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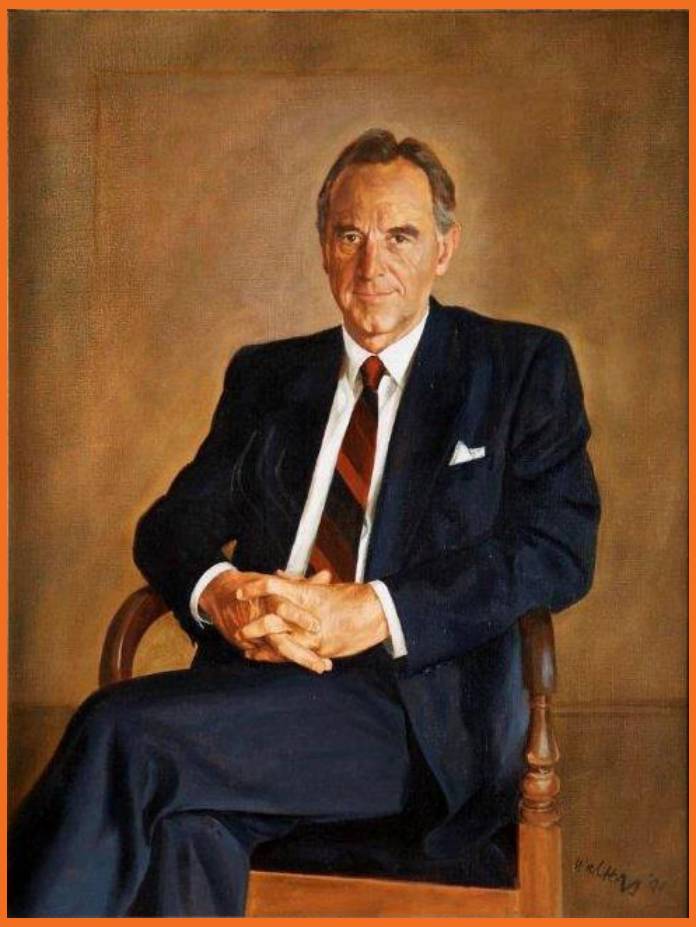

PREPARING MELBOURNE FOR AUTONOMOUS TRANSPORT

A Policy Paper of the John Cain Foundation

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Melbourne May 2018

Contents

Glossary

AV – autonomous vehicle (partially or wholly self-driving)

CAV – connected autonomous vehicle (communicating with other vehicles, transport management systems)

EAV – electric autonomous vehicle

IV – Infrastructure Victoria

MaaS/TaaS – mobility solutions that are consumed as a service. This is enabled by combining transportation services from public and private transportation/fleet providers through a unified gateway that creates and manages the trip, which users can pay for with a single account. Users can pay per trip or a monthly fee for a limited distance. The key concept behind MaaS is to offer both the travellers and goods mobility solutions based on the travel needs. MaaS is not limited to individual mobility; the approach can be applied to movement of goods, as well – particularly in urban areas.

PT – public transport

EXECUTIVE SUMMARY

The development of autonomous vehicle (AV) technology has been rapid. Worldwide interest in its uptake is accelerating, but there remain great uncertainties about how and when such technologies can be deployed safely in economically sustainable ways. There are major implications for city planning – potentially as large as occurred with the spread of private car ownership – but these are also subject to considerable uncertainties as to timing and impact.

City planning and infrastructure provision involve long time frames and the commitment of large sums of money. In thinking about the impact of AV technologies and services, it is critical that governments, the private sector, and communities are well-informed and prepared for this latest and challenging opportunity for improving mobility and the liveability of Melbourne and Victoria more generally. The primary purpose of this paper is to provide an informed reference point for key stakeholders, in particular the Victorian State Government.

In summary, the key issues are:

- As semi-autonomous vehicles appear in the marketplace and with fully autonomous vehicles under development, new opportunities and challenges are rapidly emerging for land use and transport planning in Melbourne, and Victoria. The resulting changes are potentially as large as that experienced with the widespread adoption of private motor vehicles seventy years ago.
- Uber-style fleets of autonomous vehicles are forecast as a near-future transport offering, with some predicting disruption to the extent that private car ownership will quickly become unnecessary and unattractive for day-to-day mobility.
- This concept – Mobility-as-a-Service (MaaS) – is seen as driven by wide-spread adoption and use of fleets of autonomous vehicles 'on call' for both passenger and freight movements, driving down total costs significantly, and opening up new opportunities for mobility for many groups in society whose access to travel is currently very limited.
- The adoption of electric power, or hydrogen, as the main sources of power for vehicles, will reduce the consumption of fossil fuels, disrupting energy industry business models while creating environmental benefits.
- There are large potential benefits from high-level adoption of AVs across many aspects of the development of Melbourne — competitiveness, sustainability and community well-being: but also major negative effects – increased congestion, compromised privacy and system security. – Government, therefore, has a major societal obligation to shape policy, regulatory and economic/financial pathways that facilitate adoption of AVs in ways that support public policy goals. This would be assisted by support for MaaS services across Melbourne and, progressively, across the State. The Commonwealth Government also shares this obligation.
- This obligation is especially evident in relation to the scope for reducing deaths and injuries caused by vehicle accidents. The annual economic benefit of reducing road accident levels by up to 87% (the share of accidents due to human error indicated by 2017 data) is estimated at $1.32 billion. Hence, there appear to be major opportunity costs to Victoria of not proceeding with the introduction of autonomous vehicles as quickly as possible.

- The principle land use-transport planning policies for Melbourne's future are set out in the State Government's Plan Melbourne 2017–2050. However, the Plan has a major blind spot: it does not address the impact of the introduction and adoption of AV-based services over the life of the plan, especially the development of MaaS.
- Using scenarios calibrated by the rate of AV penetration, we have explored how AV-based mobility might contribute to Plan Melbourne's objectives. Our work suggests that rapid adoption of AVs, shaped by a clear policy framework focused on maximising societal benefits, will make the achievement of Plan Melbourne's objectives and directions much more likely than would be possible under the basic assumptions about mobility currently underpinning Plan Melbourne.
- Delivery of optimally configured AV mobility services across Melbourne offers great economic and social opportunities. This will require government leadership and analytical/managerial capabilities of a high order to ensure that the money for infrastructure and services, ultimately provided by taxpayers and customers, is deployed to the highest public return and that the private and public sectors play complementary roles in meeting Melburnians' needs for effective, sustainable and affordable mobility.
- A consistent and transparent policy and decision-making process for accommodating AV mobility is very important but, in the meantime during preparatory work and transition, a similar approach is required for current and ongoing land use and transport planning to avoid increased congestion and other negative impacts of the demands for mobility from Melbourne's growing population.
- Reflecting these considerations, we have set out a plan for the Government to shape and facilitate the adoption of these emerging transport technologies and new business models in the broad public interest. (Table 1).

Table 1: Autonomous Vehicles and Critical Related Issues: Recommended Victorian Government three year Implementation Plan

Action Areas/Objectives			
Policy/strategic leadership:	2018 Actions	2019 Actions	2020 Actions
• Understand societal benefits, costs and risks of range of AV adoption paths • Gain practical experience of AV operations and technologies • Shape AV providers' expectations of regulatory environment in a competitively neutral fashion • Establish a clear, transparent and flexible policy and regulatory framework that supports economic and socially beneficial adoption of AV based services in Melbourne/Victoria	1. Set clear, competitively neutral terms for AV trials on the streets of Melbourne or one of the four main regional centres of Geelong, Ballarat, Bendigo and the Latrobe Valley (drawing on international experience and working as necessary with other jurisdictions to establish rigorous but practical safety standards) 2. Establish consistent and transparent framework for benefit/cost evaluation of supply and demand management measures across all land transport modes, including those arising from AV technologies (including the necessary investments in AV/transport system data capture, processing and communications) 3. Invite all providers and manufacturers of AVs to test their products in Victoria, to signal the State's 'forward-leaning' policy approach 4. Extend terms of reference for Infrastructure Victoria AV inquiry to ensure it addresses both vehicle technologies/road systems infrastructure data/GIS management system capacity and capabilities that minimise specialised road infrastructure investment	1. Publish Government White Paper/ statement on Victoria's policies for the future of AV based services in Melbourne/Victoria 2. Set 2050 performance congestion and safety objectives for Melbourne's road transport system 3. Commit to full scale trialling of road pricing across greater Melbourne, including the potential for congestion-charging in Melbourne's Central Area that progressively favours AV access during peak periods 4. Transport agencies, along with stakeholders, establish framework for ensuring AV systems integrate with Victoria's public transport systems, and how those systems must be adapted to operate successfully with AV based services	1. Work with other jurisdictions to establish agreed national standards for AV operations governing safety, data security, connectivity, and interoperability 2. Legislate to remove regulatory/other barriers to the introduction of AVs and replace them with relevant regulations to support an orderly, safe transition to AVs that maximises public benefits. 3. Finalise design of road pricing and demand management trial for Greater Melbourne consistent with these objectives, including the establishment of clear and publicly transparent evaluation criteria and protocols 4. Implement, monitor and publicly report on agreed road pricing and demand management trials

