are ranked by the number needed on highest-order classification roads. We need 2098 towers to ensure full coverage on current M, A, B and C class and sealed roads. As discussed in the methodology, this assumes that no organic growth or private investment increases cell tower coverage.

Table 4.2 LGA Cell tower requirements

LOCAL GOVERNMENT AREA	M CLASS	A CLASS	B CLASS	C CLASS	SEALED ROADS	TOTAL REQUIRED
Strathbogie	4			13	22	39
Moorabool	2			6	16	24
Wangaratta	1		2	10	21	34
Benalla	1	2	1	5	20	29
Indigo	1		4	9	8	22
Macedon Ranges	1			5	9	15
Wodonga	1		2	1	1	5
Mildura		17	13	12	15	57
East Gippsland		15	11	46	28	100
Buloke		11	9	37	58	115
Glenelg		10	3	24	41	78
Southern Grampians		9	9	22	53	93
Horsham		9	3	17	27	56
Wellington		6		27	52	85
Moira		4	6	19	35	64
Greater Shepparton		4		14	12	30
Moyne		3	11	21	63	98
West Wimmera		3		36	52	91
Loddon		3	10	27	46	86
Corangamite		3	7	24	29	63
Hindmarsh		3		18	31	52
Colac Otway		3	4	14	13	34
Northern Grampians		2	12	24	33	71
Campaspe		2	8	21	27	58
Ararat		2	9	12	33	56
Pyrenees		2	8	9	31	50
Greater Bendigo		2	6	13	18	39

LOCAL GOVERNMENT AREA	M CLASS	A CLASS	B CLASS	C CLASS	SEALED ROADS	TOTAL REQUIRED
South Gippsland		2	4	12	16	34
Surf Coast		2	1	5	9	17
Golden Plains		1	4	11	16	32
Hepburn		1		5	10	16
Latrobe		1		3	5	9
Ballarat		1	1	1	1	4
Yarriambiack			16	28	44	88
Swan Hill			15	14	33	62
Gannawarra			7	13	22	42
Murrindindi			7	3	15	25
Towong			6	26	14	46
Central Goldfields			4	7	15	26
Mansfield			3	9	5	17
Alpine			3	8	4	15
Mount Alexander			1	7	15	23
Mitchell			1	6	11	18
Yarra Ranges			1	11		12
Mount Hotham Alpine Resort (UNINC)			1			1
Bass Coast				2	4	6
Melton				2	1	3
Wyndham				1	2	3
Mornington Peninsula				1		1
Hume					1	1
Whittlesea					1	1
TOTAL	**11**	**123**	**213**	**689**	**1062**	**2098**

Figure 4.2 shows the location of the non-cell coverage on M class (yellow) and A class (red) roads. Figure 4.3 shows the location of the non-cell coverage on B class (purple) and C class (blue) roads. Figure 4.4 shows the location of non-cell coverage on sealed roads. For locations with missing cell coverage, the number of cell towers required to provide coverage assumes the 5km coverage radius.

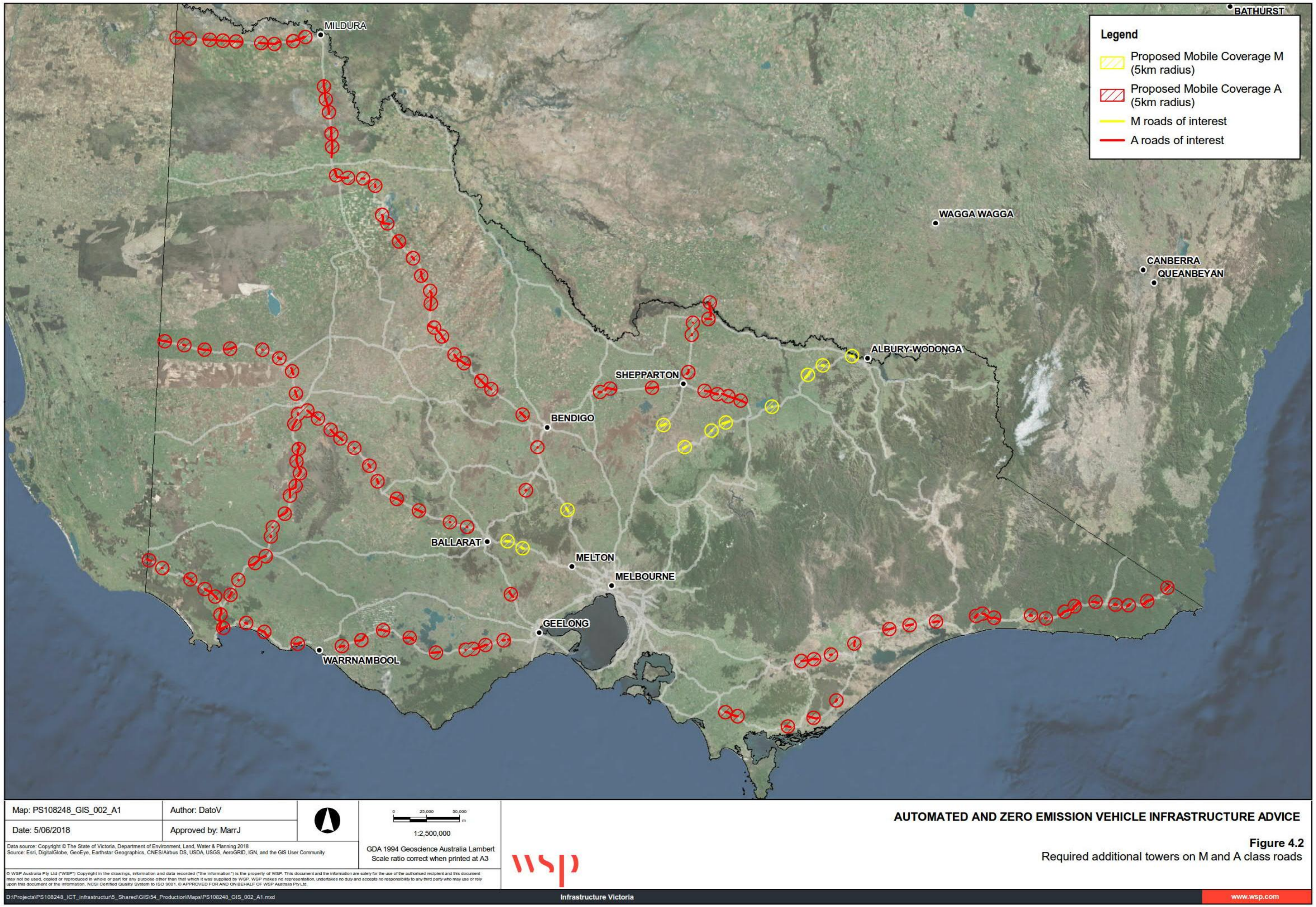


Figure 4.2 Additional towers – M and A class roads

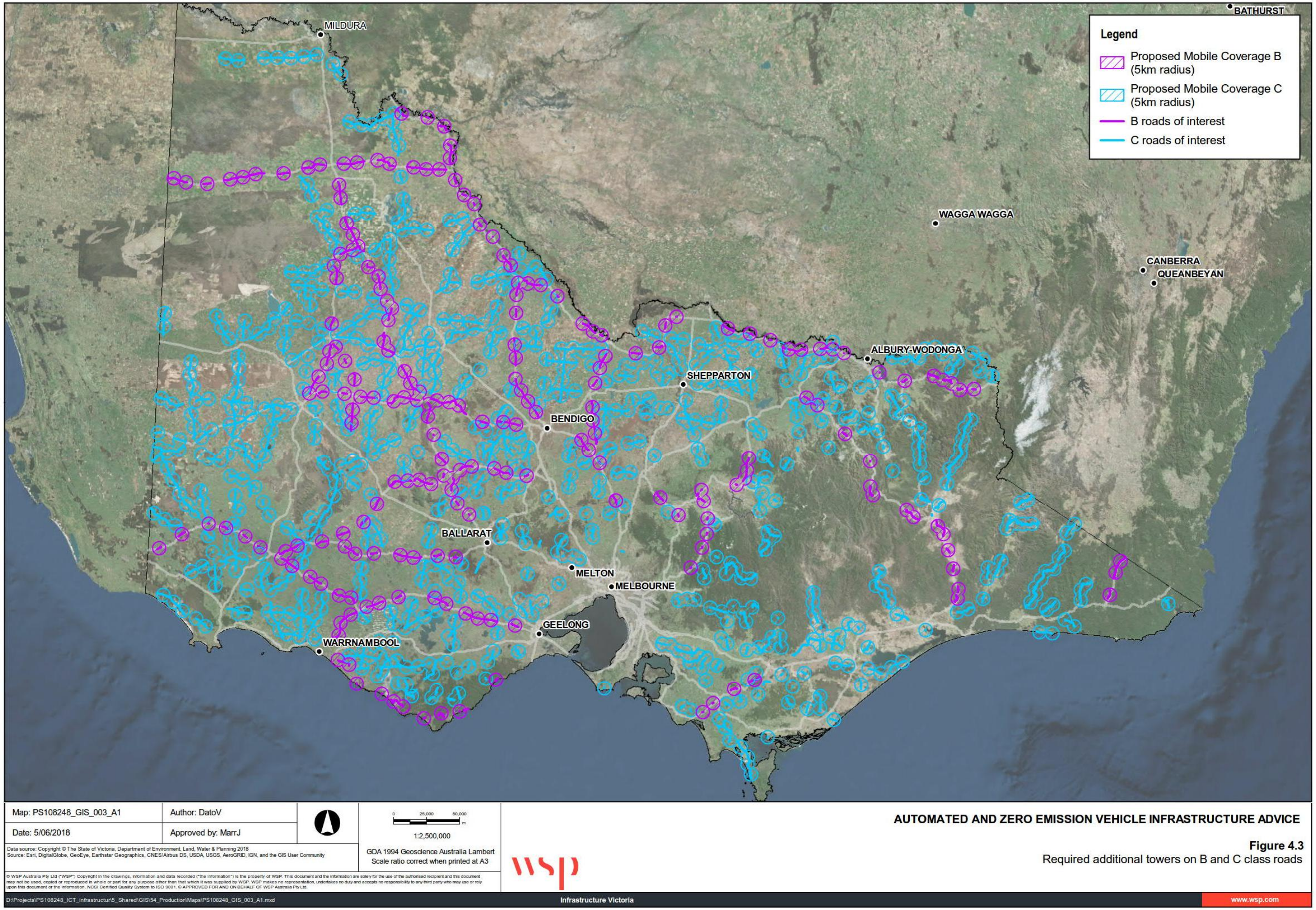


Figure 4.3 Additional towers – B and C class roads

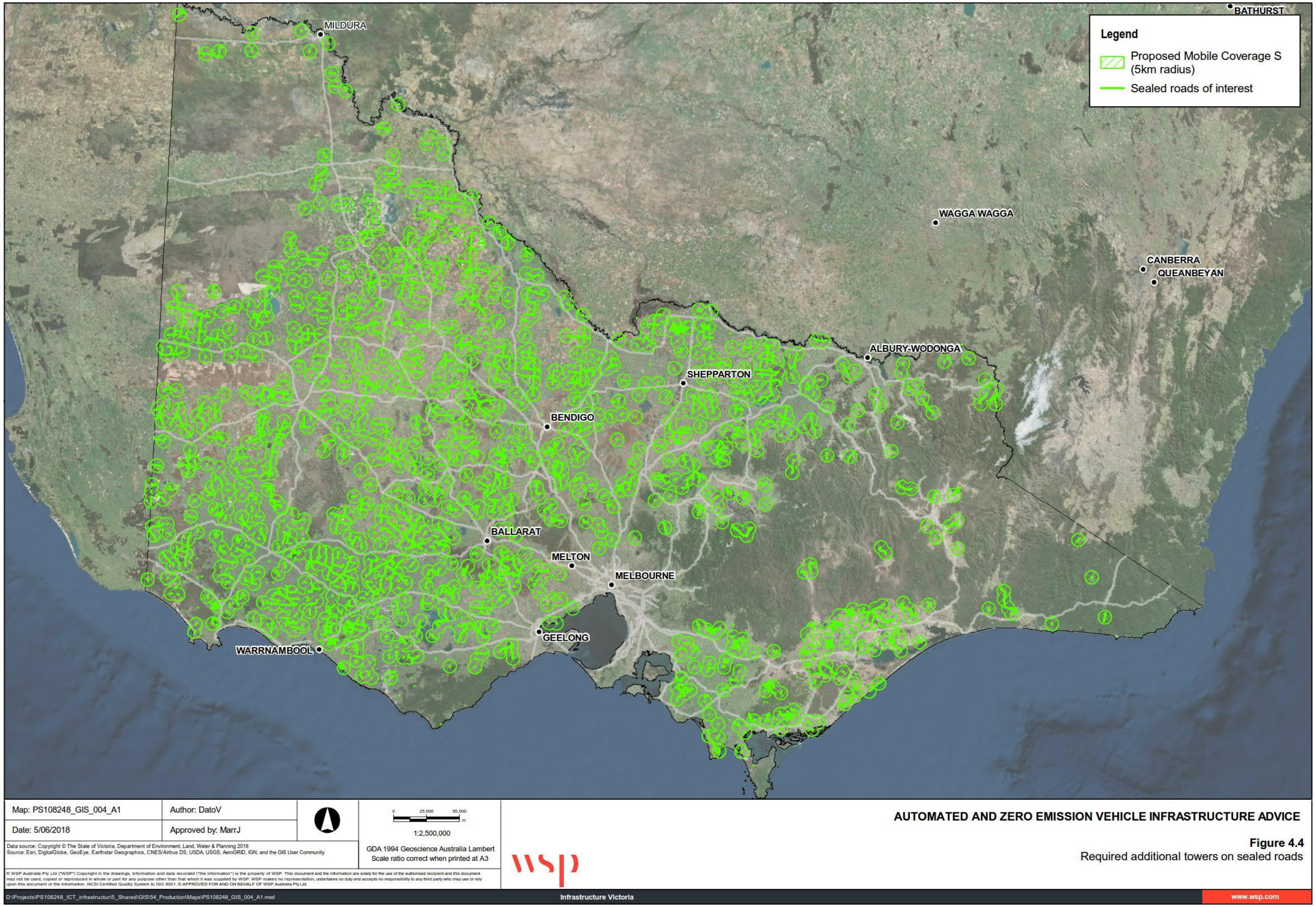


Figure 4.4 Additional towers on all sealed roads

Figure 4.2 to Figure 4.4 shows some overlap with the new proposed towers, due to the random road lengths that had no coverage and the set 5km radius of assumed cell tower coverage. While steps taken rationalised the number of towers, there is still a certain amount of overlap, particularly with the lower order roads. Further analysis and rationalisation should reduce the total number of towers, depending on each location's specific site properties.

Table 4.3 summarises the current percentage of cell tower overlap. The lower order roads have a higher overlap percentage, due to the higher number of towers needed and the strong likelihood that lower order and sealed roads will exist closer together.

Table 4.3 New cell tower coverage overlap

ROUTE	TOTAL LENGTH OF ROAD (KM)	NO OF NEW TOWERS	AREA COVERAGE TOTAL (SQKM)	AREA OVERLAP (SQKM)	% OVERLAP
M	62	11	78630	500	0.6
A	729	123	85006	3150	3.7
B	1440	213	96795	4564	4.7
C	5612	689	133956	13434	10.0
S	7679	1062	170994	34776	20.3

4.2.3 COST ESTIMATES

We used the costs of recent (from the past three years) new cell tower installations in New South Wales and Victoria to generate a per site order of magnitude cost estimate. The average site costs between $570,000 and $815,000. This considers costs of design, civil work, tower supply and erection, communications hut, security, power, communications and mobile network operator-supplied equipment, and contingency. Costs were sourced from similar recent construction projects and the Federal Blackspot Program. Based on the extent of the data available, it was not determinable what ground conditions may have been prevalent and therefore ground considerations are a factor which may impact on these estimates. The cost of acquisition of any land in order to locate a tower is also not considered as part of the estimates.

Beyond the assumptions discussed in Section 2.5.2 (i.e. towns, regional cities and metropolitan areas having sufficient coverage), large sections of the rural road network remain without continuous coverage.

For the minimum ICT infrastructure investment level, we considered requiring no additional mobile cell towers. However, WSP proposes that cellular network coverage should be extended on M and A class roads that rural public transport must use, to facilitate minimum mode interoperability.

The minimum number of new cell towers required is 134, focussing on M and A class roads. Order of magnitude cost estimate is from $76m to $109m.