Institutions	2018 Actions	2019 Actions	2020 Actions
• Establish government mechanisms and capabilities to undertake effective long term integrated transport and land use planning, data architecture, capture and management	1. Assign single point Ministerial and public sector accountability for strategies required to facilitate introduction of AV technologies and services in Victoria, and understand their impact on all aspects of Greater Melbourne's mobility services	2. Examine options for an agency/ organisational structure (including a new, standalone entity) best suited to deliver a Melbourne wide, integrated approach to road infrastructure, public transport and AV services (including data systems/security and management, energy and EAV charging facilities; and the regulation) 3. Determine clear public and private sector roles, responsibilities and commercial arrangements to enable the introduction of AV technologies that optimise their contribution to meeting the needs of Melbourne's growing population	1. Establish agreed organisational structure, capabilities and mandate for planning, oversight and management functions
Urban Planning	**2018 Actions**	**2019 Actions**	**2020 Actions**
• Ensure local government and state government planning policies and frameworks support cost-effective deployment of AV technologies and services in ways that are consistent with the public interest within existing and new urban areas • Anticipate and take advantage of potential redesign opportunities created by freed-up urban lands	1. Victoria's urban and regional planning agencies collaborate with local government and stakeholders to investigate regulatory barriers to the introduction of AVs in the urban planning system and recommend the 'least risk' changes that will facilitate Victoria's early adoption of AVs 2. Development Victoria lead, and work with the community-development industry, on design guidelines for new communities that will enhance the adoption of AVs and MaaS services in ways that deliver maximum public good in new urban developments through land-use planning responses to AV opportunities.	1. Remove regulatory barriers in the planning system to the introduction and operation of AV-based services in established suburbs and environs 2. City of Melbourne review access and parking policies in Melbourne's Central Area in consultation with the AV services sector and the community, to address AV service impacts, such as kerb-side access for pick-up and drop-off patterns, and the impact of road pricing and demand management measures 3. Re-examine the potential distribution of jobs (more concentrated centrally or more suburban opportunities) and the potential for MaaS to assist in achieving the '20-minute neighbourhoods' that are a core objective of Plan Melbourne	1. Promulgate revised design guidelines for new communities and for urban renewal that will support adoption of AV-based services 2. Prepare amendments to planning provisions and regulations to facilitate the shift to autonomous vehicles and falling car ownership 3. Amend Plan Melbourne 2017-2050 to include directions, policies and actions that will avoid the potential negative impact of AVs (e.g. faster urban sprawl) and support the introduction of AVs, especially MaaS services, reflecting the likely need for less parking, and the opportunities for increased dwelling densities and enhanced public spaces (e.g. more pedestrian streets) across Melbourne.

Community Education	2018 Actions	2019 Actions	2020 Actions
• Ensure people understand the long-term outlook for Melbourne's transport system and the options for effectively, sustainably, and affordably meeting community needs • Understand and address community interests and concerns about the potential impact of AV technologies/ MaaS and services on mobility options	1. Develop a full understanding of community attitudes/concerns about such issues as AV/human driver/other road user interactions, data security/ privacy, travel outside metro areas 2. Undertake comprehensive public consultation and education about potential benefits, costs and risks of AV technologies and services, in the context of the long-term alternative futures for Melbourne's transport system, with a special focus on potential 'early adopters' of AVs (e.g. older people who are becoming nervous about driving, people with disabilities, and young people who unable to readily access private transport and /or low-cost public transport) 3. Empanel citizens juries to consider emerging options for servicing Melbourne's activity and mobility needs, drawing on independent and comprehensive assessments of different adoption scenarios and associated costs, benefits and risks	1. Engage with the AV suppliers to deliver community demonstrations of AVs in a wide range of different operating conditions 2. Publish proposals for addressing community concerns about full AV deployment (e.g. safety, data security and privacy, connectivity with non-metro areas) 3. Work with other jurisdictions to ensure consistent and effective approach that delivers outcomes in the public interest	1. Embed agreed proposals to addressing community/user concerns in policies, primary/secondary legislation etc.

Economic/social impacts	2018 Actions	2019 Actions	2020 Actions
• Understand the potential economic and employment implications for Melbourne and Victoria of differing possible transition pathways to high penetration of AV-based transport • Maximise the potential economic advantages for the Victorian community through 'forward-leaning' policies and programs supporting the transition to AVs. • Establish Victoria as the leading Australian location for AV based services in Australia	1. The Department of Treasury and Finance and Infrastructure Victoria forecast potential government investment needed to facilitate the cost effective transition to AVs and AV services, and to maximise the public good outcomes of the transition 2. Undertake and publish analysis of the impact of different scenarios for the transition to AVs/EAVs on the structure of the Victorian labour market, and on levels of employment in the automotive industry and other existing or emerging sectors linked to AV-based services. 3. Analyse and publish the results of the total/societal costs, benefits and risks of different options for supporting an accelerated transition to AVs under differing adoption scenarios, taking account of Victoria's strengths in vehicle manufacturing and the potential role for developing competitive advantage in AV data management and support systems in Victoria	1. Evaluate benefits and costs of providing public incentives for MaaS fleet owners to take up electric vehicles, as a pathway to EAVs 2. Work with the Federal Government and other jurisdictions to identify options for addressing the loss of fuel excise revenue from the transition to electric vehicles, and agree on new road charging arrangements that best meet national and state transport and fiscal objectives 3. Commence negotiations with the Commonwealth on access to the bandwidth likely to be necessary to accommodate high-data producing/consuming AVs, and the manner in which the rules of access are standardised across Australia and, if possible, consistent with international standards.	1. Establish clear strategy for State transport financing and mobility provision, addressing need for transparency and public accountability for ensuring value for money in terms of total public interest 2. Implement a preferred strategy for data management capacity and capabilities that best meets Victoria's economic and mobility objectives, negotiating as necessary with the Federal Government and other stakeholders on technical (e.g. the relevant spectrum, capacity and networks) and financial arrangements outside Victoria's direct control
Mobility Access/Equity	**2018 Actions**	**2019 Actions**	**2020 Actions**
• Ensuring introduction of AV-based services supports delivery of increased mobility across the community	1. Evaluate emerging cost structures of AV-based services (including 'external' sources of income such as in-vehicle advertising, social network/ internet services), the resulting pricing structures and the competitive and economic implications for 'traditional' public transport services, conventional private transport and mobility access and equity objectives	1. Work with local councils to ensure AVs can access all public facilities for kerb-side or other pick-ups and drop-offs for all public institutions and amenities. 2. Identify and evaluate the scale and scope of demand for public transport under different scenarios for penetration of AV services, and the economic and financial implications for current public transport models and services.	1. Establish and begin implementation of a priority plan for infrastructure and regulations to facilitate effective and safe AV access to public amenities 2. Adjust operating principles, policies and frameworks for Melbourne's public transport system and operators

1. INTRODUCTION

We have prepared this paper for the John Cain Foundation as a contribution to a much-needed public debate about how, when and where rapidly emerging new transport technologies can best contribute to protecting and promoting the quality of life for Melbourne's rapidly growing population.

Potential for major disruption and opportunities

In twenty years' time, digital and post-digital (such as quantum) artificial intelligence, communications and data management will likely be the key determinant of the efficiency and effectiveness of mobility in Melbourne as autonomous vehicles (AVs), mostly powered by electricity, revolutionise travel as we know it today.

And autonomous vehicles will not only be today's 'car with a brain'. They will take multiple forms, with varying passenger capacity, and some may not even require a road network for their operation. But all forms will likely be interacting and operating through a massive system of communications and data exchange at a scale yet to be fully comprehended.

City governance will involve new agencies and responsibilities in order to maximise public benefits from technological transformation, and to ensure equitable and secure access to the city's data management system. And city planning will have entered an entirely new age of possibilities.

The implications for rapidly growing cities, like Greater Melbourne, are potentially widespread and profound, offering major opportunities for positive economic and social change. In the words of a recent in-depth study:

"AV technology, with its "new" private-sector proponents, has the potential to transform cities in ways not seen since the rise of the private vehicle 70 years ago, and re-shape the role of capital in urban governance, …the rise in AV technology and its rollout in cities is strengthening the set of interrelationships that allow the public and private sectors to partner in planning, but it presents new challenges with respect to "blur[ring] the distinction ... between private and public modes of transportation" … This has a direct impact on how accountability in decision-making is attributed and raises new questions about the role of democratic participation of civil society in transportation planning."

Uncertain change pathways

The move to fully autonomous vehicles is variously forecast to be rapid, with maximum adoption by the 2030s, or more gradual, driven by capital turnover cycles for vehicles, diverse consumer preferences and an unwillingness to give up the art, pleasure and flexibility of driving one's own vehicle under widely differing circumstances. Different cities will adapt at different speeds, and the learning curve for change will accelerate rapidly.

Because of the differing benefits to differing groups in the community, some groups will press for faster adoption than others – older people may be more likely to be early adopters, because they will benefit most and will most likely have the resources to make changes to their mobility preferences.

Given the right policy and regulatory settings, lives will be saved, the environment will be improved, congestion will ease, and mobility will be accessible across more of the community. Car ownership will fall as autonomous vehicles become available through smart-phone based 'call-up' services, operated by the private sector, and costing far less per kilometre than conventional owner-operated vehicles.