The next step would be a more detailed geographic study matching existing and proposed public transport routes to surveyed cellular network coverage.

For the optimum ICT infrastructure investment level, the cellular network coverage was extended to all sealed roads. This would enable most trip distances to be fully optimised for all Victorians. This increases tower numbers fifteen-fold to 2098 covering an additional 14,731km of road network at an order of magnitude cost estimate of about $1.1b to $1.7b.

4.3 ROADSIDE INFRASTRUCTURE

The Use Cases and Functional Analysis indicated that some form of RSU (or V2I device) would benefit AV operation. Roadside infrastructure that provides vehicles with active and legally enforceable controls had the strongest case for V2I augmentation.

Active roadside infrastructure includes traffic signals (intersection, pedestrian or other), overhead lane control signs, variable speed limit signs, ramp metering signals and roundabout signals.

Within this subsection of electronic roadside infrastructure, electronic speed signs were removed for all scenarios, assuming any speed changes would be communicated via cellular network. If a vehicle observes a speed sign in conflict with the authorised digital layer, it would travel at the lower speed.

Within Victoria, this resulted in a total of 4599[38] current roadside infrastructure sites. Adding planned infrastructure and existing signal growth rates results in 6626 roadside infrastructure sites by 2046. We consider this the optimal number of roadside infrastructure sites to have V2I augmentation due to the benefits of connected roadside infrastructure sites. It is an upper estimate that could be reduced if low volume sites were removed.

Of these, 4225 are in Melbourne and Geelong. VicRoads manages the sites most critical for maintaining the transport network flow. Removing pedestrian crossings, emergency services access and other less critical traffic signal sites results in 2887 intersection signals, ramp metering and roundabout signals. VicRoads (in discussions) estimated that about 33% (or 907) of these sites are critical to network functions (i.e. located on key arterial routes, experience high degrees of saturation). By 2046, this would grow to about 1283 sites (assuming pro rata 33 per cent of the 6626 roadside infrastructure sites by 2046).

V2I devices provide vehicles with supplementary location information likely to be needed in built up areas such as Melbourne CBD where GNSS occlusion has an impact. Including these estimated extra 120 sites in the minimum scenario, based on estimated number of Melbourne CBD traffic signals, the total increases to 1403 sites.

Adding V2I devices to roadside infrastructure would usually be straightforward with communications, power and elevated mounting positions already available. Drawing on experience with similar current V2I trial installations and VicRoads costings, $30,810 is the estimated cost per site. This includes 20 per cent contingency and allowances for complex sites. Based on today’s costs WSP estimates capital expenditure by 2046 would need to be in the order of magnitude of $39.5m for the minimum scenario and $204.2m for the optimum scenario (2018 dollars).

This order of magnitude cost estimate was developed using similar techniques to roadside ICT infrastructure business case estimates over the past five years in Victoria. While land acquisition costs were not included, with the proposed infrastructure very likely to use existing assets land acquisition is unlikely to be required for vehicle to infrastructure roadside ICT devices.

4.4 CENTRAL SUPPORT SYSTEMS

4.4.1 OVERVIEW

Over the last 100 years we have gradually used supporting infrastructure to centralise control of vehicle systems, initially traffic signs, then electronic traffic signals, and electronic information signs. In the last 30 years authorities have increasingly recognised the importance of monitoring and optimising individual vehicle movements and vehicle flows across transport networks. Stronger recent interest focuses on understanding individuals’ travel activities rather than traffic flows alone, towards new ways of better managing demand and optimising people and freight movements rather than focusing on vehicle movements. We need to optimise vehicles’ movements to improve efficiency and/or prioritise public transport, freight and emergency services. The need for roadside and centralised monitoring of individual vehicles and people movements, creates new data sources, and data services such as those being provided by Google, TomTom, HERE and Intelematics. Many Australian cities currently use BlueTooth/Wi-Fi technology to monitor vehicle travel times and origin-destination data in real time as about 20 per cent of vehicles pass connected traffic signals.

[38] https://vicroadsopendata-vicroadsmaps.opendata.arcgis.com/datasets/traffic-lights (updated Feb 2018)

It has become clear in the last five years that CAVs will be another distinct, key step in technology evolution. Automated vehicles can act as probes (collect useful data) and also receive real-time safety and road condition data, eventually making it possible to optimise network outcomes by automatically rerouting individual vehicles or whole fleets.

Recently-available data flows from external parties are a relatively new development compared with the age of much of the existing ICT infrastructure, such as central support systems developed and managed by road operators. These systems were developed to maintain a physical communication infrastructure network with some centralised computation and associated physical infrastructure (racks, switches and servers). But availability of new information on a variety of connected vehicle technologies will change how we consider the central systems.

IoT technologies also allow analysis of huge datasets to improve how we manage our transport and infrastructure including structures, lighting, pavements, and car parks. Central systems must bring together a wide range of previously unavailable data requiring highly flexible architectures. While they may be centralised in some form of logical architecture, the parties involved will need to be physically separated or distributed.

The Open IoT standard is one approach being considered. Also, service-oriented architectures (SOAs) like the National ITS Architecture. These approaches recognise the importance of open integration to support a wide range of services. Most road agencies are currently considering how to shift from an infrastructure focus – where vehicles are monitored and controlled throughout many thousands of network points – to an approach where all vehicles could potentially be monitored all the time[39].

To make such a large change towards SOAs, transport agencies are considering a range of microservices managed on various levels. Cloud computing to support service delivery (infrastructure as a service, platform as a service, application as a service, or data as a service) offers significant benefits to the operation of large scale data exchange platforms needed for CAV and transport operation like MaaS. Beyond these standard offerings, other sub services are emerging, including Machine Learning as a Service.

Figure 4.5 outlines data exchange needed between various key systems and users. Some Australian agencies are already considering and deploying cloud-based microservices. The highly flexible approach allows any aspect's 'owners' or stewards to agree on an exchange format and share this immediately with other parties without consultation, provided they are using industry standard protocols and terminologies. The use of standard cloud-based hosting tools such as those offered by AWS will further simplify use and data exchange improvement.

The assumption is that vehicles share 10MB per driving hour of and receive 10MB per driving hour. This figure is based on data provided by autonomous vehicle manufacturers, 3rd party map providers, and SAE standards for frequency and size of CAM messages (i.e. 150 bytes sent 10 times per second). Calculations were based on an average of 1 hour driven by a vehicle per day and the premise that once data is shared by one vehicle, it does not need to be shared by other vehicles in the same geographical area as they will be made aware. In the Tesla example, daily data per vehicle averaged 50MB per day[40], but this reflects Tesla's additional information capture for technology improvements. Each vehicle will have its own map provided by a 3rd party map provider. Map updates will only be sent when an exception occurs and small map updates from centralised systems will be passed down as required. 10MB per hour covers the map information, fleet operators, vehicle manufacturers, V2V, V2P, V2I and V2X communications required. This only covers the communication across wireless networks. Communications across wired networks are supported by separate infrastructure that is mostly already in place today.

Data storage is another critical element of the data picture. Once data is shared via the backhaul network and then processed by manufacturers/fleet operators, only 10 per cent will need to be stored for up to a month, sufficient to assist authorities with any police/legal queries. Queries will be completed within a month and requested information will be transferred to the requesting organisation. The monthly data can then be compressed and archived to 5 per cent of its original size and stored long term for up to 20 years.

---

39 Internal VicRoads ITS Communications Architecture & Management Review – 2016
40 https://electrek.co/2017/06/14/tesla-autopilot-data-floodgates

The percentages of data stored per month (10 per cent) and reduced for long term storage (5 per cent) is based on VicRoads current storage and usage practices. For long term storage, it was conservatively increased by a factor of five. Further analysis could further reduce these storage volumes, even though cloud storage costs are low.

It is assumed that a single tower can connect the maximum number of vehicles the road coverage area can support.

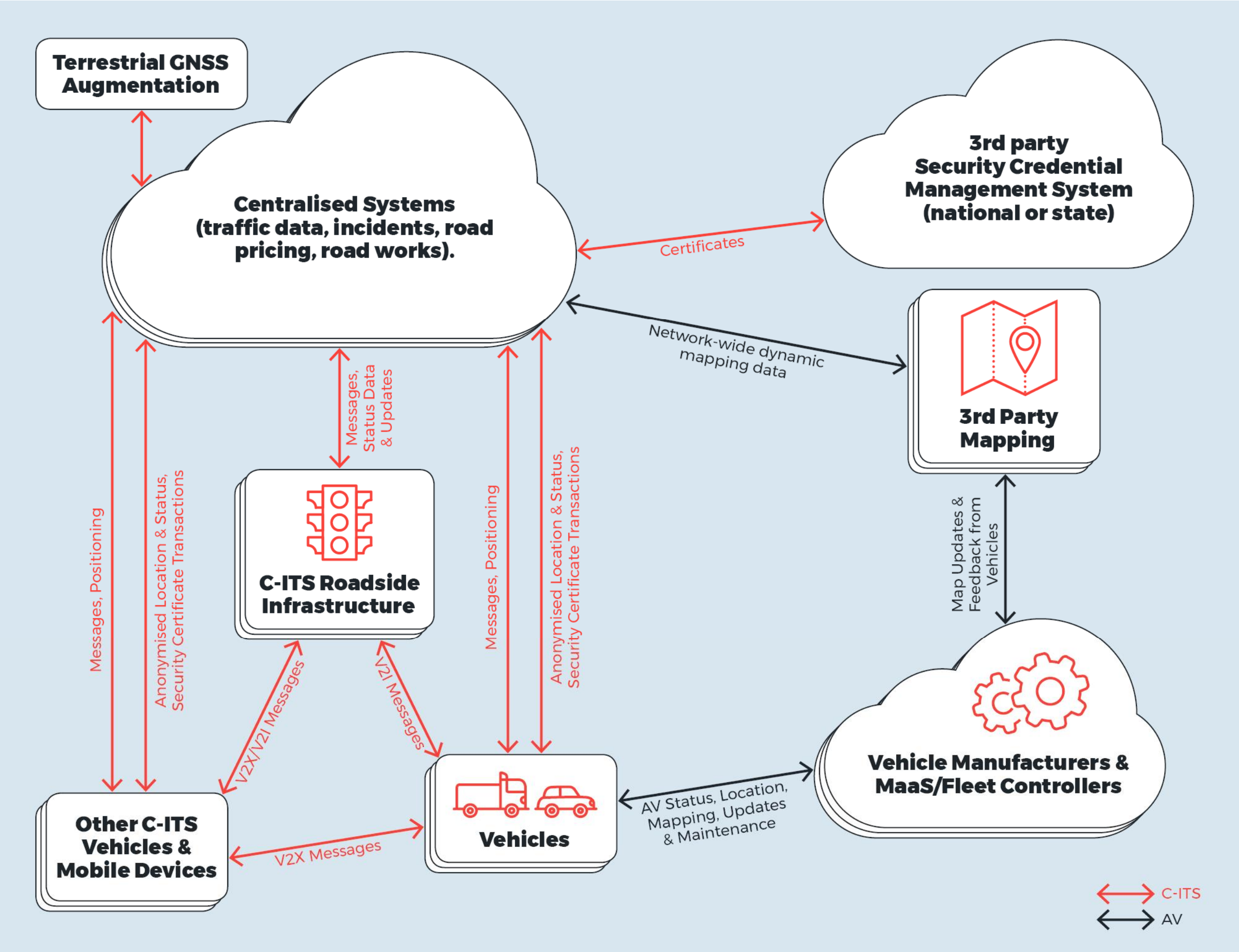


Figure 4.5 Potential Cloud-based - Key system interactions

4.4.2 HARDWARE VENDOR APPROACH

Valuable discussions with a hardware vendor helped form ideas on potential field and centralised architectures. We provided the vendor with an estimated number of information requests per second, estimated data generated per hour, estimated data to be held in short-term storage, and estimated data to be held in long-term storage. High level cost estimates were provided by the hardware vendor based on this limited information.

The minimum capital expenditure on network and storage hardware is $8.5m and the maximum is $11.5m. The average cost per year is $2.5m.

Software will be developed to bring together all the serviceability, reliability, security, privacy and accessibility requirements. If Victoria develops this uniquely, it may cost in the order of magnitude of $10m to $50m based on similar software projects of similar complexity. However, Victoria is not isolated nor likely to develop a bespoke system when we could implement a modified system developed by other road authorities. WSP has not been able to obtain sufficient supporting information to form a strong view on capital or ongoing software expenditure.

4.4.3 CLOUD-BASED APPROACH

The cloud-based provider consulted had a more agnostic approach to ICT physical infrastructure with strong tools and support capabilities. Cloud-based systems are used extensively in modern mission-critical ICT infrastructure[41]. WSP believes they are more than sufficient for supporting AVs (see Section 5.8).

The minimum cost per year was $600,000[42] and the maximum was $750,000. These costs are based on a current Sydney-based facility. Costs are likely to reduce over time and will be similar if a new facility is constructed in Melbourne.

Capital cost would be minimal unless government wanted to incentivise local Melbourne-based data storage. The latency between Melbourne and Sydney is relatively low. Nonetheless WSP would prefer to reduce any 'optional' latency and have the data storage located in Melbourne.

There would be some upfront software costs but less than those described in Section 4.4.2 due to common tools used across many cloud-based implementations. WSP was unable to obtain sufficient supporting information to form a strong view on capital or ongoing software expenditure.

With the large difference between a traditional hardware and a cloud-based approach, WSP would recommend first consideration be given to a cloud-based approach to support AVs (assuming all performance, reliability and security concerns are managed).

4.5 BACKBONE LINKS

Backbone links provide communication between the 'cloud' or centralised systems and the physical network connection points across Victoria;

- Road Side Units (RSUs)
- Cellular Towers

RSUs (or V2I devices) would typically be located at traffic signals, lane control signs and ramp metering sites. In the past five years, traffic signals have converted to ADSL/cellular that has a reasonable percentage of spare bandwidth. Planned new sites will be connected to the NBN and have sufficient bandwidth. Overhead lane control signs and ramp metering sites are connected to a dedicated fibre network that VicRoads controls and maintains. Current use of that network is less than 5 per cent[43]. WSP believes the existing roadside ICT infrastructure is sufficient. Data from these locations is treated like any other on the Victorian backbone.

Cellular towers are connected to the Victorian backbone either directly to a high capacity fibre connection or via microwave to another cell tower (typically for rural locations due to the cost of expanding the fibre backhaul for only a cell tower). WSP believes that rural coverage for V2X is likely to rely on microwave backhaul. Our evaluations and Telstra, in discussion, indicate that low vehicle densities (and other internet service users) mean microwave can provide sufficient bandwidth.

WSP also assessed total data generated on some of the busiest rural roads. We found the volumes amount to a small fraction of overall use in terms of maximum connection numbers and total data across the bandwidth. For example, the road between Melbourne and Ballarat[44] has an average daily volume of 22,000 vehicles (both directions) and a conservative peak of approximately 2,000 vehicles per hour[45] (both directions). With each cell tower covering 5km radius, at most 100 vehicles will be connected to any one tower at a time.

---

[41] https://aws.amazon.com/solutions/case-studies/
[42] https://aws.amazon.com/kinesis/data-firehose/pricing/ & https://aws.amazon.com/s3/pricing/
[43] VicRoads ITS Communications Architecture & Management Review (2016)
[44] The busiest rural link is Melbourne – Geelong however it already has full cellular network coverage
[45] https://vicroadsopendata-vicroadsmaps.opendata.arcgis.com/datasets/147696bb47544a209e0a5e79e165d1b0_0

We had limited results investigating with NBN and Telstra the existing capacity of backbone links and those planned. Both organisations referred WSP to external charters[46], Acts[47] and constitutions[48] around legal and commercial expectations to plan for and meet demand.

Considering current AV trends and overall network usage, the Cisco VNI Forecast tool[49] estimated average data speeds will increase from 18.8MB per second to 43.6MB per second over the next three years. Average traffic per capita per month will increase from 42.5GB to 125.8GB. At most, the average AV will be generating 500MB a month.

WSP considers the scale of data AVs transmit and receive is a fraction of the overall network traffic and warrants no significant infrastructure funding to expand backbone links.

4.5.1 SENSITIVITY ANALYSIS

WSP's prediction of future AV data requirements will likely prove inaccurate, despite being based on current connected vehicle interactions. Uncertainties make it prudent to conduct sensitivity analysis of total network bandwidth and expected network bottlenecks against data generated at higher orders of magnitude.

The most aggressive AV growth is seen in the High speed scenario with full deployment by 2031. At peak vehicle volumes, maximum internet network impact is 8.5TB per hour (Section 3.3.7).

Cisco predicts[50] Australian internet traffic to grow 3.3-fold from 2016 to 2021, a compound annual growth rate of 27 per cent. Given an estimated average 2021 rate of 32,400TB per hour to 2031, we estimate an average of 353,657TB per hour, reduced to 84,875TB per hour pro-rata for Victoria.

Assuming the network has been expanded to cope with this internet traffic level, even a hundred-fold increase in vehicle numbers and data generated makes the share of vehicle-generated internet traffic one (1) per cent.

With no work completed on the current backbone infrastructure (peaking at 11,232TB per hour in 2016), a hundred-fold vehicle and/or data increase makes the share of vehicle-generated internet traffic eight (8) per cent.

WSP is comfortable that even with a hundred-fold increase in vehicle data use, the backbone infrastructure will be more than sufficient in the context of wider network growth.

---

46 https://www.telstra.com.au/aboutus/our-company/future/Ourcorporatestrategy
47 https://www.legislation.gov.au/Details/C2016C00381
48 https://www.nbnco.com.au/content/dam/nbnco2/documents/nbn-constitution.pdf
49 https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html#
50 https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html#

5 ENABLERS AND BARRIERS

5.1 INTRODUCTION

This section explores key topics most relevant for assessing factors that facilitate or hinder AVs' expansion in Victoria.

Identifying the key contributing factors to these topics is important, even if they currently cannot be quantified: it provides focus and momentum for future work.

WSP drew on the strong local and international experience of colleagues currently at the forefront of this industry. Concepts or illustrations are referenced, where feasible. Where conclusions are based on recent experience or opinion, they are clearly identified.

5.2 ICT INFRASTRUCTURE

Consider first, pure Autonomous or Automatic Vehicles (AVs) without cooperative operation. When AVs are in use, they should be able to communicate with the vehicle manufacturer and possibly the mapping provider for status data transfer and dynamic map updates. This will require reliable mobile 3G/4G/5G telecommunications infrastructure of sufficient speed and capacity. This will be provided by MNOs and current 3G/4G capacity should suffice.

It is highly probable that the Global Navigation Satellite System (GNSS)[51] will need a wide area augmentation service, where there is insufficient positioning accuracy or when GNSS is lost. As discussed above, a hybrid navigation systems approach may be needed to provide augmentation for highly automated operation, such as positioning augmentation where GNSS positioning is inadequate or unavailable (systems including, SBAS, real time kinematic (RTK), on-board sensors, C-ITS roadside stations and cellular, Bluetooth and Wi-Fi telecommunications infrastructure).

Data telecommunication needs for AVs per vehicle are expected to be around 10MB per hour for data upload and 10MB per hour for data download. We base this on combined communications with vehicle manufacturers' head offices, providers of mapping systems, manufacturers' dedicated battery recharge stations, and infotainment. Most of the messaging/data transfer for AVs is not safety critical: it needs low-latency telecommunications, minimal in real time. This should lessen the cellular load, provided the vehicle's telecommunication setup considers Quality of Service (QoS).

If highly automated vehicles are to provide many of their touted benefits, they will need to include C-ITS technology to enable communication with each other[52], the Central C-ITS System and Roadside C-ITS Stations, as well as traffic signals, tunnels and similar locations. However, few AV manufacturers currently allocate sufficient importance to vehicles being able to operate cooperatively with other AVs or roadside infrastructure.

Therefore, we also allow for **Cooperative AVs (CAVs)**. Cooperative messaging will require additional ICT infrastructure capable of providing low-latency Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) or Vehicle-to-everything (V2X) telecommunications of sufficient speed and capacity. This will require high-level system integrity as V2V or V2X is mission-critical technology that may directly support in-vehicle functionality, including vehicle braking, steering, or acceleration.

Roadside ICT infrastructure needed for CAVs will also be based on wireless telecommunications provision, primarily:

1 Direct, peer-to-peer telecommunications via DSRC or Cellular V2X (C-V2X) in the 5.9Ghz band between mobile C-ITS stations, and mobile C-ITS stations-to-local Roadside C-ITS Stations (RSUs). This will enable cyclists,

---

[51] Austroads Publication AP-R431-13

[52] https://www.qld.gov.au/transport/projects/cavi/cooperative-automated-vehicles or http://www.ieee-vnc.org/2013/media/IEEE_VNC_BostonKeynote_Shladover.pdf

pedestrians and motorcyclists also carrying mobile V2X devices to communicate with each other, with C-ITS-enabled vehicles, and roadside C-ITS stations.

2 Cellular 3G, 4G and 5G telecommunications between mobile C-ITS stations and the Central C-ITS System. This will enable mobile V2X devices and C-ITS-enabled vehicles to communicate with the Central C-ITS System and obtain relevant messages such as local incident information.

3 Bluetooth and Wi-Fi telecommunications infrastructure potentially needed for augmentation to enable highly-automated operation, such as positioning augmentation where Global Navigation Satellite System (GNSS) positioning is inadequate or unavailable.

4 Backhaul telecommunications between Roadside C-ITS stations (RSUs) and the Central C-ITS platform via either Cellular 3G, 4G and 5G or other available wired communications channels.

The Central C-ITS platform should be a cloud-based system that consolidates speed, incident and other CAV operational data, generates C-ITS messages and sends them to C-ITS vehicles and mobile V2X devices located in areas where the messages are relevant. To enable targeted messaging, C-ITS vehicles and mobile V2X devices should provide location and status information to the Central C-ITS platform so that messaging can be appropriately targeted and only sent to vehicles and mobile V2X devices in the message-relevant location. The Central C-ITS System could also use this data to extract network-wide traffic information. We expect this data may reduce the need for many of the current network-wide ITS devices.

To target relevant messages to C-ITS vehicles and devices, the Central C-ITS System should include a Geo-Relevant C-ITS Message Brokerage function, which would perform a geo-fencing and geo-tiling function within the C-ITS network. When it receives location and status information from each C-ITS vehicle and device, the Geo-Relevant C-ITS Message Brokerage function should send only the C-ITS messages relevant to that device and location.

A Security Credential Management System (SCMS) should be an integral component of the Central C-ITS System. This will require all C-ITS devices and stations sending and receiving messages within the C-ITS network to have required credentials, so the C-ITS system can provide network security and data anonymity across all C-ITS devices and stations. The Queensland CAVI project is currently trialling an SCMS implementation, which could form the basis of a nationwide SCMS for C-ITS use.

The Central C-ITS System can operate as a proxy for access to (or devices and stations within the C-ITS system) GNSS augmentation to provide more accurate and reliable positioning capability.

5.3 MAPPING INFRASTRUCTURE

There is no single technology that can provide a solution for CAV positioning in all locations and situations. Different uses create different needs for maps, infrastructure, and understanding context. GNSS contributes to real-time vehicle localisation as well as map-making.

GNSS-based positioning for AVs will need varying degrees of augmentation (depending on location) to provide sufficient lane-level accuracy for safe operation. Optimal accuracy is 10cm or better, but the minimum is +/- 1m. To achieve minimal and optimal positioning in all situations, the positioning information source will vary. The 2018 Federal Budget allocated $224.9 million over four years to enhance GNSS capability towards the level of accuracy needed – three to five centimetres for regional and metropolitan areas with mobile phone coverage, and up to 10 centimetres elsewhere. In areas without mobile phone coverage, terrestrial GNSS augmentation will be based on cellular towers. Satellite Based Augmentation Systems (SBAS) will also form part of the positioning mix, where available.

Accurate positioning is so important to AVs and CAVs, we will need other forms of positioning in areas where satellite systems are unavailable or are insufficiently accurate, such as in a tunnel environment where GNSS signals cannot be directly received. In these instances, augmentation systems will provide the primary positioning. Similarly, in areas where there is insufficient GNSS reception and/or where SBAS is not available, such as in city high rise areas where high-rise buildings create urban canyons that often block GNSS signals, we will need augmentation from other sources.

In these open-road or tunnel situations, the positioning accuracy available to AVs from their on-board, high-resolution maps in conjunction with their built-in sensors (Lidar, Video and Microwave) will form an important component of the positioning mix that provides the necessary accuracy.

However, for sufficient positioning accuracy in a tunnel environment, the positioning solution will ultimately involve an application that accesses location data from multiple sources. Trials are currently underway based on Bluetooth, Cellular and DSRC augmented positioning systems for GNSS augmentation, and GNSS replacement in some of these locations.

5.4 CENTRALISED TRAFFIC MANAGEMENT CENTRE

Over the past decade, the disconnect between transport authorities operating Melbourne's road, rail, tram and bus networks has been acknowledged.

In June 2016, the Victorian Government established Transport for Victoria (TfV) to 'integrate the transport network for simpler, quicker and safer journeys that connect places…' and 'over time, Transport for Victoria will become a single source of real-time information on how road, rail and bus networks are performing'[53].

Outcome 3 of the Victorian Government's 2017 *Plan Melbourne Strategy*[54] aims to establish in Melbourne 'an integrated transport system that connects people to jobs and services and goods to market', further acknowledging the need for improved integration between road networks and public transport.

In 2016, VicRoads commissioned WSP to develop a strategic Intelligent Transport Systems Communication Architecture to meet current and future needs (including AVs). We provided a framework around likely technology changes, mostly related to connected and automated vehicles and growth in IoT systems. This transitioned into a wide-ranging review that included stakeholder workshops and consultation.

Findings included:

- Existing road network control systems will need to be supported in the short to medium future
- VicRoads' role is transitioning from providing data to 3rd parties and incident management, to holistic proactive network management
- VicRoads' Kew site has challenges around data quality, security and geographical dependency
- Risks that need managing relate to accelerating technology support requirements, existing systems' flexibility and the process(es) for responding
- Need to explore opportunities for working more closely with other transport agencies.

Public Transport Victoria (PTV) strategic directions around intermodal transport are less visible. However, we are comfortable assuming PTV supports its parent authority's (TfV) strategic direction.

A recent summit held by the U.S. Federal Highway Administration and Department of Transport provided insights on car manufacturers' perspectives. Requests for comment related to infrastructure requirements and standards to enable safe and efficient operations[55]. Car manufacturers' responses varied but one strong theme was that of reliance on one source of information for incidents and road conditions[56]. Some industry groups argued that government's role is to quickly establish policy and procedures and allow road operators and the wider industry to directly interact[57]. We support these views and believe there is a policy and infrastructure imperative to establish centralised data and network management.

As a minimum, centralised data provision would collate relevant information and process it to add value as needed. A cloud architecture would be desirable to provide the requisite responsiveness, security and reliability (see Section 5.2).

---

[53] https://transport.vic.gov.au/about/

[54] http://www.planmelbourne.vic.gov.au/highlights/a-more-connected-melbourne

[55] https://www.transportation.gov/AV/avsummit

[56] Association of Global Automaker, Inc – Comments for FHWA Summit 1 March 2018

[57] 5G Automotive Association – Comments for FHWA Summit 1 March 2018

Data providers (i.e. transport authorities) would still need to be held accountable for data quality, edge device availability, and timely data delivery.

Recent project experience has allowed WSP to observe that there is still a significant disconnect between transport authorities when managing routine (roadworks, maintenance) and non-routine (weather, incidents, emergency maintenance) changes in operational conditions. The gaps in resourcing, policy and support systems require significant government investment to promote a holistic transport network management approach.

A centralised network management approach would require new ICT infrastructure to collect, integrate and manage the different control and reporting systems. It is preferable to co-locate operators but not critical with modern communications.

5.5 MOBILITY AS A SERVICE ENABLERS AND BARRIERS

Mobility as a Service (MaaS) is a transport system and philosophy whereby transportation and mobility are viewed, treated and consumed as a service. The MaaS vision represents a radical innovation that could potentially revolutionise the transport system for both passengers and goods. MaaS aims to be more attractive than car ownership.

The concept is based on integrating transport modes, systems and technologies to create an ecosystem that operates cooperatively to provide a range of services to meet users' needs. The MaaS concept integrates services offered by multiple independent providers (e.g. public transport, taxi, bike share, car share) into one smartphone application, allowing travellers to plan and pay for their mobility needs through a single portal. It not only integrates transport modes, but also the back-end operations including finances and transport data.

Elements of MaaS are already part of the Victorian transport environment, largely driven by societal changes and enabled by technological developments – factors we expect will continue and accelerate. For the purposes of this study, we consider MaaS as having two streams:

1. Consumer Mobility as a Service — the largest revenue opportunity in the Passenger Economy, generally the direct effect of AVs converting drivers into passengers as consumers shift away from vehicle ownership.
2. B2B Mobility as a Service – comprising two components: Long-haul Transportation as a Service (fully-loaded trucks operating between major centres) and Local Delivery as a Service (AVs transport parcel carrier services and goods less-than-truckload (LTL)).

When we consider MaaS, we need to factor in broader social and political factors including formal rules and less formal social norms and perceptions. Government has a major role creating preconditions for successful and guided implementation via legislation, taxation, and government agency business practices.

For example, the legislative framework will need to be in place to manage a significant change in Victoria's current zonal system for public transport fares and how these fares are purchased. MaaS would probably require the public transport fare system to match the likely fare system on other transport modes, i.e. by distance travelled. If current restrictions prevent this, legal or otherwise, they will restrict the viability of a MaaS system.

To support a MaaS system, we need to satisfy the following prerequisite conditions[58]:

- 'A wide range of transport modes are available in the city'
- 'Majority of the transport operators open their data including real-time data to a third party'
- 'Majority of transport operators allow a third party to sell their service'
- 'Majority of the transport operators offer e-ticket or e-payment to access their services'

These are shown in the flowchart in Figure 5.1.

58 Li, Y., Voege, T,. (2017) Mobility as a Service (MaaS): Challenges of Implementation and Policy Required

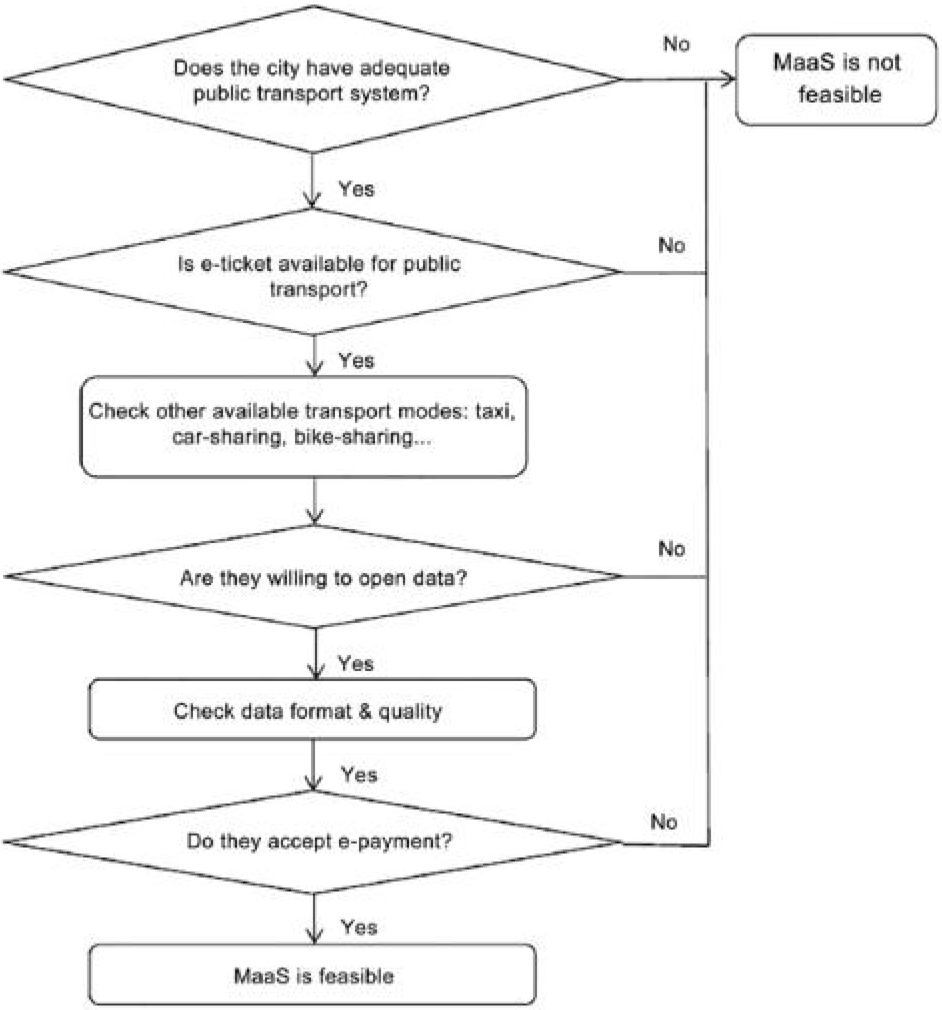


Figure 5.1 MaaS feasibility checklist

One challenge will be engaging a MaaS developer able to aggregate all the systems, transport data and financial payment methods into a singular system and singular interface – one of MaaS' key benefits. The other challenge would be negotiating the transition with existing financial systems, transport operators and transport providers.