No-one can predict accurately what the autonomous vehicle era will mean for city development. However, researchers, manufacturers, and city officials across the world are concluding that policies and actions that facilitate and enable city-wide operation of autonomous vehicles (including drones) will be essential to promote mobility in ways that support people's work and leisure activities.

In adopting such policies, governments and their planning and urban management agencies will need a clear vision for the city's future, and a firm and a constant policy of maximising the public good. Failing to take this stance will lead to both chaos and the loss of many of the potential benefits available from this technological change. Cities that are slow to adapt in ways that support societal welfare or do not create clear and consistent policies and programs for autonomous mobility will inevitably become less attractive places to live, work and invest in a rapidly changing world.

Plan Melbourne needs to address a future with autonomous mobility

Plan Melbourne 2017-2050, released by the Victorian Government in early 2017, sets out the Government's aspirations, expectations and policies for the city and our diverse ways of urban living, all aimed at ongoing improvements in the quality of life for Melbourne residents and its visitors. It looks ahead thirty-three years.

The Plan provides a framework of vision, goals and objectives, as well as implementation plans that, we assume, reflects community expectations and aspirations. But it has not yet addressed the future of the city through the lens of autonomous mobility. A discussion to this effect was published by Lyndsay Neilson in the Planning Institute of Australia's Planning News in November 2017.

In October 2017, the Government released the five-year Victorian Infrastructure Plan responding to detailed modelling and analysis undertaken by Infrastructure Victoria (IV) in preparing its inaugural 30-year infrastructure strategy. In relation to transport planning, IV noted that:

One of the greatest uncertainties for the transport system is the how and when of driverless vehicles. Though we expect fully automated vehicles are some way in the future. Automotive vehicles will progressively become more automated and connected. The challenge for government is to work out how to best support the deployment of these new technologies as they become available, minimising barriers and ensuring their value to the community is maximised. There is a role for both federal and state governments to set appropriate standards, establish transport strategies and mediate between different transport types.

It's not all about driverless vehicles, but we think this technology is likely to have the most profound effect on the way Victorians travel. We have commissioned modelling that suggests driverless vehicles and/or transport pricing could dwarf the effect of any single major transport project (emphasis added).

In response to this challenge, the Government has supported enabling the trial of highly automated vehicles and have commissioned IV to prepare written advice on Victoria's infrastructure requirements to support the introduction of automated and zero emissions vehicles. But it has set aside consideration of road pricing.

This paper recommends policies and actions that need to be taken now to maximise the prospect and minimise the cost of continuing to meet Plan Melbourne's vision in an era of potentially dramatic shifts in our dominant means of transport, likely to be well within the Plan's time-frame. As such, it is intended both to provide input into IV's work and to inform broader public debate about what government needs to do to ensure the rapidly evolving transport related technologies make for a more liveable and sustainable Greater Melbourne and Victoria.

2. WHAT IS THE FUTURE FOR AUTONOMOUS TRANSPORT SYSTEMS?

Four critical system drivers

I. Autonomous driving – a shift towards vehicles being largely or wholly controlled by an automated driving system i.e. levels 4 and 5 of the SAE International Index (see text box). Such vehicles could be either privately owned or owned and operated as part of a fleet providing transport services. For the purposes of this paper, we term such vehicles as autonomous vehicles (AVs)

II. Connectivity – vehicle-to-vehicle (V2V) communication or vehicle-to-transport system infrastructure (V2I) communication, enabling crash prevention, safety, mobility, and environmental benefits. In this paper, such vehicles are termed connected autonomous vehicles (CAVs).

III. Shared mobility – the increased use of autonomous taxis or shuttles, reducing reliance on privately owned vehicles, increasing overall system capacity utilisation and mitigating congestion.

IV. Electrification – a shift from fossil-fuelled vehicles towards electric motive power, reducing vehicles' operating and maintenance costs, and local air pollution and greenhouse gas emissions.

Vehicle autonomy can, in principle, operate regardless of the type of power that is driving the vehicle, and could include any of the following:

- Existing vehicles, which can be fully converted
  - Petrol/diesel/LNG-engine vehicles
  - Hybrid engines e.g. Prius
  - Electric vehicles e.g. Tesla, Leaf, BMW
- New conventional vehicles with options for full autonomous functions
- New electric vehicles designed to be fully autonomous
- Modular autonomous vehicles that can be linked together
- New vehicles not dependent on existing road infrastructure such as drones or systems like the TransPod Ultra-High-Speed Tube.

Autonomous Vehicle Classification:

SAE Index

Level 0 – No automation

The full-time performance by a human driver of all driving tasks, even when assisted by warning systems.

Level 1 — Driver assistance

The driving mode-specific performance of either steering or acceleration and deceleration, using information about the environment and with a human performing all other dynamic driving tasks

Level 2 — Partial Automation

The driving mode-specific performance by one or more automated systems of steering and acceleration and deceleration using information about the environment, with a human performing all other dynamic driving tasks

Level 3 — Conditional automation

The driving mode-specific performance by an automated driving system of all driving tasks, with an expectation that a human will respond appropriately to a request for intervention

Level 4 — High Automation

The driving mode-specific performance by an automated driving system of all driving tasks, including when a human does not respond to a request for intervention

Level 5 — Full automation

Full-time performance by an automated system of all driving tasks in all modes

There are currently many vehicles deployed across Greater Melbourne with autonomous functions such as self-parking or auto collision-avoidance technology (Level 2 automation). Until a vehicle can drive itself independently, it is not a true autonomous vehicle (AV). A fully AV (Level 5) does not require a human driver – it is computer driven.

Major vehicle manufacturers worldwide will phase in various levels of autonomy until fully autonomous vehicles are widely tested, certified and generally accepted by the community. Other manufacturers, not traditionally in

the automotive industries are developing specific AVs designed from the outset to be fully independent of a human driver.

As noted above, an additional and important element in introducing autonomous vehicle operations is the concept of Connected Autonomous Vehicles (CAVs), where the technologies allow all vehicles to communicate with each other and the external environment.

Most modern vehicles today are 'connected' in various ways – through navigation guidance systems (GPS), and where the GPS system receives information on road conditions through cellular signals (4GLTE). The current 'connected vehicle' concept does not imply that the vehicle is making choices for the driver. Rather, it supplies information to the 'brain' of the vehicle to assist the driver.

AV and Connected Vehicle (CV) technologies combined, including vehicle-to-vehicle dynamic communications, are seen as fundamental to the efficient, high-density road use that comes from enabling 'platoons' of vehicles to travel close together and in groups.

NEXT Future Transportation Inc in California is experimenting with autonomous vehicles (pods) that can physically couple together to form a 'bus'. The pods are designed to enable passengers to move between the pods and group into common destinations. Pods can 'break off' and travel to their respective destination. A number of cities in Germany are expected to assist in developing the technology.

Also in the 'autonomous vehicle' categorisation are new drone technologies developed in China and Germany (and currently being tested by the Roads and Transport Authority in Dubai) which allow travel independently of the road network.

There are other similar concepts across a wide range of technologies, including the TransPod Ultra-High-Speed Tube technology being tested by a number of companies, including the Hyperloop backed by Sir Richard Branson.

The impact of drone technologies

Electric-powered drones are already approaching high levels of autonomy and as they are scaled up to carry parcels and passengers, they will create a new technological 'edge' for electric power over conventional fossil-fuelled vehicles.

The most rapid take-up of drone technologies in the urban transport scene is likely to be in association with e-commerce. Drones will supplement and then potentially replace light commercial vehicles in the delivery of many on-line purchases. In Melbourne that would eliminate some 200,000 vehicles from the road system, with a concomitant potential to shave the peak loads on the road system that generate costly congestion.

Passenger drones are being built and tested in Germany and Japan, with the Roads and Transport Authority in Dubai taking a leading role in providing a testing ground for one and two-person drones from these manufacturers. Another decade is likely to see high levels of technological development in this sector, with the costs of freight drones reducing, while passenger drones appear likely to grow only in the luxury vehicle sector. Nevertheless, they too will take some car travel off the road network.

3. AUTONOMOUS VEHICLES WHAT AND WHEN WILL THEY DELIVER?

The evidence base

There is now an extensive literature exploring the potential nature, timing and impacts of autonomous vehicle technology, broadly described. These include: academic studies of the technical and economic performance affecting how and when AV will impact urban transport and planning; guidance documents from public sector transport research agencies addressing the likely changes to infrastructure required to accommodate AV technology/services; and consultancy studies evaluating potential introduction strategies and impacts in particular jurisdictions, often involving scenarios exploring different adoption paths (e.g. RethinkX, McKinsey, KPMG, BCG).

Critical factors affecting deployment of AV-based services

Desired societal outcomes and decision-making frameworks

The focus of testing of autonomous capabilities has been on the capabilities per se, rather than on the uses and scenarios relating to drivers, non-drivers, vulnerable demographic groups, wider community impacts, and socio-economic growth potentials. Human factors, and the influence between behaviours and services, which AVs look to provide, have received less attention to date.