Any integration shortfall or backlash from operators would nullify the entire MaaS model. To prevent such issues, we will need strong policies and governance in place with MaaS systems. To prevent undesirable outcomes, such as price exploitation, we will need strong regulatory frameworks to avoid the kinds of business models currently used by some transport modes, such as buses or taxis. The current government subsidies provided to many (mostly public) transport operators would also need to be reviewed to ensure an appropriate balance between subsidising services for vulnerable people and aiding profitable commercial enterprise.

Another policy issue to consider involves integrating MaaS and car sharing. Infrastructure Victoria's Fleet Street scenario suggests that MaaS operators use their own dedicated vehicle fleet. Without fleet size controls in place, an oversized fleet could worsen congestion on existing infrastructure, with a significantly oversized fleet providing similar results to the Infrastructure Victoria Private Drive scenario.

Implementing a MaaS system makes a range of assumptions where we may currently have limited detail or understanding, especially in the differing transport or geographical contexts. The primary assumption is that we can deliver an appropriately flexible system that is financially acceptable to commuters and meets their needs. With a system like MaaS, we do not yet know what travel time gains and associated costs commuters would be prepared to pay for, or the trade-offs they would be willing to make. This could differ for each transport system in each city.

Data security and privacy is another potential issue. MaaS integration would require users to have a single identity to access the system, and would involve collecting data on individuals' movement patterns. We would need to develop measures and safeguards to protect users, but some commuters will still not be prepared to trade their privacy for the convenience. It remains to be seen if alternative, less data-intrusive packages can be offered. MaaS development has focused on full integration to realise the full potential benefits. Little research exists on privacy issues.

Finally, MaaS deployment will depend on high-quality telecommunications network, data sharing among providers, and integrated applications (or a single application) that provides a seamless customer experience. The main technological enabler and/or barrier to MaaS success is the physical cellular network's ability to develop fast enough to accommodate network demand from known technological developments (i.e. smart cites, CAV operation etc.) and sufficient spare capacity to accommodate as-yet unknown technological developments.

5.6 MAJOR URBAN INFRASTRUCTURE PLANNING IMPACTS

There are four components of ICT infrastructure; cellular network towers, roadside infrastructure, central support systems and backbone links.

Major urban infrastructure projects include; new railway lines (e.g. Melbourne Metro), motorway upgrades (e.g. Monash Freeway Upgrade), new motorways / toll roads (e.g. North East Link), housing / precinct developments (e.g. Fisherman's Bend).

Table 5.1 Major Urban Infrastructure projects – Recommended Planning Requirements

INFRASTRUCTURE	CELL TOWERS	ROADSIDE DEVICES	CENTRAL SYSTEMS	BACKBONE LINKS
New railway lines	Ensure coverage for full route to enable booking of linking transport services.	NA	NA	Cell tower connectivity
Upgraded Motorway	Ensure coverage and density of cell towers to cope with predicted traffic volumes	Include power and communication cables preinstalled from roadside cabinets to sign gantries/traffic signals. Provide sufficient spare power and communications capacity at roadside cabinet.	Plan for increased device number support requirements.	Upgrade existing communication links to include all future V2I traffic. Design to allow external connectivity (cloud to V2I)
New Motorway	Ensure coverage and density of cell towers to cope with predicted traffic volumes	Include power and communication cables preinstalled from roadside cabinets to sign gantries/traffic signals. Provide sufficient spare power and communications capacity at roadside cabinet.	Plan for increased device number support requirements.	Design communication links to include all future V2I traffic and allow external connectivity (cloud to V2I)

INFRASTRUCTURE	CELL TOWERS	ROADSIDE DEVICES	CENTRAL SYSTEMS	BACKBONE LINKS
New precinct / housing estate	Ensure coverage and density of cell towers to cope with predicted population	Include V2I devices on traffic signals	Plan for increased device number support requirements.	Design communication links to include all future V2I traffic and allow external connectivity (cloud to V2I)

5.7 CROSS-STATE OPPORTUNITIES AND RISKS

Traditionally Australia has had difficulty coordinating technology and standards across states. For CAVs, the interoperability across state lines demands coordination. It is not feasible to have a situation where cars are prevented from crossing state borders due to differing standards or technologies. If states work together and a nationwide authority is created, it can alleviate risks and create many opportunities.

5.7.1 NATIONWIDE AUTHORITY TASKED WITH ALIGNING STATE REGULATIONS AND TECHNICAL STANDARDS AND GUIDELINES

It would be very valuable to support, expand or mimic a group like the multi-modal National Transport Commission that provides nationally-aligned advice that the States are committed to delivering.

5.7.2 OPEN DATA AGREEMENTS AND PROTOCOLS FOR SHARING C-ITS MESSAGING AND TRAFFIC DATA BETWEEN APPLICATION PROVIDERS AND C-ITS CENTRAL PLATFORMS.

Mobile phones and other devices may run C-ITS applications requiring data to be shared. There are standards for C-ITS messages but these are open to interpretation and the transport layer needs defining, among other things. A single national authority responsible for all aspects of AV implementation (similar to the current NTC but with enhanced accountability for States) should be considered.

While it may be early days, there are opportunities to incorporate these applications in trials. If we stay ahead of the game, we may obtain a competitive advantage that gives us a voice in how various sources manage data and provide it for traffic management purposes.

5.7.3 C-ITS STANDARDS INTERPRETATION FOR NATIONAL IMPLEMENTATION

The European Telecommunications Standards Institute (ETSI) standards for C-ITS are not fully developed and are open to interpretation. To harmonise the messaging and operational aspects of these standards, we should adopt a national approach that considers current learnings and understandings from national and international trials. Empowering a single national authority responsible for all aspects of AV implementation (similar to the current NTC but with enhanced accountability for States) should be considered.

5.7.4 FLEXIBLE/SCALABLE C-ITS CENTRAL STATION PLATFORM DEVELOPMENT FOR NATIONAL IMPLEMENTATION.

There are standards identifying some aspects of how a C-ITS Central Operation System should operate that are incomplete and open to interpretation. There are also national trials currently underway that include the development of a C-ITS Central Station for use in these trials. The learnings from these trials should be considered at an early stage to ensure we adopt a consistent approach to developing a national C-ITS structure.

5.7.5 INTEGRATION OF C-ITS CENTRAL STATION INTO NATIONAL ITS ARCHITECTURE

Development of a C-ITS Central Station should consider incorporating the C-ITS Central Station into the National ITS Architecture, which needs modification to adequately account for CAV traffic operation. The National ITS Architecture provides for connectivity between road operators to help traffic management. This should be considered, with reference to C-ITS and AV integration.

5.7.6 DATABASE DEVELOPMENT FOR C-ITS I2X MESSAGING

We have an opportunity to develop a common understanding of a C-ITS Central Station and how it should operate. Part of this operation involves using existing databases or developing new databases for the C-ITS Central Station to use to produce C-ITS messages on road-works warnings, incident warnings, road weather warnings as well as variable and static speed zone and other in-vehicle messaging. Some of this work is already underway in current trials, creating an opportunity to leverage development work and lessons learned and offer this to the CAV market early in the deployment process, to take best advantage of data sharing-negotiations with AV OEMs.

5.7.7 NEXT GENERATION INCIDENT MANAGEMENT SYSTEM

There are numerous information sources for events and planned/unplanned incidents. Many sources are not obtaining this information from road authority resources. With the expected proliferation of CAVs, more and more data will be derived from the CAVs themselves. Therefore, we need to reconsider how future incidents will be detected and managed. All states and territories should develop incident management systems that can take advantage of CAV operation. Staying ahead of CAV deployment appears essential. There are good reasons to develop a standard approach to incident management, which would include data sharing between all road operators and incorporate the latest technologies, including artificial intelligence.

5.7.8 NEXT GENERATION FREEWAY TRAFFIC MANAGEMENT SYSTEM AND CENTRE

The expected proliferation of CAVs warrants consideration of next generation Freeway/Traffic Management Systems and Traffic Management Centres that can take advantage of CAV operation. As conventional vehicles are phased out, Freeway/Traffic Management will change. Initially, any next generation system must integrate with current systems or incorporate current operations.

5.7.9 DATA WAREHOUSING

If C-ITS data received by the road operator is used to extract traffic information, there would be a requirement to store and manage a lot of data. We would need data warehousing and management processes in place to ensure security and integrity. Data should be accessible only by specific users with privileged system access. Using a data warehouse also allows data to be extensively analysed without operational impacts on the management system. As with other aspects of new generation CAV-centric systems, there are good reasons to develop a standard approach to Data Warehousing across all road operators. All data generated by the system should be made available once it has been adequately applied through privacy and security screens. Agreements should be put in place around what data can be provided to third parties.

5.7.10 GEO-RELEVANT C-ITS MESSAGE BROKERAGE FUNCTION AND MESSAGE TRANSPORT PROTOCOLS

To target relevant messages to C-ITS vehicles and devices, the Central C-ITS System will include a Geo-Relevant C-ITS Message Brokerage function together with a common agreement on message transport protocols. For the C-ITS functionality to work across all road operators, nationwide agreement on functionality will be required across all parties. Agreement on a standard approach to Geo-Relevant C-ITS Message Brokerage function and message transport protocols will be essential, across all road operators.

5.7.11 NETWORK SECURITY, DATA ANONYMITY AND THE SECURITY CREDENTIAL MANAGEMENT SYSTEM

As discussed in Section 5.8, there are multiple aspects to Network security associated with CAV operation. One is data anonymity. A Security Credential Management System (SCMS) would provide this as well as mutual authenticity. There should be agreement on all aspects of network security and data anonymity for CAV operation across all road operators, and discussion around Road User Charging, given the data anonymity requirement. An SCMS implementation is currently being trialled as part of the Queensland CAVI project and this may form the basis of a nationwide SCMS for C-ITS use by all states. The SCMS service should be provided by a third party and be independent of road operators.

5.7.12 GNSS TERRESTRIAL AUGMENTATION

CAVs operate with accurate positioning and a synchronised time clock. GNSS should provide the primary basis for this, under most circumstances in conjunction with SBAS augmentation. However, CAVs should also have access to other forms of augmentation, including terrestrial, as well as other primary methods of positioning for when GNSS systems are unavailable. Agreement should be sought on standardisation for (and sharing of) augmentation services and alternative primary positioning as well as time-synchronisation technologies for tunnels and the like.

5.8 DATA COLLECTION, SHARING, PRIVACY AND SECURITY

As outlined in Section 4.3 (Central Support Systems), the nature of our data needs (collection, analysis, action, dissemination) has shifted significantly over the last 5 to 10 years. We need to shift to an SOA and microservice-based approach to developing ICT networks and cloud computing.

Cloud computing offers organisations extensive benefits, including access to virtually unlimited resources, flexibility to scale cloud capacity up or down, improved business continuity, access to cutting-edge technology, faster resource provision, and improved security that can satisfy even the most security-sensitive organisations. Cloud computing's efficient resource use can also help organisations reduce their environmental impacts. Considering these powerful benefits, WSP recommends the infrastructure supporting the centralised traffic management centre (TMC) be designed, provided and managed in the cloud. We note that significant risks need to be properly accounted for when developing any system, cloud-bases or otherwise, but competent engineers can readily manage all.

Data from highly automated vehicles is a paradigm shift from traditional data handling – both the technical needs for ingesting and disseminating the data quantities, and the privacy and security requirements.

Privacy is a critical consideration. Open and transparent personal data management is the first privacy principal in the *Australian Privacy Act 1988*. And we must also consider the *Surveillance Devices Act 2004* when building systems that automatically collect people's personal data[59].

Recent work to implement the EU General Data Protection Legislation (GDPR) that came into force on 25 May 2018. The new legislation affects management and protection of all information related to EU Data Subjects including EU employees wherever they are based, end users of EU-based services, even those offered from a country outside the EU. The connectedness of global data, ICT and vehicle manufacturing industries makes these legislative developments significant here in Australia and worldwide. It will impact the global technology approach around CAVs.

---

59 https://d1.awsstatic.com/whitepapers/compliance/Using_AWS_in_the_context_of_Australian_Privacy_Considerations.pdf

All these legislative instruments build on the concept of 'Privacy by Design' that was developed into a systems engineering concept[60]. Article 25 of the GDPR outline the need for 'Data protection by design and by default'. It requires a ground-up system developed and maintained to uphold privacy. **Data minimisation** is key to the GDPR and the Australian Privacy Act, i.e. collect only what is needed and what the people involved have transparently agreed to. If anonymity must be provided, take great care in how this is achieved. CAVs will be especially challenging to consider. It will be extremely important to balance the rights of the data owner/originator, the perceived rights of the car manufacturer to that data, as well as other agencies or organisations involved in the data chain. System designs need to consider privacy and security from the ground up.

The new GDPR is intended to be adopted by many global system developers. Key potential measures include:

- The pseudonymisation (de-identification) and encryption of personal data
- The ability to ensure the ongoing confidentiality, integrity, availability and resilience of processing systems and services
- The ability to restore the availability and access to personal data in a timely manner in the event of a physical or technical incident
- A process for regularly testing, assessing and evaluating the effectiveness of technical and organisational measures for ensuring processing security.

It is likely that, in the coming decade, guidelines will be enforced across all jurisdictions, especially given that many highly automated vehicles will be required to operate in many regions. The following recommendations represent the ongoing best practice for data privacy, security and management as we progress.

It is critical to incorporate mechanisms that guarantee confidentiality, integrity and availability of information associated with automated vehicles, users and stakeholders. We recommend adhering to the following best practices[61] when designing and operating the cloud infrastructure to support the centralised traffic management centre (TMC).

1. **Shared responsibility model**: The cloud provider will be responsible for managing and controlling computing devices and host operating systems that power its services; as well as the virtualisation layer and physical security of building and installations in which it operates. On the other hand, the platform owners (the TMC) will be responsible for implementing all the necessary security design, configuration, and management for all services implemented in the cloud.

2. **Secure network architecture design**: Sufficient network segmentation is required among all functional components to provide network traffic isolation. To minimise the surface attack of exposed services, open ports must be restricted to approved services, accessible only from authorised network sources. Data must be disseminated via specifically designed and configured programming interfaces that allow direct control over data access and the enforcement of privacy restrictions before the data leaves the private network[62].

3. **Data transmission**: All network traffic between the centralised traffic management centre (TMC), vehicles, 3rd party application programming interfaces (APIs) and the open internet, require secured communication. Strong encryption solutions must be implemented for data at REST and in-transit.

   Third party data consumption should be via an API that allows controlled data access, whatever prevailing technology underpins it. Authenticated users will have access to limited data sets. Limitations should be imposed to protect user privacy and protect the system against malicious use of the API.

4. **Scalability, high availability, and fault tolerance**: By leveraging the elasticity and scalable features of cloud computing, the centralised traffic management centre (TMC) can be designed to meet workload changes and

60 http://www.privacy-regulation.eu/en/article-25-data-protection-by-design-and-by-default-GDPR.htm
https://d1.awsstatic.com/whitepapers/compliance/GDPR_Compliance_on_AWS.pdf
http://www.privacy-regulation.eu/en/index.htm

61 https://d1.awsstatic.com/whitepapers/AWS_Cloud_Best_Practices.pdf

62 https://d1.awsstatic.com/whitepapers/Security/AWS_Security_Best_Practices.pdf

seamlessly adapt to failures. It should observe design best practices such as, stateless applications and components, distributed processing, asynchronous systems, and a server-less architecture.

5 **Geo-blocking regulations**: Controls must be in place to ensure that TMC data is only processed and stored using approved Cloud Services available in Australia, for example, a Content Distribution Network can be used to improve response time, impose geo-restrictions rules and provide a mitigation layer for DDoS attacks. Access to data outside geo restrictions should be done via a built-for-purpose API.

6 **Redundancy, chaos, testing:** Testing plans should be implemented to replicate partial or total system outages (Chaos Engineering[63]). System errors will occur throughout a system life cycle. Outages can be costly to the system operators and, more importantly, dangerous in the case of mission-critical safety systems. Even if the system is built with redundant oversight, bugs and complacency can creep in. It is current industry best practice to systematically take parts of a production system offline to test redundancy. Even with these considerations, we must assume that vehicle systems will inbuild redundancy to allow graceful degradation of the automation level.