A critical issue here for Melbourne is determining how best to use AV-based services to address the needs of growing and under-served outer areas fast:

> "Twenty-first-century development is shaped around increasing polarity between service-rich inner suburbs and car-dependent lower-cost housing development on the urban fringe increasingly isolated from higher-level employment and educational opportunities. While many planners and citizens believe Australian suburbs to be of such low densities that alternatives to car dependence are impractical, careful consideration of the evidence shows that it is political and institutional will rather than the nature of the urban form that prevents greater use of alternatives to the car"[v]

More generally, the very uncertainties about how and when AV technologies will begin to significantly affect urban and mobility planning, together with the dominant role of the private sector, appears likely to impede governments' willingness and ability to shape AV developments in the public interest.

> There currently appears to be an operative consensus among public sector agencies to follow developments in the AV industry closely, but hold back on policy initiatives that could have real impact – an attitude of "watch and wait"… The public sector thus finds itself in a fundamental dilemma. It is clearly required as a significant "shaper" if the rollout of AVs is to occur in alignment with the public interest, yet it remains unclear whether the necessary political support and resources to underwrite such a role…There is a significant difference between proactively shaping the rollout of AVs in full awareness of the impact on the public interest that this technological transformation presents and just waiting for this transformation to take shape.[vi]

Safety

One critical factor is certain to be safety, real and perceived, of AVs. In particular, there is currently no consensus on how safe autonomous vehicles should be. As RAND has indicated:

> Some will insist that anything short of totally eliminating risk is an unacceptable safety compromise; it is acceptable if humans make mistakes, but not if machines do. However, waiting for autonomous vehicles to operate nearly perfectly misses opportunities to save lives, as it means the needless perpetuation of the risks of human drivers. [vii]

But as RAND has also pointed out, real-world driving experience is needed for safety evaluation but involves risks to early adopters or to other road users.

> This is analogous to the risk of allowing teenage drivers on the road: They may not be good drivers yet, but they need experience to become good drivers. However, until then, they pose risks to themselves and to others. We have policies in place to try to limit risks from inexperienced young drivers, such as a minimum driving age and restrictions on learner's permits. Those policies seek to balance the goal of long-term improvement with the need for near-term experience.[viii]

To avoid the best becoming the enemy of the good, we would argue for allowing autonomous vehicles on Victoria's roads when they are judged safer than the average human driver. More lives would be saved while still ensuring that autonomous vehicles do not increase risk

This is an area where political leadership is required, particularly in relation to leading community debate and ensuring a balanced, long term approach to managing the risks and benefits of the transition to safer, more efficient autonomous transport systems. Nominating at least one Victorian regional city serving as a 'proving ground' for autonomous vehicles from 2018 onwards would be a valuable step forward. Geelong, with its automotive background, is an obvious choice.

The role and detailed design of experimentation is, however, crucial in ensuring people are safe and public confidence is maintained in the emerging technologies. In the case of Victoria, this could be assisted by initial testing of candidate technologies and mobility systems in controlled conditions, whether on dedicated proving grounds or specially allocated and tightly controlled urban areas. An additional fundamental safety measure is to ensure that AVs entering the Australian market comply with the long-established Australian Design Rules, ensuring there are no backward steps in safety arising from radical new vehicle types and designs.

What will be the winning technologies and business models?

Players in the AV space are working on a range of technologies and business models to exploit and capture what they see as a major money-making opportunity. Overwhelmingly from the private sector, key players include incumbent car OEMs, software and IT majors (Alphabet, Apple, Baidu) and ride sharing companies and transport service providers (Lyft, Uber). There is a rich underlying ecosystem of start-ups and potential new entrants (for example, the Australian start-up Zoox which was recently licensed to test its AVs on the streets in California).

It is not clear which, if any, of these current approaches will be commercially successful, let alone dominate AV related markets, as was the case with automobile propulsion in the early years of 'horseless carriage' development. Looking from the perspective of an emerging disruptive technology, motive power could have standardised on steam or electric traction, as opposed to the internal combustion engine that came to dominate in the early years of the 20th century with the parallel development of the US oil industry. Similar uncertainties surrounded the evolution of the electricity generation, distribution and use in terms of choices of AC/DC current and centralised versus distributed/local generation. Both these transitions involved the creation, over decades, of a broad ecosystem to support the development of commercial opportunities in response to technological development.

One infrastructure that all AV-based services will need and will use in common will be the digital (or quantum) communications and data management networks. The design, development, ownership, management and necessary scale of such networks and data management capacity, will involve intensive debate about the extent to which they are private sector or government owned and managed, and how they might be regulated.

Similarly, toll road owners and operators like Transurban are likely to increase their investment in 'smart' technologies that ensure the maximum flexibility for their infrastructure to meet the needs of AVs.

How quickly will necessary changes to urban governance and support systems take place?

To ensure smooth transition of AV-based services and avoid perverse impacts, major changes in urban governance and systems affecting urban planning and management, transport infrastructure, and mobility service provision will be required. Studies indicate that, in addition to road infrastructure modifications, these changes will need to involve:

- Identifying and funding the necessary deepening/expansion of communications, and IT/data systems to accommodate increased demands for data/IT availability for integrated real-time information capture, dissemination, billing, etc.
- Identifying and funding the augmentation of power supplies to accommodate greatly increased penetration of electric vehicles (reducing particulate emissions and, subject to a shift to renewables, lower greenhouse gas emissions).
- Determining a legal structure that accommodates human occupants not being in direct control of vehicles and the resulting liabilities for damage and injury to other vehicles and road users. This would also need to include the allocation of risks and liabilities for privacy and cyber security between transport system operators, road authorities, AV manufacturers, software suppliers and integrators for damages caused by computer hackers, disgruntled employees, or terrorist organisations who may target the disruption of AVs, resulting in collisions, traffic jams, city 'lock-downs'
- Defining a regulatory framework governing system operation and allocation of roles and responsibilities. For example, road and highway authorities and suppliers of AVs will need to agree on who controls traffic flows and speeds on existing highways. If AVs displace public transport in some metropolitan areas, as people prefer

the flexibility of a driverless vehicle over bus and rail, decisions will be required on matters such as whether AV providers should provide public transport-type waiting stops and passenger shelters. Regulatory change will also need to encompass major impacts on the criminal justice system as driving offences progressively reduce in number, revenues from fines and penalties from such offences and parking diminish, and courts are freed of their single heaviest workload (traffic offences). New definitions of 'offences' by autonomous vehicles and service providers will be needed.

- Introducing comprehensive and consistent infrastructure pricing and funding policies to mitigate the major risk that AVs will generate more road trips than the current mix of technologies:
    - with population projected to nearly double in Melbourne by mid-century under current policy settings (i.e. road pricing limited to a small number of roads, largely determined by financing, rather than demand management considerations), the community will face the choice of increased congestion and time delays or the costs of funding yet more roads.
    - this sensitive but, in the longer term, unavoidable political issue is compounded by split Federal/State responsibilities for vehicle taxation, with fuel excise levied by the former, an important source of general Federal tax revenue threatened by a major shift to electric vehicles.

How will consumer and community attitudes to AV-based transport services evolve?

Consumer and community attitudes to AV are important determinants of how quickly and how far AV-based transport will penetrate in Greater Melbourne. Overseas research indicates a significant shift towards ride-sharing and away from private car ownership and use of taxis and buses, implying that people are likely to be open to other newer mobility offerings associated with AV.[ix] Two key considerations are likely to affect consumers' choice between conventional and AV-based transport services – the comparative cost, convenience, and safety of the alternatives.

The modelling of costs in different studies produces a range of results for shared electric AV. In general, the estimated direct costs of ownership for an electric AV are well below those for a comparable conventional vehicle (e.g. a taxi), with savings generated from not needing a driver, as well as lower fuel and technical maintenance. These savings are, however, nullified in some studies by the assumed cost of cleaning and wear and tear on shared service AVs resulting from poor in-car consumer behaviour when there is no supervision by a driver.

Given the slow turn-over of the vehicle fleet in Australia at present, it would take some 20 years to achieve a fleet that is fully autonomous. Another factor that will slow change will be the highly variable willingness of consumers to change their driving preferences – many will resist moving from self-driving vehicles, despite the potential safety and other benefits.

Convenience may also be a factor in inhibiting reduced private car ownership if the AV-based service offering is not effective outside the metropolitan area. Generally, however, consumer studies indicate the perception overall of artificial intelligence (AI) applications in the automotive industry, in agriculture, in utilities management and other sectors (and in autonomous vehicles themselves) is very positive, with only a small minority not believing in the technology's long-term viability.

As noted above, the safety performance of AV-based services, perceived, as well as actual, will clearly be an important factor in influencing both consumer take-up and community attitudes towards AV ownership and services. This is supported by overseas consumer studies that indicate cybersecurity and AV/human driven accident are the largest customer concerns about AV. In both cases, the current perception is that standards in both these areas need to increase.

In general, the actual safety performance of Level 4/5 AVs in nearly all operating environments is forecast to surpass that of human drivers over the next 10-15 years, but with the pattern of deployment in different transport uses dependent on market and commercial benefits and regulatory requirements in relation to safety and other operating parameters.