7 **Software updates:** Protocols must be installed to allow rolling updates for network assets. Roadside infrastructure must have redundant backup systems that allow the system to partially go offline during software updates. Cloud infrastructure should be designed around a service-oriented architecture. Using containerised versions of stateless applications means that new updated applications can be introduced to completely replace the old ones. Since multiple versions of applications will be running concurrently, updates can be done by replacing the old containers with updated versions.

8 **Database and Storage:**

Data at Rest – Databases at rest should be transparently encrypted. This both protects the data and significantly reduces the incentive to attack the system.

Durability of data – Data storage techniques allow us to persist regardless of underlying hardware failures. It is expected that these techniques will continue to improve as future requirements will demand handling more operations per second. By current standards, every eight years (statistically) a single object per petabyte of data should go missing. This level of durability will increase moving forward and cloud providers should be consulted as to the current best practice at the time of implementation.

Implementing this system will require multiple types of databases working in parallel.

9 **Time series data:**

Due to the volumes and near real-time requirements, new software techniques will be needed for allocating data access. Time series databases are in active development and a growing quantity of data has the following properties:

a 'Write-only' – data is appended only and never rewritten.
b 'Ephemeral' – whereby the data's greatest value is immediate, and the data's value decreases over time.
c Aggregations – happen over the temporal dimension of the data.

Data produced from highly automated vehicles meets these criteria. This is an emerging field in database technology but one that is rapidly maturing. Current offerings are still being developed but will provide an integral part of the future solution.

Time series databases should house data for near real-time consumption, and warehouse it after its critical operational utility has expired.

10 **Data Warehousing**

Data warehousing techniques allow the long-term storage and offline analysis of the data to gain insights about the networks operational properties and to improve the operation moving forward.

---

63 https://www.gremlin.com/media/20171210%20%E2%80%93%20Chaos%20Engineering%20White%20Paper.pdf

Data should be accessible by specific users with privileged system access. Using a data warehouse allows expensive analysis to be done on the data without impacting the operational side of the management system. All events that are ingested into or generated by the operation systems should end up in a single data warehouse.

11 **Audit and Log Management**: Relevant network traffic must be collected, processed and stored for audit and compliance purposes, including API calls, admin and superuser account activity, application endpoints and database access. Data transformation for anonymisation and encryption might be required to comply with data privacy regulations and secure storage.

12 **Compliance**: The cloud provider must comply with the relevant standard and regulations, including but not limited to ISO 27001 for information security management systems; ISO 27017 - Implementation of cloud-specific information security controls; ISO 27018 - Code of practice for protection of personally identifiable information (PII) in the cloud; SOC controls; IRAP Security Assessments; ASD Certification; Privacy and Data Protection in Australia, and General Data Protection Regulation[64].

Aspects of this specification should be particularly noted:

a Continuous improvement of practices and policies
b Risk management policies – maintaining and updating a register of security risks

Publication of security incidents, both internal and external (likely to legislated).

5.9 CYBER SECURITY

Reliance on external communications exposes AV networks to threat vectors which impact safe operations. In contrast to data privacy where confidentiality is of highest concern, continuous and reliable AV operation relies heavily on data integrity and availability. Some typical malicious acts that can lead to traffic disruption and cause passenger harm include:[65]

— Compromising (hacking) the AV Engine Control Unit (ECU) to take over vehicle control and critical systems such as vehicle safety
— De-calibrating AV sensors and modifying maps to distort guidance and vision
— Jamming the GPS to prevent tracking after theft of the AV
— Denial of Service (DoS) attacks to prevent receiving critical information and/or rendering the AV inoperable by flashing firmware
— Intercepting and hacking the AV Event Data Recorder System (black box)
— Spoofing C-ITS messages to confuse other vehicles or infrastructure.

To address the AV cyber security measures listed above, there are security features and processes which should be considered by the OEM (Original Equipment Manufacturer) during the AV design phase. These are best industry practices which are widely implemented in aviation, rail, industrial control and critical infrastructure and can be adopted by the emerging AV industry.[66]

64 https://d1.awsstatic.com/whitepapers/compliance/AWS_Risk_and_Compliance_Whitepaper.pdf
65 Autonomous Vehicles for Smart and Sustainable Cities: An In-Depth Exploration of Privacy and Cybersecurity Implications, Hazel Si Min Lim and Araz Taeihagh, National University of Singapore, 25 April 2018
66 McKinsey & Company, Shifting gears in cyber security for connected cars, February 2017

5.9.1 AIR GAPPING

Creating air gaps between critical and non-critical systems by removing any physical, logical and virtual connectivity reduces the attack footprint for a given AV. A typical example is isolating the infotainment system which is usually connected to the IoT, from vehicle control and monitoring systems such as assisted braking, steering and collision detection.

5.9.2 NODE ENCRYPTION USING LIGHTWEIGHT CRYPTOGRAPHY

In a developed AV industry, it is expected that vehicle componentry will form communications nodes as part of a secure AV network, most likely as an IoT subset. The vehicle engine control unit (ECU) is one of the most critical AV nodes as it not only controls the drivetrain but other important systems such as safety systems and engine assisted driving mechanisms. While there is currently no standard for AV inter-node communication cryptography, it is acknowledged that a form of lightweight cryptography (LWC) is required that is efficient and consumes minimal AV device memory and energy while providing secure inter-nodal communications. [67]

5.9.3 ANOMALY-BASED INTRUDER DETECTION

AV operation dictates certain constant (or typical) instrumentation readings, such as tire pressure, power consumption, AC temperature, digital compass, intelligent cruise control speed, etc. Anomaly-based intruder detection most often uses artificial intelligence (AI) driven rules to differentiate between normal operation and disruptive or anomalous activities.[68] Though not yet adapted in the AV sector, this cyber security measure is proven in power generation and complex network monitoring[66] and can potentially provide early detection of suspicious vehicle behaviour before a traffic incident occurs.

5.9.4 REDUNDANCY

In the context of automation, redundancy implies that there is no single point of failure, and that any given function can be performed by two or more components or systems. Should one system be hacked, there is a failover procedure to continue performing the relevant function by the secondary or redundant system. Current examples in AVs include redundant collision detection, redundant power sources, dual self-driving computers, alternate paths between computers, sensors and actuators and different means of vehicle localisation (e.g. GPS, Wi-Fi and LiDAR).[69]

5.9.5 SCMS CERTIFICATE REVOCATION

Revocation of SCMS issued certificates to allow the removal of a bad actor in the C-ITS environment. This would mean that all other vehicles and infrastructure would ignore any broadcast C-ITS messages from a bad actor with a revoked SCMS certificate. The current SCMS implementation only allows for expiration of certificates and not revocation meaning that bad actors form part of the trusted peer-to peer network until expiry of their certificates.

---

[67] Lightweight Cryptography for the Internet of Things, Masanobu Katagi and Shiho Moriai, Sony Corporation

[68] Anomalous Payload-based Network Intrusion Detection, Ke Wang and Salvatore J. Stolfo, Columbia University

[69] General Motors 2018 Self-Driving Safety Report

5.10 OTHER ENABLERS AND BARRIERS

Over a series of workshops and during research of this document additional enablers and barriers were identified. Additional research would be beneficial in exploring or developing these further.

5.10.1 ENABLERS

Table 5.2 List of additional enablers and commentary

ENABLER	COMMENTS
Increased Transport Network Efficiency	Reduced cost of transport with varied mode choices (i.e. not owning a car) very likely to reduce cars on the network and encourage fleet mode changes.
Revenue Benefit to Mobile Network Operators (MNOs) from CAVs	Increased data, available diagnostics around user behaviour are financial incentives for MNOs to provide strong coverage.
Black box used in insurance industry	This technology gives similar AV technologies a head start.
Decrease in component costs (particularly LIDAR)	Recent reports have LIDAR significantly reducing in price.
Inclusion of Advanced Driver Assistance Systems as standard features on new vehicles	Research driving the horizon encourages today tech and makes people more comfortable with new tech
Car OEMs are planning to install V2I devices on vehicles.	Recent announcements from Ford and Toyota in the US are maybe promising. The global market and the wider technology context can shift rapidly. The opportunity for wider access to this data is not yet clear
Governments engaged in CAVs	Willingness of governments internationally and an interest in innovation is driving development
Clear business cases around automation with commercial / freight vehicles	Freight and commercial vehicle industry and vehicle manufacturers are already realising some benefits with basic automation. Removing drivers is an easily understood and defined cost saving to drive investment.
Improved data on operation of road networks	Greater understanding enables quicker reaction to incidents (reducing secondary congestion, improving safety).
Rollout of 5G network essential for full C-ITS rollout to enable fast communications in a high-density device environment.	Will be required for high density population areas of Melbourne. 5G function of frequency separation for priority systems may also be required.
Reliable communications and storage backup systems will be essential for full C-ITS rollout. Enhanced real time data collection from multiple sources, storage and reporting systems will be required in order to provide accurate information to C-ITS vehicles.	This is now feasible in metropolitan Melbourne and regional cities, extension of cellular network coverage would benefit rural locations.
Interactions between multiple information owners, storers and users of the data need to be formalised and systems/agreements put in place.	Needs to be lead nationally (NTC or similar) with cross-state agreement.
Council/private Parking for CAVs	Efficient and responsive MaaS operators will require vehicles to be near customers – need to resolve where they can wait.

5.10.2 BARRIERS

Table 5.3 List of additional barriers identified with commentary

BARRIER	COMMENTS
Accurate Navigation Systems (pending clarification Fed announcement).	While the recent Federal announcement to provide funding for SBAS the amount of funding appears to be less than what the industry thought may be required. A lack of funding and implementation delays could impact AV utilisation, particularly in rural locations (e.g. lack of line-marking, narrow pavement etc.).
Large data volumes (getting value, managing what's worthwhile, aggregation vs raw data)	Vehicles may internally generate in the vicinity of 50GB per hour, manufacturers may be cautious and attempt to upload increased levels of data, particularly video, due to unforeseen operational complications. How does this impact the network? How do we manage this data and provide value?
Computing resources - good algorithms (AI, machine learning, pattern matching e.g. maintenance, network optimisation)	Requires centralised funding.
Policy & Regulations (also motorbike V2I / V2V)	Requires government policy.
Legal Framework & insurance – International Differences (equipment selection, vehicle availability e.g. similar to current emissions regulations)	Requires government policy.
Insurance / liability	Requires government policy.
Wireless connectivity coverage (LTE, 5G, Satellite, DSRC)	National security issues with hardware provider for 5G hardware (particularly with Huawei)
Aftermarket Applications Policy (parts, technology modifications)	Requires government policy.
HMI Policy (disability / elderly / kids)	Government needs to proactively plan how vulnerable road users will interact with a transport system dominated by AVs.
Satellite Interference Issues (solar flares, how to manage when this happens)	Degraded mode policy development.
Uncertainty over ownership of data	Requires government policy to enhance interoperability and maximise network optimisation opportunities.
Data privacy concerns - C-ITS standard messages deemed personal info	Requires government policy – application of recent European standards would be appropriate.
Lack of expertise & resources within local authorities / public sector	Requires commitment from government to proactively skill up and resource.
Lack of money for installing/maintaining infrastructure	Funding for ICT maintenance in Victoria has been anecdotally insufficient.
Lack of overall failsafe and appropriate safety harbours	For vehicles that fail and end up in degraded mode – are we happy for them to be managed as they are today? Should road designs (particularly all lane running) change?

BARRIER	COMMENTS
Complexity in determining liability when driving task is shared between human and vehicle. Automated vehicles not legally permitted to operate on road	Some legal work is underway. Need to ensure it reflects the technical capabilities.
Traffic signal controllers need to upgraded to next generation & C-ITS RSUs installed at signalised intersections in order to enable CAV benefits, until full C-ITS saturation.	Significant investment could be required. Propose replace as part of ongoing routine obsolescence replacement.
Dynamic and Static Speed, Incident/roadworks management databases need to be developed/made available to C-ITS equipped vehicles	Requires commitment/funding from government.
Data from C-ITS vehicles needs to be retrieved by road agencies for traffic management to enhance existing road sensor data in the interim and to ultimately replace road sensor data.	Requires commitment/funding from government.
Dynamic and Static advisory signage data needs to be made available to C-ITS equipped vehicles	Requires commitment/funding from government.
Road tunnel systems will need to be upgraded to provide lane level positioning accuracy on approach to and within tunnels for CAV vehicles	Requires commitment/funding from tunnel operators (in Victoria this is Transurban and ConnectEast.

5.11 TRIGGERS AND INTERVENTIONS

We examined the scenarios (where relevant) and main infrastructure components over their lifespan of policy/strategy, planning, funding, design and implementation and have highlighted important triggers and interventions from an ICT infrastructure perspective. Most of these triggers and interventions are based on a broad sensitivity analysis that extrapolate critical assumptions.

5.11.1 PRIVATE DRIVE

The level of private car usage would have to be closely monitored for impact on central systems. If data usage exceeds expectations at a low level of AV fleet penetration (say 10%), then infrastructure investment will need to be re-assessed. By engaging early with car manufacturers, we can model this. Without monitoring, central systems can become overwhelmed, but cloud-based central systems somewhat mitigate the problem.

Cellular network congestion will need to be monitored in high vehicle density areas. If the limit of connections per cell is exceeded (2200 for 4G), it would require a priority upgrade to 5G (if available) or additional microcells. Assigning priority frequencies to critical services may somewhat mitigate 5G sites' need.

5.11.2 FLEET STREET

The approval process should include engaging early with fleet operators around expected vehicle communication data flows. If expected (or observed) data flows are abnormally large, fleet operators should be involved in optimisation and advised on any additional strategic planning. Transport for Victoria should undertake strategic planning using a detailed understanding of the existing ICT infrastructure and developing trends to provide direction to industry, government or regulators related to capital funding or technical expectations.

5.11.3 SLOW LANE

Infrastructure improvement planning should be broken into logical investment steps, after reassessing the current rate of AV fleet penetration. Cloud-based central systems somewhat mitigate this.

Investment in cellular network coverage has benefits beyond transport that mitigate any perceived overinvestment. Benefits include enabling a connected community, better business support and improving responsiveness and management of emergency incidents.

5.11.4 HIGH SPEED

Infrastructure investors should actively monitor AV fleet penetration using registration and readily available monthly vehicle sales information[70]. Sustained growth over six to twelve months that exceeds modelled expectations is likely to show any accelerating trend that could impact ICT infrastructure planning.

5.11.5 CELLULAR TOWERS

Investment in cellular network coverage has benefits beyond transport that will mitigate any perceived overinvestment.

Roll out of AVs where coverage is needed will initially trigger new cell towers – likely freight demand due to higher investment returns for freight operators. A second trigger would be the wide release of vehicles. Forging closer industry connections would help minimise gaps between vehicle roll outs and infrastructure being built.

During the early roll-out phase, there is a high risk of drivers using AVs on roads without coverage. Adverse outcomes, especially road safety issues, will require government intervention.

Vehicle regulations need to be developed and must detail when nimble degradation must occur, and under what circumstances. This should be the responsibility of a single national authority responsible for all aspects of AV implementation (like the current NTC but with enhanced accountability for States).

5.11.6 V2I TRAFFIC SIGNALS – CRITICAL

Installing roadside V2I devices represents the highest ICT infrastructure overinvestment risk.

There are two competing communication protocols that increase the overinvestment risk beyond meeting end user demand. Either one protocol will emerge as dominant, or a technical solution will be developed to reduce the cost of supporting both. Investigation is needed to determine if both solutions can be cost-effectively accommodated. If not, then WSP recommends NTC and Austroads (through grant projects) monitor overseas trends and engage with vehicle manufacturers and fleet operators to learn their intentions regarding preferred V2I technology.

If this issue remains unresolved when AVs are entering the network, the 300 highest-priority sites (i.e. Melbourne CBD) could receive a reduced $10m investment that starts acquiring AV fleets.

5.11.7 VULNERABLE ROAD USERS

Motorcyclists need a passive beacon or similar device that provides information on their vehicle to nearby vehicles and roadside infrastructure. Ensuring this eventuates will require policy changes or regulation. Factors such as driver distraction need to be considered when interactions (alerts) increase between motorcyclists and other road users.

---

70 https://www.fcai.com.au/sales

6 KEY FINDINGS

6.1 SCENARIOS

For ICT infrastructure, the relevant scenarios are Private drive/Hydrogen Highway, Fleet street, Slow lane, High speed and Dead end.