In this context, companies such as BMW claim that their AI and GIS systems in AVs already are sufficiently powerful to obviate any need to modify current road infrastructure (except in obvious ways such as eliminating on-road parking) and have huge capability to operate safely.

Perceptions currently favour speedy AV deployment, but this could change markedly in response to a major incident involving hacking, particularly one leading to major loss of life, serious injury and/or major economic and social disruption. By definition, major incidents are most likely to occur as a result of a successful attack on a CAV-enabled system, for example, bringing entire vehicle fleets to a halt to create city wide transport gridlock, or (at the extreme) using a number of them for terror attacks.

As we have seen in the case of terror attacks on the air transport system, while unlikely to block AV deployment completely, government regulatory and security responses may impede deployment, increase operational costs (such as liability insurance), or reduce customer convenience. This places a high premium on risk identification and management for service providers, infrastructure operators and system regulators and guardians, as well as careful experimentation at an early stage of the testing and introduction noted above.

Ultimate accountability for system performance and integrity unavoidably rests with government. This places a premium on the relevant level of government ensuring that the AV-enabled transport system is set and meets clear performance standards in relation to customer and community safety and security. This is a challenging task, since the system will likely comprise a mixture of private and public sector players.

Significant potential economic and environmental benefits

A wide range of studies broadly agree on the type of potential benefits associated with AV/CAV technology and services, delivered either by encouraging direct positive effects or reducing negative effects, notably reduced congestion and improved journey times, fewer accidents and expanded mobility options, particularly for those not able to drive conventional vehicles (see Table 2 below). A widespread adoption of electric traction, in concert with AV/CAV technology, would be required to deliver significant reductions in local air pollution and greenhouse gas emissions.

There are significant artificial intelligence initiatives in the freight and logistics industry where automation of freight handling using driverless vehicles is already common. Further advances in technologies where freight 'talks to' the vehicle and vehicles become more autonomous (driven in part by the shortage of human drivers) will increase the productivity of the sector. [xi]

Table 2:Potential Benefits of Connectivity and Automation[xii]

Driving Externality	Connectivity (Full V2X)	Autonomy* (L4,5)	Shared Autonomy (L4,5)**	Electrification***
Safety				
Congestion				
Emissions				
Land Use				
Mobility				

Strong benefits
Some expected benefits
Weakest benefits/no impact
Uncertain impact

*Autonomy is defined for this purpose as individually owned vehicle.
**Shared Autonomous Vehicles (SAV) are on-demand self-driving vehicles supporting shared rides as part of a privately or publicly managed fleet.
***While not a focus of this NCHRP research, the team provides assumptions of potential benefits of electrification based on known literature.

Source: US Transport Research Board

Shared autonomy important for reducing congestion

The impact of driverless vehicles on the demand for road infrastructure is uncertain and may result either in restrained demand or a surge in demand across the network. A shift away from vehicle ownership in favour of using shared autonomous transport might increase the perceived cost of travel on a per trip basis. Fares could include all associated costs including registration, insurance, and maintenance and road usage. This may reduce total distance travelled and time spent in cars, and a shift towards the use of public transport. Under this scenario, driverless cars would have a limited impact on transport demand.

But if people continue to own driverless cars they might take more frequent and longer road trips in their own cars. This would reduce the perceived travel costs, as users would be able to do other things instead of concentrating on driving. In this case, the number of trips is likely to increase because motorists would no longer park at their destination but could send their cars home to park until needed again. There is also potential for an array of new mobile services using driverless vehicles. In this future, travel demand could explode, making road congestion much worse in the absence of other road management levers.

Broad agreement on likely end-point but speed/nature of transition contested

Widely differing perspectives/projections

There is a broad consensus that delivery of major potential benefits is directly dependent on high AV/CAV penetration of passenger and commercial vehicle fleets and hence a dominant proportion of journeys being undertaken by AV/CAV transport systems. The timing and scale of AV deployment will also be influenced by the degree to which national and local policies support and shape the introduction of AV-based transport and how particular cities are configured i.e. physical form, economic structure, demographics, and related factors. Some studies suggest this would involve 70-80% of transport fleets having level 4/5 capabilities and that this should be achievable by 2040-50. Others argue for a more gradual and variegated roll out (see Table 3 below).

Table 3: Selected studies' findings on market penetration/impact of AV

Source	Market	2030	2040	2050	2060	2070
		Penetration	Penetration	Penetration	Penetration	Penetration
AustRoads (2017) (a)	Australia – unclear but probably new vehicle sales	Level 4 – Limited to certain roads	100%	100%	100%	100%
VTPI (2017) (b)	Australia – distance travelled	1-4%	10-30%	30-50%	50-80%	?
ADVI (2016) (c)	Australia – new vehicle sales	2-5%	15-30%	30-60%	60-90%	100%
Insurance Industry study (2015) (d)	Canada: total vehicle market	1-4%	10-30%	30-50%	50-80%	100%
MRCagney (2017) (e)	New Zealand – total vehicle fleet	0	3%	25%	55%	73%
ReThinkX (2017) (f)	USA – total miles travelled via Transport as a Service	95%				
[Out years interpolated]	[~100%]	[~100%]	[~100%]	[~100%]		
IAG (2018) (g)	Austral–a – Fully driverless vehicle penetration	1-2%	14%	NA	NA	NA

Notes:

a. Assessment of Key Road Operator Actions to Support Automated Vehicles (Austroads Research Report AP-R543-17; May 2017)

b. Autonomous Vehicle Implementation Predictions: Implications for Transport Planning (T Litman, Victoria Transport Policy Institute; September 2017)

c. Position Pap–r — Economics Impacts of Automated Vehicles on Jobs and Investment (Australian Driverless Vehicle Initiative: September 2016)

d. Automated vehicles: Implications for the insurance industry in Canada (2015 – quoted in ADVI paper)

e. Autonomous Vehicles: Research Report (MRCagney; December 2017)

f. Rethinking Transportation 2020-2030: The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries (James Arbib & Tony Seba, ReThinkX; 2017)

g. Future of motor insurance (IAG Investor Presentation, April 2018)

A bullish view – rapid deployment over the next decade, based on shared service models

By way of illustration of the differing range of views on adoption paths and impacts, RethinkX argues that AVs will be rapidly adopted, especially as the changes in technology accelerate, because autonomous electric vehicles (AEVs) with fewer moving parts than internal combustion engine vehicles and operated 24/7 will become more cost-effective than the many possible alternatives. This will create major incentives for households to not own cars, but rather to use the Uber-style services that the authors see as rapidly emerging.

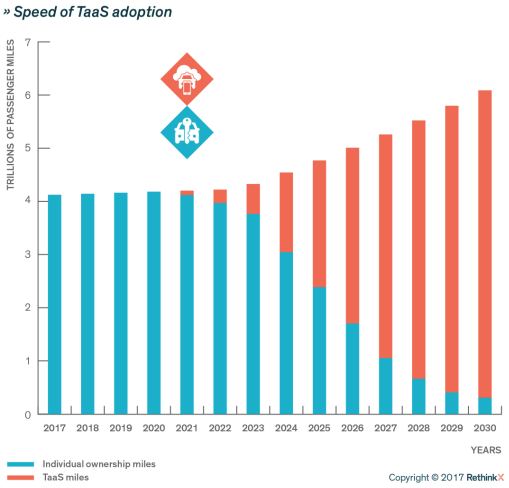
Put simply, a smart-phone 'app' would be used to call up a car, from a service provider like Uber, and the vehicle would arrive, on demand. On completion of the journey the vehicle would be expected to depart to make another trip.

The authors define their concept as having two forms:

> TaaS: transport-as-a-service. A new model for passengers to access transportation on-demand, providing a level of service equivalent to or higher than current car-ownership models without the need to own a vehicle. TaaS involves services based only on autonomous vehicle (AV) technology, delivered by vehicles that are owned by fleet operators, and that are used 10+ or more times per day than Individual owner vehicles.
>
> TaaS Pool: a subset of TaaS that entails sharing a vehicle ride with other people who are not in the passenger's family or social group — the equivalent of today's Uber Pool or Lyft Line. The vehicles delivering TaaS will be the same as TaaS Pool; only their usage (whether passengers are sharing) dictates what they are called. TaaS Pool might eventually grow in numbers of passengers to possibly replace many elements of today's public transportation.

ReThinkX forecast large-scale, rapid development and adoption of these concepts worldwide, resulting in major disruption to the entire auto-industry sector and to the oil industry. They argue that this will happen because the costs per kilometre of travel will become dramatically cheaper than current costs of car ownership and operations. The modelling predicts that the TaaS model will rapidly undermine the sales in the USA of internal combustion engine vehicles (ICEs), starting in 2020, with a total collapse of ICE sales by 2024 (see Figure 1 below).

Figure 1: ReThink X TaaS Penetration Projections[xiv]



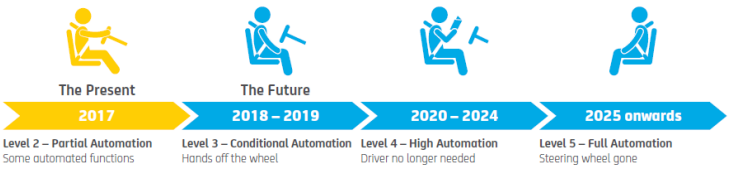
Source: James Arbib & Tony Seba

This is, clearly, a very important and at the same time very debateable assumption on many grounds. It is said to reflect the take-up experience of other disruptive technologies (lap-top computers, digital cameras) in the recent past, noting, however, that vehicles are much longer-lived assets with much higher up-front capital costs, factors that may inhibit the rapid transition seen in digital consumer goods.

The NRMA has published a report exploring the potential impacts of the introduction and early adoption of autonomous vehicles across Australia, and specifically New South Wales.[xv] Like RethinkX, the NRMA has pointed to Mobility as a Service (MaaS) as the major factor engendering major reductions in car ownership. Uber-style call-up services, ride sharing, and related services making better use of the vehicle and hence lowering costs per kilometre travelled, will underpin this change. High-capacity digital communications, artificial intelligence and machine learning, lidar, GPS, cheaper battery costs and massively increased computing power are converging factors that will drive the transformation of cities, including Melbourne.

The NRMA has placed the different levels of automation into a time-frame for adoption in Australia that shows that we are already at Level 2 – Partial Automation, and from 2025 onwards fully automated vehicles will be introduced in Australia (see Figure 2 below).

Figure 2: Autonomous Vehicle Introduction in Australia (NRMA/Australian Driverless Vehicle Initiative)[xvi]



Source: NRMA

Among the NRMA's main findings are the following:

- Despite Australians' love of the motor car, and our cities being designed and built around self-drive motoring, Australia will face, in the next decade, increasing changes in mobility preferences and decisions
- Traditional car manufacturers face new competition based around the principle of flexible mobility, not car ownership, and this competition is driving a major 'struggle' in the world of vehicle manufacturing
- High level autonomous vehicles (no steering wheel or pedal controls) will arrive in Australia as early as 2020
- Some level of human interaction with the motor car will still remain by 2025, but after that car ownership will no longer be a necessity.
- Declining car ownership does not result in fewer vehicle-kilometres travelled – indeed this metric is expected to increase as AVs become widely available and provide cheap, speedy, reliable services, including services for people who are not car owners today due to age, disability, or other factors.
- Governments should give consideration to how an autonomous vehicle future integrates with current transport and land use policies – significant reforms will likely be necessary.

Unlike RethinkX, however, the NRMA analysis provides no projections of the likely overall rate of transition to an AV/CAV system world, either in terms of vehicle sales or distance travelled via AV/CAVs.

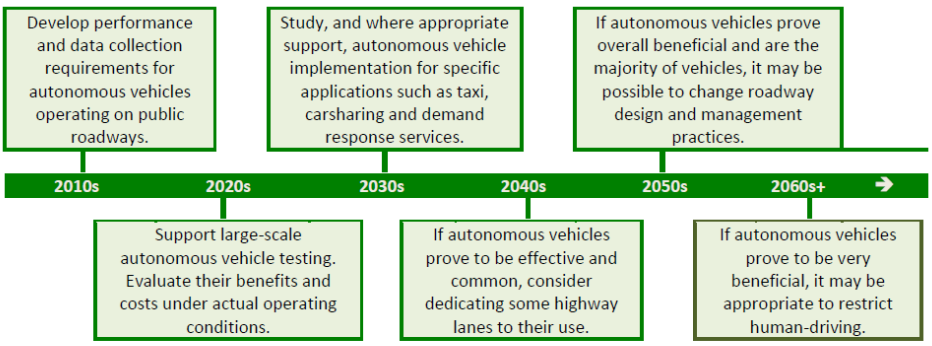
More modest expectations – limited deployment before mid-century, with focus on continued personal vehicles

More bearish views on the speed of transition are suggested, for example, by the Canadian think-tank, Victoria Transport Policy Institute (VTPLI) and recent work by IAG Ltd, one of Australia's largest motor insurers, to quote, VTLPI:

> "..some benefits, such as independent mobility for affluent non-drivers, may begin in the 2020s or 2030s, but most impacts, including reduced traffic and parking congestion (and therefore road and parking facility supply requirements), independent mobility for low-income people (and therefore reduced need to subsidize transit), increased safety, energy conservation and pollution reductions, will only be significant when autonomous vehicles become common and affordable, probably in the 2040s to 2060s, and some benefits may require prohibiting human-driven vehicles on certain roadways, which could take longer.[xvii]

These findings reflect concerns about the underestimation of AV costs, particularly for the maintenance costs of shared vehicles, and overestimation of the speed with which AV related technologies can be widely applied across transport networks. The result is a markedly slower implementation timeframe than proposed by RethinkX, offering governments a more measured approach to policy making and regulation (see Figure 3 below).

Figure 3: AV Vehicle Impacts Planning Timeline [xviii]

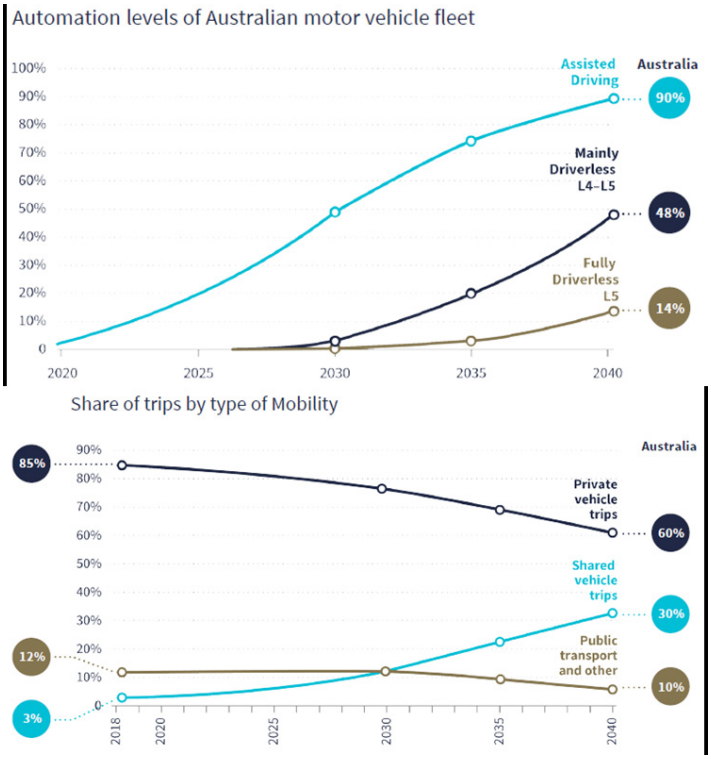


This timeline summarizes how autonomous vehicles are likely to impact transport planning.

Source: VTPLI

More recently, IAG has also suggested that both fully autonomous (i.e. full Level 5) vehicles and shared mobility services in Australia will follow gradual penetration curves out to 2040, with resulting significant continuing role for private vehicle trips (see Figure 4 below). These projections reflect views on the large barriers to full autonomy created by software costs (arising from the complexity of automation systems), and the scale of regulatory change required across Australian governments (involving some seven hundred separate laws and regulations).[xix]

Figure 4: IAG Australian AV and Mobility Projections to 2040



Source: IAG

The important role of electric vehicles

As noted (see Table 2 above), assuming electricity generation is increasingly focussed on renewables, electric vehicles (whether autonomous or not) offer very significant benefits in terms of the reduction of local air pollution and greenhouse gas emissions. Driven by these concerns, a number of countries are mandating a move to EVs over the next 10–20 years.

Globally, the number of electric vehicles sold each year is growing rapidly, with a 40 per cent increase from 2015 to 2016. There are now more than two million electric vehicles on the road. Australian electric vehicle sales fell 23 per cent from 2015 to 2016. Australians purchased 701 plug-in hybrid electric vehicles and 668 fully electric vehicles in 2016, making up 0.1 per cent of the Australian market.[xx]

Projections of the future penetration rates for EVs for Australia and globally exhibit the same variability as AV/CAV systems more generally. RethinkX argue for the strongly disruptive impact of new transport concepts based on the combined impact Autonomous Vehicle technologies in fully electric (battery-powered) cars, leading to 95 per cent of light passenger vehicles being electric powered by 2030.[xxi] This joins the ClimateWorks figure at the extreme end of the current projections for Australia and globally (see Table 4 below), reflecting both arguments about rapidly falling ownership costs and high levels of government policy intervention.

Table 4: Projected penetration rates for Electric Vehicles [xxii]

	Study	Year	Uptake rate
Australian projections	Network Transformation Roadmap (ENA and CSIRO, 2016)	2035	**20%** of light vehicle fleet
	Pathways to Deep Decarbonisation in 2050 (ClimateWorks Australia and ANU, 2014)	2030	**45%** of light vehicle fleet
	Zero Carbon Australia, Electric Vehicles (Beyond Zero Emissions, 2016)	2030	**100%** of passenger car fleet
	Australia's emission projections 2016, (Department of the Environment and Energy, 2016)	2030	**15%** of new light vehicle purchases
	Projections for the National Electricity Market (AEMO, 2016)	2025	**6.5 to 27%** of new light vehicle purchases
		2036	**16 to 45%** of new light vehicle purchases
Global projections	Global EV Outlook 2016 (International Energy Agency 2016)	2030	**10%** of light vehicle fleet
	Bloomberg New Energy Finance, 2016	2040	**25%** of light vehicle fleet

Source: ClimateWorks/Australian Electric Vehicles Council

Summary – a mixed and uncertain view on AV challenges and opportunities

As has been true for many transport (and indeed many other) innovations, the impacts of AV technologies and business models on the urban environment in places like Melbourne could be net positive or negative (see Table 5 below). Government can have major control and influence over adoption pathways and outcomes, which will reflect interaction of relative commercial returns of different technologies, models and effective policy and regulatory frameworks.