Private drive would likely result in the highest ICT infrastructure use due to the volume of vehicles generated.

All scenarios require a centralised authoritative source of road incidents, travel conditions and roadworks.

Minimum level of ICT infrastructure investment would:

- Emphasise safe operation over efficiency or economic benefits
- Provide minimum possible ICT infrastructure to still ensure safe AV operation on critical Victorian roads
- Minimise all over-investment or technical obsolescence risks
- Ensure Victoria is not disadvantaged compared with other states or countries.

Optimum level of ICT infrastructure investment incorporates the minimum levels, and would:

- Emphasise economic benefits, networks efficiencies, and best use of existing assets
- Promote a more effective and holistic transport network management approach
- Ensure vehicles can run optimally for most trip distances.

6.2 USE CASES

Exploring use cases provided a breadth and depth of detailed user interactions that was previously not well understood. Some of the key findings include:

- Vehicles will communicate with centralised infrastructure primarily via cellular networks and roadside infrastructure.
- Location accuracy is sufficient at the lane level. Vehicle manufacturers are currently planning to use digital mapping with LIDAR for fine positioning.
- Centralised systems will need developing to determine V2I information and proactive messaging to AVs in all scenarios.
- Road pricing will most likely be facilitated through information available to car manufacturer clouds. A policy should be established early to determine whether car manufacturers or end users will directly interface with government.
- Private vehicles will most likely need to run in a ‘degraded’ state on link routes not covered by cellular networks.
- Emerging market information suggests that fleet vehicles will have similar live ICT infrastructure usage but likely increased long-term usage (compared to private vehicles).
- Freight vehicles will have the same ICT requirements as private vehicles. If industry supports platooning, then fine positioning with LIDAR and V2V communications should suffice. A central authority may impose some transport network policies, including where or when platooning is permitted.
- Vulnerable road users (motorcyclists, cyclists and pedestrians) will need their needs and interactions carefully considered to ensure they are safe and not disadvantaged.
- Traffic signals will need retrofitted V2I device solutions, requiring careful planning and liaison particularly between states. Deciding between technologies presents significant risks, i.e. is DSRC or C-V2X the preferred option?
- Passive roadside infrastructure such as Variable Message Signs should be maintained for the medium term (i.e. more than 10 years). Given these devices’10-year lifespans and benefits, VicRoads should, where appropriate, continue installing passive roadside infrastructure.

6.3 FUNCTIONAL ANALYSIS

From the user interactions, we used current trials, proposed technical standards, or established technologies to see technical understanding. The key findings include:

- Vehicles will communicate with each other, with active roadside infrastructure, and with the Central System via cellular networks.
- Vehicles will have a permanent cellular connection with vehicle manufacturers or fleet operators. Mapping will likely be transmitted over this connection.
- Vehicles will also communicate with centralised systems via roadside infrastructure and cellular connection.
- Vehicles will position themselves using a hybrid navigation system comprising Global Navigation Satellite System (GNSS) with positioning augmentation from various internal and external systems. In tunnels, or other environments with poor or no GNSS coverage, additional systems have been trialled internationally, including WiFi, Bluetooth, Cellular, C-ITS Roadside Stations and other alternative technologies, such as magnets imbedded in pavement[71]. The results of these trials are yet to be made public and would require further analysis to establish their local viability. Infrastructure investment will be informed by the results of these alternative technology trials.
- The Australian Government has announced funding to increase GNSS coverage, improving accuracy to three to five centimetres for regional and metropolitan areas with mobile phone coverage, and up to 10 centimetres elsewhere.
- Vulnerable road users such as cyclists and pedestrians could use opt-in cellular (cooperative V2X) phone tracking that is centrally integrated and anonymised and provided to other road users. Some passive tracking of cellular phones is also feasible through the mobile network operator or WiFi or Bluetooth roadside tracking. Such trials are already underway and could be integrated into roadside devices in areas of historical high risk for vulnerable road users.
- Some regulation or policy may be needed to ensure motorcyclists have a passive beacon or similar device providing vehicle information to nearby vehicles and roadside infrastructure. Any increased interaction (alerts) between the motorcyclist and other road users needs to consider factors such as driver distraction.
- Automated vehicles (AVs) will generate around 20GB of data per hour through on-board sensors, cameras and technology, but most of this data does not need to be shared. We conservatively estimate that 10MB per vehicle per hour will be transmitted and 10MB downloaded via the cellular network.

6.4 INFRASTRUCTURE

6.4.1 CELLULAR TOWER COVERAGE

The minimum number of new cell towers required is 134, focussing on M and A class roads. Order of magnitude cost estimate is from $76m to $109m.

For the optimum level of ICT infrastructure investment, the cellular network coverage was extended to all sealed roads. This increased the number of towers fifteen-fold to 2098. Order of magnitude estimate would be $1.1b to $1.7b.

WSP believes that key triggers for roll out of cell towers should be linked to freight usage. Government, through peak industry bodies, should gain an understanding of proposed fleet changes (which may involve platooning) that would strongly benefit from increased cellular network coverage. From this government (most likely Transport for Victoria) would need to gain an understanding of actual surveyed cellular network gaps on proposed freight routes. If there is no financial driver for MNOs to provide it, then government will need to provide this coverage through a mechanism much as it has with the current blackspot program.

---

71 http://www.dot.ca.gov/newtech/researchreports/two-page_summaries/magnetometer_research_note_rev1.pdf

6.4.2 ROADSIDE INFRASTRUCTURE

VicRoads estimates that 33 per cent of intersection signals in metropolitan Melbourne and Geelong are critical to maintain transport network flows. WSP believes that by 2046, for the minimum scenario, about 1283 sites will provide the minimum level of V2I roadside infrastructure, costing in the order of magnitude of $39.5m.

For the optimum level of ICT infrastructure investment, V2I coverage was increased to all active roadside infrastructure including traffic signals and lane control signs. This will cost in the order of magnitude of $204.2m.

6.4.3 CENTRAL SUPPORT SYSTEMS

WSP believes that of the 10MB per hour of data generated by vehicles, 10 per cent will be stored for a month in a facility with high availability. For long term storage (up to 20 years) this will halve to 5 per cent of total data generated. Using maximum vehicle numbers, and modelling provided by others, we found over the different scenarios that:

- Maximum number of connections is 643,647
- Maximum total data stored per month is 664 terabytes.
- Maximum data stored per month is 3,986 terabytes.
- Cost of a hardware vendor approach would be in the order of magnitude of $8.5m - $11.5m (capex) and $2.5m per year (ongoing)
- Cost of a cloud-based approach would be in the order of magnitude of $600,000 - $750,000 per year (ongoing)
- Cost of integration software has not been estimated. It was noted that if Victoria is an international leader in implementing AVs then this cost could be extensive.

6.4.4 BACKBONE LINKS

WSP considers the scale of data transmitted and received by AVs to be a fraction of the overall network traffic. As such, no significant infrastructure cost should be assigned to expanding backbone links.

A sensitivity analysis was also undertaken of vehicle data transmitted and received in the context of overall network size. Increasing the vehicle data transmitted and received a hundred-fold was still less than one (1) per cent of total network traffic in 2031 (the most aggressive scenario).

6.5 ENABLERS AND BARRIERS

Centralised systems supported by government must have inherent flexibility, future proofing, expandability, security and reliability. A cloud-based system provides these features cost effectively.

Funding should be sought for achieving a true centralised transport management centre that all transport authorities are committed to. In Victoria, this should be sought from Transport for Victoria.

The complexity of integrating all the key systems, transport data and financial payments into one single system and interface can only be resolved if there is clear government policy and an associated framework.

Major project authorities should be advised to ensure basic compliance with support infrastructure (available power and communications) so that implementing the likely technical AV solution is as cost-effective as possible.

Planning should start soon towards nationwide standards, agreements and protocols for security credentials, vehicle communication technology requirements, and Open Data between application providers and central systems. National coordination is critical for success. Thought should be given to empowering a single national authority responsible for all aspects of AV implementation (much like the current NTC but with enhanced accountability for States).

Data management discussions including collection, sharing, privacy and security should be nationally directed and regulated. If a national authority is established, this should form part of its responsibility. Whether national- or state-managed, the most likely infrastructure solution is cloud-based and it will require strong policy, design principles, industry provider liaison, and architecture planning. Funding should be allocated for planning and industry provider liaison. While international providers are still determining the best approach, if Victoria takes a proactive engagement approach, it could significantly contribute to meeting Victoria's main interests.

For cyber security a reliance on external communications exposes AV networks to threat vectors which impact safe operations. Solutions include air gapping, node encryption, anomaly-based intruder detection, redundancy and SCMS certificate revocation.

6.6 TRIGGERS AND INTERVENTIONS

Engagement and awareness of vehicle manufacturer and fleet operator intentions regarding vehicle data flows and preferred V2I technology is critical for future planning and adjusting strategic investment.

Early engagement with industry-leading cloud-based service providers, such as Amazon Web Services, could be advantageous in potentially providing influence through early leadership.

7 LIMITATIONS

This report is provided by WSP Australia Pty Limited (*WSP*) for Infrastructure Victoria (*Client*) in response to specific instructions from Infrastructure Victoria and in accordance with our Agreement for services.

7.1 PERMITTED PURPOSE

This report has been produced by WSP for the purpose of providing the Client with indicative advice regarding Victoria's potential ICT infrastructure needs to support automated vehicles. The report contains advice, conclusions and/or statement which fully or in part may be based on information and documentation provided to WSP, by or on behalf of the Client, regarding Victoria's potential ICT infrastructure needs to support automated vehicles. No responsibility is accepted by WSP for the use of the report in whole or in part, for any purpose, goal, interest, need, circumstance or project.

7.2 QUALIFICATIONS AND ASSUMPTIONS

The services undertaken by WSP in preparing this report are limited to those specifically detailed in the report and are subject to the scope limitations set out in the report. The findings contained in the report are subject to the qualifications and assumptions set out in the report or otherwise communicated to the Client.

Except as otherwise stated in the report, statements, opinions, facts, conclusions and / or recommendations in the report (*Findings*) are based in whole or in part on:

(a) information, opinions, data, materials, models, documents and the like at the time of preparing this report:

   (i) found in publicly available sources or otherwise made available to WSP by Infrastructure Victoria; and

(b) assumptions by WSP of the reliability, adequacy, accuracy and completeness of such information, opinions, data, materials, models, documents and the like.

WSP has prepared the report without regard to any special interest of any person other than the Client when undertaking the services described in the Agreement or in preparing the report.

Due care and attention has been taken with the report in relation to the interpretation of the information relevant to recommendations or suggestions for order of magnitude costs and likely technical solutions. However, WSP does not assume responsibility for:

(a) changes in material costs or other supply change costs or market dynamics;

(b) changes in market forces or technology developments;

(c) changes in policy or interpretation of policy by statutory authorities; or

(d) the actions of contractors responding to commercial pressures when pricing or constructing capital works of the nature referred to in the report.

7.3 USE AND RELIANCE

In preparing this report, WSP relied, in whole or in part, on data and information provided by Infrastructure Victoria and third parties, which information has not been independently verified by WSP and which WSP has assumed to be accurate, complete, reliable, and current. Therefore, while WSP has utilised its best efforts in preparing this report, WSP does not warrant or guarantee the conclusions set forth in this report which are dependent or based upon data, information, or statements supplied by third parties or the client or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. This report is intended for Infrastructure Victoria's sole and exclusive use, and is not for the benefit of any third party and may not be relied upon by, any third party. This report should be read in full and no excerpts are to be taken as representative of the findings. Use of this report or any information contained herein, if by any party (other than Infrastructure Victoria), shall be at the sole risk of such party and shall constitute a release and agreement by such party to defend and indemnify WSP and its affiliates, officers, employees and subcontractors from and against any liability for direct, indirect, incidental, consequential or special loss or damage or other liability of any nature arising from its use of the report or reliance upon any of its content. To the maximum extent permitted by law, such release from and indemnification against liability shall apply in contract, tort (including negligence), strict liability, or any other theory of liability.

8 ABOUT WSP

WSP is a wholly owned subsidiary of WSP Global Inc — an international professional services company listed on the Toronto Stock Exchange. We have approximately 42,000 employees, including engineers, technicians, scientists, architects, planners, surveyors, program and construction management professionals, and various environmental experts. We are based in more than 500 offices across 39 countries. WSP is one of the world's leading engineering professional services consulting firms. We are dedicated to our local communities and propelled by international brainpower. We design lasting Transportation & Infrastructure, Property & Buildings, Resources (including Mining and Industry), Water, Power and Environmental solutions, as well as provide project delivery and strategic consulting services. For over 50 years, our company has built a wealth of multidisciplinary technical skills and local knowledge in Australia. With 4,610 talented people in 62 offices across Australia and New Zealand, we engineer projects that will help societies grow for lifetimes to come. wsp.com

We have a strong commitment to technical excellence, a diverse workforce, and providing high quality service to clients, which is reinforced by our range of experience: from the mega-projects that define an entire region to smaller, more local projects that keep a community functioning. Our ability to collaborate successfully on these broad-ranging projects has made us an industry leader in alliances and other relationship-based contracting environments.

Within the field of Intelligent Transport our expert practitioners from around the world have deep personal and professional links. This has created a strong collegiate culture of sharing knowledge and lessons from similar projects as other governments grapple with this global issue. Locally we are well-connected with professional and academic organisations through industry groups such as ITEANZ.

An industry leader in the field of AVs and ZEVs, WSP is working with clients globally as they consider strategy for the implementation of both policy and technology. We offer a dedicated team of specialists in AV/ZEV policy and technology, backed by leading-edge Intelligent Transport expertise and the resources of one of the world's leading engineering and professional services firms.

BIBLIOGRAPHY

- Terms of Reference – Advice from Infrastructure Victoria on automated and zero emission vehicle infrastructure (TOR).
- Request for Quotation – Automated and Zero Emission Vehicle Infrastructure Advice – ICT Advice (RFQ).
- Deloitte Infrastructure Capability Assessment – ICT for Infrastructure Victoria (2016). Retrieved 30 March, 2018, from www.infrastructurevictoria.vic.gov.au.
- WSP 2017, 'New Mobility Now White Paper', retrieved 12 March 2018, https://www.wsp.com/-/media/Campaign/Global/Document/WSP-New-Mobility-Now.pdf.
- SAE International J3016-2016, 'Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles', published September 2016, http://standards.sae.org/J3016_201609.
- Austroads Research Report AP-R543-17, 'Assessment of Key Road Operator Actions to Support Automated Vehicles', Published May 2017.
- ITS World Congress 2017, 'Next Generation Mobility: Driving Smart Cities – Post-congress Report', www.ITSWorldCongress2017.org.
- Combs, T, 'Limitations in Detection Technologies for Automated Driving Systems and Implications for Pedestrian Safety', TRB 2018 Annual Meeting – Paper 18-03947.
- Infrastructure Victoria, 'Infrastructure Capability Assessment – ICT', retrieved April 2018, http://www.infrastructurevictoria.com.au/sites/default/files/files/160229-ICT-Final.pdf.
- European Commission 2017, 'Connected and Automated Transport – Studies and report', Directorate-General for Research and Innovation - Smart, Green and Integrated Transport.