Table 5 AV mobility – opportunities and challenges

Opportunities	Challenges
Wider mobility/increased safety	User education/public resistance
Lower insurance ,healthcare and enforcement costs	Safety, security (mixed AV/human interactions; cyber hacking) and legal liabilities
Reduction in fuel consumption and travel time	High vehicle costs (technology/maintenance of shared vehicles)
Reduced congestion & road investment	Rising congestion/increased road investment
Better city planning due to lesser need for parking	Extended urban sprawl
Supplementing/strengthening public transport (e.g. completing the last mile)	Eroding public transport
Job creation	Job destruction
Lower emissions/higher air quality (electrification based on renewables)	Nil or negative environmental impact (induced trips/ carbon based energy)
Real time, information rich transport planning and management	Data overload & infrastructure congestion/disruption
Demand management through road pricing/ congestion charging	Erosion of Vehicle Excise Duty/road funding through electrification

4. CURRENT TRANSPORT SYSTEM FACTS AND POLICY SETTINGS

Characteristics of Melbourne's Car Transport

Fossil-fuelled private cars dominate how people move about the city

The structure of Melbourne's road vehicle fleet (not including heavy vehicles or buses) is dominated by privately-owned cars, heavily utilised for journeys to and from work. As of 2016, over two-thirds of Melbourne households own two or three cars, and a further 16 percent have more than three cars. This is a car-dominated, driver-dominated urban transport system (see Table 6 below). It is also a hydro-carbon fuelled city, with 98 percent of vehicles powered by petrol or diesel.

It is unlikely that much has changed since 2016, with the possible exception of increases in the small shares of hybrid and electric vehicles. A rapid shift away from hydro-carbon fuels looks like a very remote possibility on the basis of current policy and regulatory settings and mobility options/economics.

Table 6: Melbourne's vehicle fleet

Characteristics of Melbourne's vehicle fleet 2016 and changes 2011-2016

OWNERSHIP	UTILISATION	AGE AND TYPE
Overall **4.56 million** vehicles registered in Victoria **1.52 million** vehicles registered in Melbourne Of these: 1.23 million (81%) were passenger vehicles 213,000 (14%) were light commercial vehicles **Household car ownership** **0 cars** - 28,100 households (1.7%) **1 car** - 552,200 households (33%) **2 cars** - 578,700 households (35%) **3+ cars** - 265,000 households (16%) **Changes** Household growth 2011-2016: **2.2%** Vehicle registrations 2011-2016: **2.5%**	**Work travel** **61%** of owners drive to work **4%** of work travellers are passengers **10%** of work travellers use public transport **0.2%** of work travellers use taxis	**Age** Average age **10.5 years** Increasing numbers **4 yrs +** **Condition** Spare parts expenditure 2011-2016 +4.6% p.a. **Engine type** Petrol engines: **76%** Diesel engines: **22%** Hybrid engines: **2.0%** Electric engines: **0.2%** **Car sales growth 2011-2016** **1.2%** average growth p.a. in new vehicle sales **2.5%** average growth p.a. in used vehicle sales

Traditionally, the debate around transportation in Melbourne is about shifting a greater share of work-related travel to the public transport system, and, indeed, over recent years the train and tram systems have seen increased services and rapid increases in passenger numbers.

The future with default policy settings

The default policy settings on offer from Victorian governments of any political stripe overwhelmingly involve spending huge amounts of public money on building more roads. In return, over the coming decades Melburnians seem likely to face more congestion, deaths and serious injury and local air pollution.

More spending on roads

The dominance of single-person work journeys in private vehicles leads to constant pressure on governments to increase road capacity in order to reduce or, at least contain, congestion. All governments have been committed to major new road capacity interventions in Melbourne over decades.

Plan Melbourne 2017–2035 attempts to integrate transport and land use planning but, while supporting growth in public transport, it accepts continued growth in demand for road travel in private cars, including for work journeys. Plan Melbourne expects an increase from today's 12.5 million trips per day to almost 23 million trips per day by 2050, when the population is forecast to be eight million people. To manage this growth, the Plan sees major expansion in all transport infrastructure and services, but especially road infrastructure.

> Although the city's transport system has sound foundations, it is coming under increased pressure from growth. By 2050, Melbourne's transport network will need to handle an extra 10.4 million trips per day. Congestion and overcrowding is already an issue on parts of the road and public transport network, particularly at peak times. Major investment in transport infrastructure will boost rail and road capacity to meet the transport challenge, boost productivity, conserve energy, curb greenhouse gas emissions and protect liveability [xxvii]

In planning for an integrated transport system, Plan Melbourne proposes four directions:

3.1. Transform Melbourne's transport system to support a productive city

3.2. Improve transport in Melbourne's outer suburbs

3.3. Improve local travel options to support 20-minute neighbourhoods

3.4. Improve freight efficiency and increase capacity of gateways while protecting urban amenity

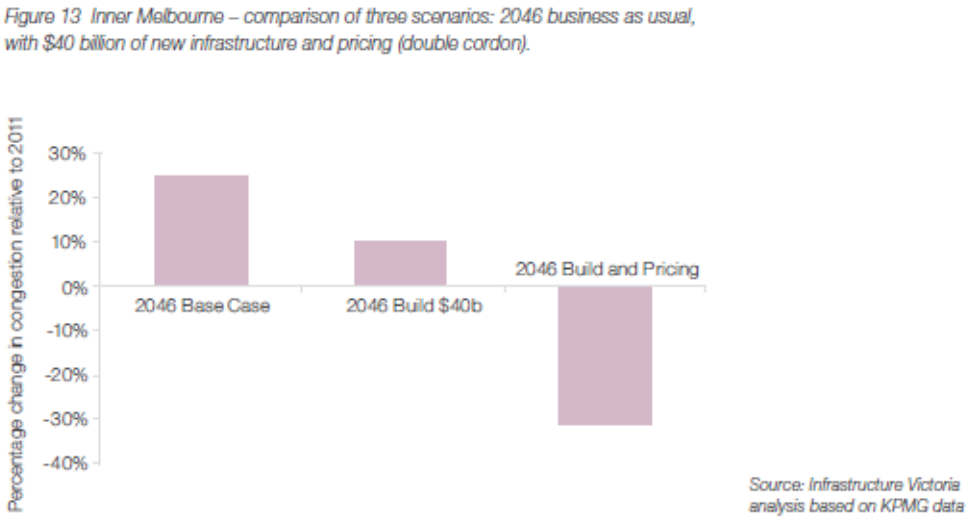
A key measure in Plan Melbourne to help manage travel demand is to support the establishment of a number of National Employment and Innovation Clusters in key locations in suburban Melbourne (e.g. around Monash and La Trobe Universities, Sunshine, Werribee) to encourage employment location out of the CBD, and hence shorten work journeys. Strengthening numerous suburban activity centres is also intended to assist with the Plan's objective of '20-minute neighbourhoods'.

At the same time, Plan Melbourne and the accompanying Transport for Victoria plans include major new road projects (as well as some rail and tram extensions) to accommodate Melbourne's projected population growth and overall demand for travel. The Plan, while mentioning smart infrastructure, includes no analysis of 'smart vehicles' – the AVs of the future – or their potential to use road infrastructure so much more efficiently that new road capacity, in some scenarios, may be unnecessary or substantially reduced. Essentially, the Plan assumes that the present structure of Melbourne's vehicle fleet will not dramatically change over the life of the Plan. This, in our view, is an assumption that is already out-dated, and significantly so.

Increasing congestion, despite major infrastructure spending

The Government's five-year Infrastructure investment plan, published in late 2017, announced road and rail transport investments costing some $16 billion [xxiv] in response to recommendations from the Government's infrastructure adviser, Infrastructure Victoria's (IV), 30 -year strategy. [xxv] IV's supporting analysis showed that, despite government spending of some $40 billion on Melbourne's transport infrastructure by 2046, Melburnians travelling across the region would still face increased congestion (see Figure 5 below).

Figure 5: Infrastructure Victoria congestion analysis [xxvi]



IV's overall findings are sobering, pointing to the need for major policy innovation; to quote:

> By 2046, congestion is expected to significantly affect almost half of all trips taken by car. This is projected to occur even with the following committed and 'business as usual' transport investments: M80 Ring Road upgrade, CityLink – Tullamarine Freeway widening, Melbourne Metro rail project, the Western Distributor and the Level Cross Removal program (This also includes the procurement of high capacity trains and trams) [xxvii].