APPENDIX A

ASSUMPTIONS

APPENDIX A ASSUMPTIONS

ASSUMPTION	SOURCE/EVIDENCE
Metropolitan Melbourne will have full cell coverage and is not included as part of the analysis.	https://www.telstra.com.au/coverage-networks/our-coverage
A 5km radius coverage range is assumed for cell towers, both existing, assumed and future/proposed, based on relatively flat terrain, less subscribers connected to a single base station than there is capacity on the roads, current 4G frequencies are used and macrocells are used to provide coverage	http://www.mobilenetworkguide.com.au/mobile_base_stations.html
A list of existing cell towers was sourced from the ACMA website on date 12/04/2018 (double check with digital?). this formed the "existing" list of cell towers.	http://www.rfnsa.com.au
It was assumed that all cell tower locations listed in the Mobile Black Spot Program for Round 1, Round 2 and "Priority Locations" would be constructed and functional by 2031, regardless of any government budget changes. This formed the "future/proposed" list of cell towers.	https://www.communications.gov.au/what-we-do/phone/mobile-services-and-coverage/mobile-black-spot-program
It was assumed that the Department of Planning and Community Development report Towns in Time (2008) had a list of all existing towns in Victoria.	https://data.gov.au/dataset/towns-in-time-victoria
A comparison was made with the location of all listed towns and assumed cell phone coverage. A list of towns was found to not have coverage, and it was assumed that a future cell tower would be built in the town. The assumed location of the cell tower was the centre of town. This formed the "assumed" list of cell towers.	https://www.telstra.com.au/coverage-networks/our-coverage (Based on reviewing list of towns with "no coverage" and current Telstra coverage map, which showed all listed towns had coverage. As such, assumed in future, these towns will have coverage)
The above assumptions with existing, proposed and assumed towers form the future "existing base" cell tower locations in 2031.	Overarching assumption - refer to above for individual assumption sources
No new future roads or road upgrades are assumed (i.e. have not accounted for any new roads or road class upgrades)	Any new road upgrades that occur in Metropolitan Melbourne are covered by first assumption (that Metropolitan Melbourne has first coverage). Assumptions relates primarily to no new regional/rural roads having been considered.
For peak vehicle number calculations, the total freight percentage across all nine assessed scenarios at 2.96 per cent. No changes were made based on any temporal distribution of freight volumes.	http://www.abs.gov.au/ausstats/abs@.nsf/mf/9309.0
2200 subscribers can be supported by a single cell site.	http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?doc_id=4555

ASSUMPTION	SOURCE/EVIDENCE
V2I is mostly I2V, CAM messages from RSI at 10Hz, 150 bytes (100 bytes w/ MQTT), DENIM V2I and I2V (running red light, accident etc.) including traffic signal info, speed info, back of queue info, hazard warning, variable speed, fixed speed from a centralised system through cell tower, vehicle positioning info sent to centralised system, 1 CAM aggregated message every 60 seconds, 1 per second, aggregation of last 60 seconds	IEEE 802.11p, ETSI?
Dynamic map being used between all cars.	Based on current implementations - CAVI
AV vehicles have fully integrated 3D-map architecture provided by mapping agents or vehicle manufacturers	Based on current implementations - CAVI
CAVs will only send updates to digital map for exceptions, this does not need to be live	Based on current implementations - CAVI
Small map updates from centralised systems will be transmitted to CAVs	Based on current implementations - CAVI
One month worth of data is stored locally/remotely.	Based on technical expertise
Assume data for incidents is collected within one month and stored as evidence elsewhere.	Based on technical expertise
Secondary data stored in long term storage for 20 years	Based on technical expertise
10 MB/hour is transmitted per vehicle. This includes information to be transmitted to the fleet operators as well as information transferred to/from any infrastructure.	Existing Driverless Vehicle trials, IEEE 802.11p, SAE J2735 version 2 ETSI
All GIS calculations are done in coordinate system GDA94 Geoscience Australia Lambert	Industry standard
Road Network - Vicmap Transport (DELWP 2018) used as network	Based on technical expertise
For any road less than or equal to 10km a tower is placed in the centre of the road.	Methodology assumption
For any roads greater than 10km a tower is placed 5km along the road and every subsequent 10km.	Methodology assumption
For M, A, B, C and S roads towers are put through a weeding process where towers less than 5km in proximity to one another are deleted	Methodology assumption
Costs are 'order of magnitude' only and shall not be used for pricing or costing with more detailed analysis required	Methodology assumption
Growth of population and usage patterns follow current trends	Methodology assumption
Technology to accommodate Road pricing is not included	Methodology assumption

ASSUMPTION	SOURCE/EVIDENCE
Development of AVs and ZEVs technologies progresses on current development arcs and operate as currently generally understood.	Methodology assumption
Pricing similar to Cohda device, including install, comms, power, UPS etc.	WSP internal experience on Victorian managed motorway infrastructure projects.
33% of intersection signals in metro melbourne are 'critical' and would benefit from optimisation	VicRoads internal staff - Discussion 11 May 2018
10% of traffic signal cabinets need upgrade, 20% of sites are complex and need extra work	WSP internal experience
Traffic signals in country Victoria (excl Geelong) generally not critical	VicRoads internal staff - Discussion 11 May 2018
All traffic signals have cellular network coverage to allow V2I devices to not be installed on non-critical sites.	Desktop survey - sample matching cell towers GIS with traffic signals
Assume 50 new intersection signals each year, 1400 by 2046.	VicRoads internal staff - Discussion 11 May 2018
Planned infrastructure excludes megaprojects such as West Gate Tunnel and North East Link.	
VicRoads plans to put lane control on all urban freeways (extra 90km on top of existing 80km) and extra 100 ramp metering sites (above existing 170)	VicRoads - Discussions in 2016 in relation to WSP central systems upgrade work.
Standard design for overhead lane control is one site every 500m in each direction. Assume 4 for each km of freeway (or 360 extra sites)	
Variable Speed Limit Signs all have cellular network coverage	All electronic speed limit signs communicate via cellular network, therefore cellular network must be present.
Variable Speed Limit Signs in future will be controlled and communicated centrally. Also vehicles can machine read electronic speed signs relatively easily.	Internal discussions, Austroads guide.
Assume 120 sites that are added to minimum scenario to augment GPS.	Based on number of intersection signals in Melbourne CBD + 10%.
All of metropolitan Melbourne and regional cities have full 5G coverage that is capable of supporting data flows generated by AVs	Commercial risks to telcos and legislative risks to NBN are too high to not meet demand.
If congestion issues on cellular network do arise, key feature of 5G is priority bandwidth, which assume is made available to vehicles.	Ericcson White Paper Uen 284-23-3204 Rev C Apr 2016 '5G Radio Access'.
Traffic signals are on ADSL and have spare capacity.	Existing usage is miniscule for SCATS (traffic signal control system).
AV data transmitted and received is a fraction of overall network data and as such does not influence or impact backbone ICT infrastructure investment.	Data generation, https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html

ASSUMPTION	SOURCE/EVIDENCE
Minimum level of ICT infrastructure investment — Emphasise safe operation over efficiency or economic benefits — Least amount of ICT infrastructure to ensure AVs can operate safely on critical Victorian Roads — Minimise all over-investment or technical obsolescence risks — Victoria is not obviously disadvantaged compared to other States or internationally.	Internal discussions with WSP and IV
Optimum level of ICT infrastructure investment — Emphasise economic benefits, efficient networks, best use of existing assets. — Promote a more effective and holistic transport network management approach. — Vehicles can run optimally the clear majority of trip distances — No missed opportunities due to lagging investment	Internal discussions with WSP and IV
Reduce scenarios to remove hydrogen, electric non-AV and ZEV.	Only difference for ICT infrastructure is a bit of connectivity around availability of charge stations. Minimal data impacts.
All C-ITS V2V messages will be peer to peer via 5.9GHz (DSRC) or C-V2X and will not require infrastructure [unless we consider locations where 5.9GHz (DSRC) or C-V2X messaging between vehicles may need augmentation {such as V2N} or backup systems {e.g. C-V2X may back up DSRC}]	Discussions with WSP Globally and clients
All low latency C-ITS I2V messages (such as SPaT and DENM messages originating from RSUs at signalised intersections or tunnels etc) will be via 5.9GHz DSRC or C-V2X and will require one or more RSUs and associated infrastructure at each roadside location	Discussions with WSP Globally and clients
C-ITS RSUs (such as those at signalised intersections or tunnels etc) will require wired or wireless (including cellular V2N) infrastructure between each RSU and the Central C-ITS facility.	Discussions with WSP Globally and clients
Medium and high latency C-ITS I2V messages (speed info, back of queue info, hazard warning, variable speed, fixed speed etc) will be via cellular networks (V2N) and will require cellular infrastructure between the Central C-ITS facility and C-ITS equipped vehicles (IVU) within the geographic area to which the message relates	Discussions with WSP Globally and clients
C-ITS V2N status/position messages from C-ITS equipped vehicles (IVU), aggregated CAM message at 5Hz continuously, 150 bytes (100 bytes w/ MQTT), to the Central C-ITS facility will be via cellular networks and will require cellular infrastructure.	Discussions with WSP Globally and clients

ASSUMPTION	SOURCE/EVIDENCE
All C-ITS RSUs associated with signalised intersections generate SPaT messages at 10Hz continuously, 150 bytes (100 bytes w/ MQTT) via 5,9GHz DSRC or C-V2X	Discussions with WSP Globally and clients
All C-ITS RSUs generate MAP messages at 2Hz continuously, 150 bytes (100 bytes w/ MQTT), DENIM V2I and I2V (running red light, accident etc.)	Discussions with WSP Globally and clients
All C-ITS RSUs generate DENM messages on an ad hoc basis, when required, 150 bytes (100 bytes w/ MQTT) at 10Hz, (red light running, Red light violation, warning vulnerable user etc.)	Discussions with WSP Globally and clients
Each C-ITS station (IVU & RSU) currently generates its own dynamic map, based on its own location and messages received from other C-ITS stations. However, CAVs will have full comprehensive high-resolution digital maps for use with AV sensors to augment positioning and will provide greater accuracy for CAV operation.	Discussions with WSP Globally and clients
2031 & 2046 Everyone will have C-ITS capability as augmentation for AVs	
Every trip need to be re-authorised by Security Credential Management System (SCMS) from a security perspective	Discussions with WSP Globally and clients
Maximum number of vehicles are captured per cell site per hour	Discussions with WSP Globally and clients
Dedicated Cellular channel for C-ITS communication with C-ITS Central Station with possible access to a secondary Cellular channel for backup purposes (e.g. alternate cellular provider)	Discussions with WSP Globally and clients
Dedicated Cellular channel for AV communication with manufacturer head office data, mapping data, manufacturers dedicated battery recharge stations and for infotainment	Discussions with WSP Globally and clients
Cellular Communication with public non-dedicated battery recharge stations possible	Discussions with WSP Globally and clients
GNSS based positioning for CAVs will require varying degrees of augmentation, depending on the location, to provide sufficient lane-level accuracy for safe operation. The ultimate example of this is a tunnel environment, where GNSS signals cannot be received directly and the augmentation systems will provide the primary positioning. Similarly, in areas where insufficient GNSS signals can be received or SBAS is not available, such as in a city high rise area where cannyoning is an issue.	Discussions with WSP Globally and clients

ASSUMPTION	SOURCE/EVIDENCE
GPS is about to get more accurate in Australia. The federal government is going to spend $224.9 million over four years to create more accurate satellite-based positional, navigation and timing capability which will enhance GPS capability. The budget measure will deliver data with an accuracy of three to five centimetres for regional and metropolitan areas with mobile phone coverage and up to 10 centimetres elsewhere. In a separate project, the Digital Earth Australia platform provides access to reliable, standardised satellite data used by businesses, individuals, researchers and government to build new digital products and services. The government plans to spend $36.9 million over three years on Digital Earth Australia. This builds on an initial investment of $15.3 million in last year's budget.	Discussions with WSP Globally and clients
When the technology is sufficiently mature and developed so as to accommodate all modes of transport appropriately, AVs do appear to have the potential to transform 'road safety' as we know it by reducing or removing the human factor from the driving equation.	Discussions with WSP Globally and clients
If the shared model for AVs becomes reality, the overall size of the car fleet could ultimately shrink dramatically.	Discussions with WSP Globally and clients
Simulations and thought experiments alike tend to agree that a move from human-driven to AVs will initially add traffic to the roads rather than reduce it. This may be offset by the shared model for AVs.	Discussions with WSP Globally and clients
Vehicle mounted C-ITS infrastructure for CAV operation will be supplied monitored and maintained by the vehicle manufacturer as an integral component of the CAV. After-market fitment of C-ITS equipment to conventional vehicles is likely to happen but has not been considered in this submission.	Discussions with WSP Globally and clients

APPENDIX B

SCENARIOS

Column1	Physical road network usage	Road pricing model	Data usage per vehicle	Mode use changes (public v private etc)	Urban / regional / rural specific impacts	Management of edge cases eg roadworks, low quality road infrastructure and incidents	Impact on infrastructure over time, and likely take up rate (eg consistent or explosive growth)	Barriers / enablers for success (government policy, cultural shifts etc)	Mapping and positioning Current GPS +/- 1-10m (existing) D-GPS 0.1-1m (lane) S-BAS 0.1 (sub-lane)	Impacts on centralised ICT support infrastructure	Impacts of ICT infrastructure changes on safety	Application user interface implications	List additional assumptions
Electric Avenue 'non-connected'	Follow current trends (pending on fuel and road pricing levers)	Mandatory for optimal cases. Some alternative to fuel tax but not strong investment in ICT required for minimal.	Minimal follow current trends. For optimal will be some increased data usage related to road pricing	Follow current trends, slight lag in freight	Follow current trends, slight lag in rural	Increased monitoring infrastructure for electric vehicle emergencies. Critical infrastructure (tunnels /bridges) require higher monitoring and response infrastructure.	Minimal ICT apart from around access and critical infrastructure monitoring.		Existing	Low	Follow current trends (outside increased danger during incident management	NA	Assuming pricing regime results in similar level of usage (i.e. neither encourage or discourage)
Private Drive	Massive increase in road usage (private), likely to impact freight road usage as well (due to congestion)	Massive increase in kilometres travelled which increases data usage, vehicle connections, 'data density'	Moderate increase in data usage	Reduction in active (peds, cycling) transport usage.	Rural - Increased coverage to meet requirements. How do we meet the last kilometre?	Requires authoritative single source data base / current road availability / ICT infrastructure availability.	Increased	Enabler - private vehicle manufactures generally see this scenario as their "ideal" outcome and are currently investing heavily to make this happen	Lane	High - increased usage, some increase in privacy and security	Increased risk of vulnerable user impacts due to increased number of vehicles on the road. Increased focus on securing public ICT infrastructure to cyber threats Private AVs will generally prioritise safety of vehicle occupant compared to outside life i.e. pedestrian/cyclist - is this an appropriate mentality (not safe system)?	Individual users will use apps to control their vehicles remotely (i.e. as seen at a low scale with Tesla)	Increase in road usage due to increase in utility, zero occupancy trips, road space infrastructure investment not meeting demand
Fleet Street	Expect current fleet to be 10-20% of current, most VKT from robotaxis etc. Freight follows current trends (possible reduction?)	Surge pricing? Mandatory for both minimal and optimal cases Road pricing would be inherently built into a MaaS system. Would other modes of transport now be charged as well, which previously have not been charged (e.g. cycling) to support new infrastructure	Highest increase in data usage per vehicle (but with less vehicles)	Increase in active (peds, cycling)	Rural - Increased coverage to meet requirements. How do we meet the last kilometre?	Requires authoritative single source data base / current road availability / ICT infrastructure availability.	Increased	Vehicle industry happy to share / integrate systems. Significantly more emphasis on e-security/privacy - requires that people's movements will be tracked and logged in real time. Would commuters make this trade off or can less data/privacy intrusive packages be offered? Also, compared to the "Private Drive" scenario, less investment in vehicle technologies from vehicle manufacturers/industry	Lane	High - increased privacy and security	Reduction in incidents? Increased focus on securing public ICT infrastructure to cyber threats	Holistic app / government managed API required. Critical for success. Would there be the scenario where multiple private MaaS services exist - lead to less efficient outcomes	Change in car manufacturer business models, government subsidy policies around PT, need to ensure still an inclusive service Need government regulation to prevent price exploitation - needs to provide a form of transport across all price points
Hydrogen Highway	Don't assume increase in freight	Assume hydrogen will have tax structure similar to petrol. No impact.	Increased for freight vehicles	*Possible increase in freight volumes if cost per trip reduces and demand for convenience outstrips economic levers*	Follow current trends, slight lag in rural	Current research shows no increased safety risk with hydrogen fuel - confirm?	Minimal		Lane (for freight)	Low	Minimal	NA	If hydrogen is being created using fossil fuels, assuming no carbon pricing is included.
Slow Lane	Similar growth to today (assume growth of private AV similar to reduction in vehicle PT trips)	Alternative pricing for electric vehicles will be required in both scenarios, but small part and less likely to be in rural / regional	Moderate increase in data usage related to Avs / Freight fleets	Some increase in choices, following todays usage patterns?	Regional and rural likely to lag urban in AV take up	Requires authoritative single source data base / current road availability / ICT infrastructure availability. Reduced benefit for investment.	Need to invest to still support Avs.		Existing , then Lane	Low then High	Increased complex mix of vehicles likely leads to increased incidents, reduced benefits of Avs as more human intervention required.	Holistic app / government managed API required.	
High Speed	Rapid decrease in road usage. Freight follows current trends (possible reduction?)	Surge pricing? Mandatory for both minimal and optimal cases. Need road pricing in place much quicker than expected.	Highest increase in data usage per vehicle (but with less vehicles). Much quicker than expected.	Increase in active (peds, cycling)	Increased coverage to meet requirements. How do we meet the last kilometre? How can we do it very quickly?	Requires authoritative single source data base / current road availability / ICT infrastructure availability.	Increased and explosive.	Government and infrastructure keeping up. Vehicle industry happy to share / integrate systems.	Lane	High, very quickly	Reduction in incidents?	Holistic app / government managed API required very quickly. Critical for success.	Change in car manufacturer business models, government subsidy policies around PT, need to ensure still an inclusive service
Dead End	Follow current trends	No infrastructure required	No change	No change	No change	No change	No change		Existing	Nil	No change	NA	

APPENDIX C

USE CASES

Appendix C

Use Cases

Users	Communications - Centralised Infrastructure	Communications - Local infrastructure	Communications - Other Nearby Users	Location Finding - accuracy	Location finding - additional onboard equipment	Latency in condition communication	Minimal	Optimal	Rural Context	Electric Avenue 'non-cooperative'	Private Drive	Fleet Street	Hydrogen Highway	Slow Lane	High Speed	Dead End
Private Use Vehicles AV & Connected AV Highly automated vehicle (SAE Level 4 or 5). Fuel source is scenario dependent.	Vehicle manufacturer, centralised anonymised tracking run by govt / 3rd party for road condition etc. Send CAM, mapping exceptinos etc. Receive incidents, emergencies, conditions, digital map tiles etc	Through cell network either through local cell or centralised system. For Traffic Signals, Lane Use Signs may use V2I if warranted.	V2V at 5-10Hz	Lane level	GPS, LIDAR with 3D mapping	Current thinking between 1Hz and 10Hz	Cell or wifi access before trip starts	Pro-active V2I, cellular connection entire trip (?) this may not be feasible in rural areas.	May have to run in devolved / degraded mode on unsealed or driveways. Where gaps in cellular coverage could wait for either back to base upload of high data volumes (ie digital maps, detailed maintenance) or for when cell tower coverage is available and not congested.	NA	May need higher data interactions due to increased volumes / density (ie 10Hz instead of 5Hz)	NA	NA	Reduced level of investment / realisation of benefits. Increased centralised interactions with non-connected vehicles. Not available in country areas. For central ICT infrastructure demand cloud based support network to reduce over-investment risk.	Management of policy / regs. Building sufficient supporting infrastructure quickly enough for optimal. Ensure enough cell phone coverage for minimal. For central ICT infrastructure probably need cloud based to manage rapid growth	NA. Cloud based ICT infrastructure reduces over-investment risk.
Non-connected vehicles Vehicles that are in common usage today, including up to and including Level 3 SAE.	Basic location, direction, maybe conditions. Receive incidents / condition/ travel time.	Through cell network either through local cell or centralised system.	Through cell network either through local cell or centralised system.	Depends on context, lane designation would be optimal.	GPS	>1 minute for route descision making	NA	Overall network improvements. Better incident / travel condition awareness.	NA	Centralised charge station location / availability.	NA	NA	Centralised charge station location / availability.	NA	NA	Large percentage of fleet
Public Transport (Bus only, publicly operated) Publicly managed & subsidised mass transit. Most likely to use unprofitable routes (rural, regional)	Central admin / customer allocation private bus operator, manufacturer (similar to Easymile structure). Centralised anonymised tracking run by govt / 3rd party for road condition etc. Send CAM, mapping etc. Receive incidents, emergencies, conditions etc	Through cell network either through local cell or centralised system. For Traffic Signals, Lane Use Signs may use V2I if warranted.	V2V at 5-10Hz	Lane level	GPS, LIDAR?	Current thinking between 1Hz and 10Hz	Realtime service tracking. Cellular network coverage entire route.	Optimised routes, better connection between the community and transport. Better use of budget.	Assume routes between towns are on M, A and B routes and within towns / regional cities. Optimally would like cell coverage for entire routes.	NA	Needs to interact with more vehicles. Similar volumes to today?	Similar level, better integration with private sector mass transport.		NA	NA	Depends on ratio of 3rd party
Private Mass Transport Privately owned and operated mass transit. Commercial, could be robotaxis or larger vehicles	Central admin / customer allocation private bus operator, manufacturer (similar to Easymile structure). Centralised anonymised tracking run by govt / 3rd party for road condition etc. Send CAM, mapping etc. Receive incidents, emergencies, conditions etc	Through cell network either through local cell or centralised system. For Traffic Signals, Lane Use Signs may use V2I if warranted.	V2V at 5-10Hz	Lane level	GPS, LIDAR?	Current thinking between 1Hz and 10Hz	Realtime service tracking. Cellular network coverage entire route. Link customers to operators. Integration with other public transport options.	Increased coverage.	Do we assume government policy promotes this in rural areas? (subsidies etc?)	NA	NA	Large segment of market.		Reduced level of investment / realisation of benefits. Increased centralised interactions with non-connected vehicles. Not available in country areas.		
Freight Long and short distance.	Company / freight allocator controller. Centralised anonymised tracking run by govt / 3rd party for road condition etc. Send CAM, mapping etc. Receive incidents, emergencies, conditions etc.	Through cell network either through local cell or centralised system. For Traffic Signals, Lane Use Signs may use V2I if warranted.	V2V at 5-10Hz	Lane level	GPS - Could need increased accuracy for platoons.	Current thinking between 1Hz and 10Hz	Platooning available on M and A class roads.	Proactive platoon management, platoon coordination across companies / industries on all MABC roads.	Cell phone coverage of all M, A and B routes would be highly desirable. C routes not as critical for freight (check)	Centralised charge station location / availability.						
Central Operators (current example is VicRoads TMC) Passive, reactive or proactive transport network managers. Combination of automated and human operated systems. Includes centralised emergency services.	Connect to other centralised systems. Provide incidents / travel time etc.	Through backhaul (currently ADSL) via centralised TMC.	NA	NA	NA	Current thinking between 1Hz and 10Hz	Similar to current	More proactive demand management.	NA	NA	Increased supporting infrastructure (more vehicles = more data and issues)	Decreased supporting infrastructure (less vehicles = less data and issues)		More complex environment will require increased central operator staff.	Increased level of investment.	If a 3rd party leased service reduces over-investment risk. Great risk of over-investment in V2I.
Emergency Services Vehicles eg police, ambulance, fire, SES	Central admin emergency services. Send CAM, mapping etc. Receive incidents, emergencies, conditions etc	Through cell network either through local cell or centralised system. For Traffic Signals, Lane Use Signs may use V2I if warranted.	V2V at 5-10Hz	Lane level	GPS, LIDAR?	Current thinking between 1Hz and 10Hz	Better integration with network conditions.	Proactive network integration / management during emergency situations.	Cell phone coverage is very important during management of incidents	NA	Increased or similar to current costs (more vehicles = more issues)	Decreased costs (less vehicles than today)		More complex environment will likely impact on numbers and workplace risk for emergency services.	NA	NA
Roadside Infrastructure - Active Traffic signals, lane control signs, variable speed signs	Through backhaul (currently ADSL) via centralised TMC.	NA	Transmit V2I to nearby road users.	NA	NA	Every 1 to 5 seconds?	Either through backend cloud service or V2I device	V2I device on all traffic control devices.	NA	NA	Strong requirement for V2I to make best use of limited infrastructure.	Could reduce V2I investment compared to Private Drive (less vehicles so less gains to be made in minor improvements from V2I)		Assume will require traffic signals / lane control / speed signs until 2046.	Assume will require traffic signals / lane control / speed signs phased out between 2031 and 2046.	Great risk of over-investment in V2I
Roadside Infrastructure - Passive Variable Message Signs, Travel Time displays, trip condition signs etc	Through backhaul (currently ADSL or cellular) via centralised TMC.	NA	Through backhaul (currently ADSL or cellular) via centralised TMC.	NA	NA	Every 1 to 5 seconds?	Collated information that this infrastructure displays made available to 3rd parties	Improved backend filtering / pattern matching / route options (AI / machine learning)	NA	NA				Will need to keep passive roadside infrastructure for a much longer period.	No passive roadside infrastructure required after 2031.	Road authorities become over-zealous in removing passive infrastructure
Cyclists Assume by 2046 that cyclists who want to use the road space have to opt-in to some way of being tracked using V2X	Via opt-in mobile phone. Cellular network connection.	Via opt-in mobile phone. Cellular network connection.	Via opt-in mobile phone. Cellular network connection. Could be V2V device on bikes?	Lane level	GPS	Every 1 to 5 seconds?	Opt-in tracking through cellular	Areas with poor cyclist safety record, integrated bike tracks etc use active roadside tracking (BT, wifi, video) that is then made available to relevant dominant vehicles.	Cell phone coverage important to inform cyclists and vehicles of each other.	NA	Decrease from present.	Increased desire for connectivity.		NA	NA	NA
Motorcycles Assume by 2046 that motorcyclists who want to use the road space have to opt-in to some way of being tracked using V2X	Via opt-in mobile phone. May also be required to install V2X device	Through cell network either through local cell or centralised system. For Traffic Signals, Lane Use Signs may use V2I if warranted.	V2V at 5-10Hz	Lane level	GPS	Current thinking between 1Hz and 10Hz	Opt-in tracking through cellular	Mandatory V2V on motorcycles (pending safety risk analysis - outside scope). May also use V2I and communicate to roadside in high risk areas and information is then made available to relevant vehicles (ie outside V2V range), particularly on zones with line of sight issues.	Areas with poor road safety records around motorcycles may require additonal road side infrastructure (V2I)	NA	Similar to current usage.	Similar to current hobby usage. No commuter usage.		NA	NA	Great risk of over-investment in V2I
Pedestrians Assume by 2046 some pedestrians opt-in but some pedestrians are not actively tracked.	Via opt-in mobile phone. Cellular network connection.	Via opt-in mobile phone. Cellular network connection.	Via opt-in mobile phone. Cellular network connection.	Lane level	GPS - Opt in, Roadside infrastructure (video recognition?)	Every 1 to 5 seconds?	Opt-in tracking through cellular	Areas with poor ped safety record, schools, etc use active roadside tracking (BT, wifi, video) that is then made available to relevant dominant vehicles.	NA	NA	Decrease from present.	Increase from present		Increased mix, increased risk, more specialist ped detection V2I / I2X?	Increase from present	NA
Roadwork sites Mobile / semi-permanent, short to long term. Assume start, finish and permission of all roadworks (planned or reactive) are tightly controlled by central authority.	Any traffic control devices connect via cellular network.	NA	Transmit V2I to nearby road users.	+/- 10m	GPS	Every 5 seconds (mobile sites)	Electronic recording of location, status etc provided as a service.	Active V2I on-site for all (?) roadworks	Cell tower coverage integral, particularly on mobile or sites with line of sight issues.	NA	All sites must be integrated / recorded in centralised systems. Must have strong V2I presence.	All sites must be integrated / recorded in centralised systems. Must have strong V2I presence.		Reduced value for money for V2I devices at roadwork sites.	Industry must rapidly adapt. Issues with sourcing, specifying compliant products (similar challenges to Truck Mounted Attenuators, trailer variable speed signs)	Great risk of over-investment in V2I
Large scale emergencies eg fire, flood, terrorism	Centralised infrastructure detects and sends out alerts to relevant users.	Centralised infrastructure uses local infrastructure to control emergency.	NA	NA	NA	NA	Reactive, control and manage.	Proactively, or authoritatively control vehicles (eg ban AV on certain roads?)	Cell tower coverage, protection of cell towers from fires / flood. Redundancy? Ability to quickly reinstate or put temporary cell towers?	NA	NA	NA		NA	NA	NA

APPENDIX D

COMMUNICATION NETWORKS FOR CAVS

Communication systems will need reliable infrastructure of sufficient speed, capacity and coverage to make CAVs viable. Cellular networks will provide the non-safety critical telecommunication technology to support Level 4/5 CAV communications. The technologies and mediums of exchange will change over time. We have assumed these channels as a basis for assessment of ICT needs and that only critical infrastructure will be equipped with this infrastructure, initially being tunnels, bridges, level crossings and road construction areas. These systems will require additional communication for backhaul to the C-ITS Central Platform. Backhaul may use either cable or wireless media for this purpose, including fibre, microwave or cellular depending on the situation. These backbone links are discussed in Section 4.4.

Safety critical C-ITS V2X (including V2V) messages need to be low latency and therefore need to use peer-to-peer telecommunications. The current peer-to-peer C-ITS telecommunications options are either to use the mature (DSRC) ETSI ITS-G5 / IEEE802.11p standard or use the less-mature 3GPP Cellular-Vehicle-to-Everything (C-V2X) standard, both of which use the 5.9GHz frequency band[72]. C-V2X has recently emerged from the cellular industry as a challenger to DSRC and is engineered to complement and extend existing cellular capabilities. Like DSRC, C-V2X provides direct peer-to-peer communications support for safety and enhance situational awareness applications by detecting and exchanging information using low-latency transmission in the 5.9-GHz band. Both technologies will provide the telecommunications channel for vehicle-to-vehicle (V2V) as well as V2I and V2P scenarios. C-V2X can function without wide area network assistance and has a range of around one kilometre, even in areas where mobile network connections aren't available.

Under perfect conditions, neither DSRC or C-V2X would require any extra infrastructure for V2V or other mobile V2X telecommunications. However, telecommunications between vehicles in the 5.9GHz band works best when there is line-of-sight between transmitter and receiver. Also, due to the high frequency nature and short wavelength of the 5.9GHz band, signals tend not to travel through trees and buildings, leaving this band as suitable for only short range communications of less than one (1) kilometre.[73] The ETSI ITS-G5 / IEEE802.11p standard however, provides the ability for equipped vehicles to act as repeaters in order to extend the range of signals to vehicles that may not have line-of-site to the originating station and thereby effectively enable operation in a built-up city environment.

As cooperation between AVs becomes operationally important, we need to consider locations where 5.9GHz between-vehicle messaging may need augmentation or where backup systems may need to be employed, or both. Augmentation can happen using DSRC roadside infrastructure and mobile vehicles within range of the transmitting and receiving vehicles that repeat the message and provide an alternative route between transmitting and receiving vehicles or other mobile V2X devices. Also, to provide message redundancy for safety-critical messages, C-ITS messages could be duplicated by both the DSRC and C-V2X telecommunications channels or a conventional 3G/4G/5G cellular channel, thereby increasing the likelihood that all relevant vehicles and devices receive them if one channel fails.

The desired safety benefits will require low-latency I2X telecommunications between Roadside C-ITS Stations, CAVs and mobile V2X devices. This will in turn need direct peer-to-peer telecommunications via DSRC or C-V2X. The infrastructure needed to support this operation includes one or more RSUs interfacing with the intersection's Traffic Signal Controller (or Next Generation Traffic Signal Controller with built-in C-ITS functionality) and associated supporting infrastructure at each intersection.

There is also a need for I2X telecommunications between C-ITS-equipped vehicles, other mobile V2X devices and the Central C-ITS System (as well as the V2X telecommunications from/to mobile C-ITS-equipped vehicles and devices, and the V2I and I2X telecommunications from/to C-ITS equipped vehicles, other mobile devices and some Roadside C-ITS (RSU) Stations).

I2X telecommunications between mobile V2X devices (including CAVs) and the Central C-ITS System do not require low latency and can therefore use the public cellular network to communicate with the Central C-ITS System. Among other things, the Central C-ITS System will produce and send C-ITS messages to vehicles and other mobile C2X devices,

72 https://www.qualcomm.com/news/onq/2018/04/25/lets-set-record-straight-c-v2x

73 https://5g.ieee.org/tech-focus/june-2017/cellular-v2x

warning of such things as downstream incidents, providing location-relevant advisory speed and traveller information to C-ITS-equipped vehicles and other mobile C2X devices in the area.

WSP have considered all the above requirements for ICT infrastructure as part of this work package except for any additional cost for upgrades of traffic signal controllers. It is assumed that controllers would be updated over time (prioritised based on safety), the additional functionality can be made available with minimal additional cost during refurbishments / replacement phase, however an optimised approach may consider earlier replacement at key locations to encourage education, uptake and use.

WSP /

Level 15, 28 Freshwater Place
Southbank, Victoria
3006 Australia

wsp.com

WSP is one of the world's leading engineering professional services consulting firms. We are dedicated to our local communities and propelled by international brainpower. We are technical experts and strategic advisors including engineers, technicians, scientists, planners, surveyors, environmental specialists, as well as other design, program and construction management professionals.
We design lasting Property & Buildings, Transportation & Infrastructure, Resources (including Mining and Industry), Water, Power and Environmental solutions, as well as provide project delivery and strategic consulting services. With 36,000 talented people in more than 500 offices across 40 countries – including 2,500 people in Australia and New Zealand – we engineer projects that will help societies grow for lifetimes to come.