The analysis echoes and strengthens findings of the Productivity Commission [xxvii] and the Victorian Economic and Efficiency Commission [xxix] of the futility of cities attempting to build their way out of congestion, and the urgent need for complementary pricing policies, supported by investment in public transport, so that drivers face the external costs of peak road usage and have access to viable alternative mobility options.

Growing numbers of road deaths and serious injuries

With today's human-driven car fleet there are large numbers of accidents each year. High levels of adoption of AVs will represent significant economic benefits to the State and to Melbourne through reducing road deaths and trauma. The default outlook, however, is for a significant growth in car related deaths and serious injuries over coming decades as Greater Melbourne's population grows.

Road accidents – scale, causes and economic costs

Given that the primary focus of the impacts of the AVs has been on Greater Melbourne, it is relevant to indicate that autonomous vehicle use can be a significant aspect of intra-state and inter-state road transport. As international literature shows, approximately 90% of all vehicle accidents are the result of human error. The following data indicate the severity of Victorian road accidents over the past three years (see Figure 5 and Figure 6 below).

Table 7: Victorian Road Fatalities, 2015–17

Victoria-Wide Fatalities			
Year	Greater Melbourne	Rural Victoria	Total
2015	103	148	252
2016	140	150	290
2017	102	156	258
5-Year Average	119		263

Source: TAC Victoria data

Table 8: 2017 Victoria-Wide Fatalities by Crash Type

Adjacent direction; manoeuvring; on road; opposing direction; overtaking; run-off straight road; run-off road on a curve; same direction	87%
Pedestrian-related/unknown	13%

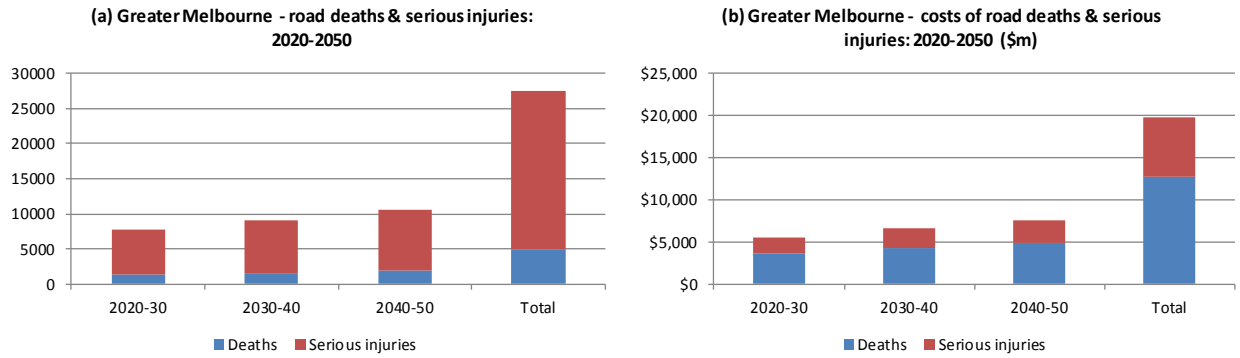
Source: TAC Victoria data

For 2017, 87% of road fatalities were human error and could have been very largely avoided with autonomous vehicle technology. If fully autonomous vehicles were operating in Melbourne, based on a minimum social cost per road fatality of A$2.6 million (BITRE estimate), total savings in 2017 would have been some $580million. Allowing for the full cost of road accidents associated with personal injuries, ambulance, police, paramedical services, and judicial costs, the total social benefits of reducing road accident levels by 87% for 2017 road accident data is estimated at $1.32 billion.

Default outlook for accidents to mid-century

Greater Melbourne's population is projected to grow by just under 60 per cent by mid-century.[xxx] With current per capita rates of deaths and serious injuries, current policy settings imply that, by 2050, just under five thousand people will die and over twenty-two thousand people will be seriously injured on Melbourne's roads. The economic cost of this road toll will total some $19.7 billion (see Figure 6 below).

Figure 6: Greater Melbourne road death and serious injuries 2020–2050



Source: TAC data/Authors' calculations

The chronic but major nature of this challenge indicates both the scope for delivering major economic and social benefits from a comprehensive shift towards autonomous vehicles across Melbourne, and the opportunity costs of overly cautious or inconsistent approaches to setting safety standards for AVs.

Road transport impact on local air pollution

According to a recent EPA Victoria report, by 2030, total motor vehicle exhaust emissions will have significantly reduced, despite the large growth expected in the use of cars and trucks. This is because improved technology is entering the vehicle fleet faster than the rate of growth in vehicle use. The net effect is a reduction in the impacts of exhaust-related pollutants: carbon monoxide, nitrogen dioxide and air toxics such as benzene. This prediction is supported by independent data. When long-term measurements of these pollutants in Melbourne were examined, a clear downward trend was seen. [xxxi]

5. SCENARIOS FOR THE FUTURE ADOPTION OF AUTONOMOUS TRANSPORT SYSTEMS IN MELBOURNE

It can be useful to approach the tasks associated with identifying the policy challenges and constraints to implementation of likely policy actions using concepts of scenario planning. Pierre Wack (Shell, 1972–1974) identified that for future oil pricing, planners had to consider what was predictable and what was fundamentally uncertain with respect to the price of oil. Predictable versus uncertain issues face the AV intervention policy questions.

Michal Kane and Jake Whitehead have recently explored, in a generic context, sub-optimal and optimal scenarios for the introduction of AVs into cities, and concluded that:

> "Scenarios involving policy inaction, including taking a business-as-usual approach to transport and urban planning, likely creates a risk of 'sleep walking' into major urban disruption.
>
> However, under the scenario of proactive planning and policy decision making, cities are provided with the opportunity to ride the disruptions, maximising their benefits and minimising the potential negative consequences." [xxxii]

For the Victorian Government to more fully understand the issues to be faced in relation to autonomous vehicles (AVs), scenario-based planning can assist in:

- identifying decisions, which are likely to be more robust under a range of alternative futures
- better quality thinking about the future of urban road transport in general, and AVs in particular
- transforming existing Victorian organisational cultures to consider scenarios involving AVs in a broader context
- developing sound strategies to consider AVs in Melbourne's metropolitan plan and their place in Melbourne's mobility fleet
- reducing the complexity of the management task to understand and cope with the potential disruptive influences of AVs.

By way of an example, Boston Consulting Group undertook just such a Scenario Planning project with the City of Boston and the World Economic Forum to assess the implications of future changes for Boston's urban management. [xxxiii] They simplified their modelling of travel into the central 0.45 square kilometres of the city of Boston by excluding walking and cycling and focusing on the breakdown of trips by mode on transit and on road-based systems. Trips were predominantly work trips. Table 9 below shows the results. In summary:

- Falling public transit use, much more substantial under the disruptive scenario
- A sharp reduction in the use of traditional personal vehicles under Scenario A and their disappearance under Scenario B
- A halving of the use of traditional taxi and ride-hailing under Scenario A and their disappearance under Scenario B
- A rapid rise in the use of shared autonomous taxis under Scenario A and then a decline under Scenario B
- The adoption of autonomous personal vehicles under Scenario A but their disappearance under Scenario B.
- The rapid rise of autonomous shuttle-buses and autonomous taxis to make up a greater total share of journeys than public transit, under Scenario B.

Although they did not put a time frame around the modelling, it clearly illustrates the scope for dramatic shifts in the structure of travel, under differing assumptions about the speed of take-up of various forms of AV technology.

Table 9: Boston Consulting Group Scenario Analysis [xxxiv]

	Structure of travel to City of Boston		
Vehicle type	Boston Today (%)	Scenario A: Gradual shift from private to shared and from human driver to AV (%)	Scenario B: Disruptive shift from private and human-driven to shared and AV (%)
Public transit	56	50	34
Traditional personal vehicle	33	11	
Traditional taxi and ride-hailing	11	5	
Shared autonomous taxi		22	14
Autonomous personal vehicle		11	
Autonomous shuttle bus			28
Autonomous taxi			24

Source: BCG

Scenarios for Melbourne

Given the uncertainties associated with predicting the take-up of these new technologies, clearly forecasting is impossible. Accordingly, to explore the potential impacts and emerging challenges associated with the adoption of autonomous vehicles in Melbourne, we have constructed a number of scenarios, as follows.

Business as Usual (BAU)

This is as currently reflected in the Plan Melbourne vision. Electric vehicles represent a minor vehicle fleet component. Autonomous vehicles have limited market penetration (converted or new). Greater Melbourne's population continues to grow; urbanisation continues to focus on historic road and rail links. The quantitative effects of this scenario are shown in Table 10 below.

In summary, the key implications for Greater Melbourne as a result of the 'do-nothing' or BAU scenario are likely to be:

- A progressive increase in the total stock of motor vehicles within Victoria and used within Greater Melbourne. Significantly higher growth rates in ownership and use of light commercial vehicles (accelerated demand as related to delivery of on-line shopping items).
- Continued sustained growth in the total number of vehicle kilometres travelled per day for both private and commercial vehicles.
- Gradual reduction in the percentage of households with two vehicles due to effects of ageing population, increased densities of inner urban suburbs, and reduced parking spaces.
- Only minor reductions in the percentage of transport costs as a component of average household expenditures. Vehicle ownership and operating costs remain a significant share (greater than 60%). Households remain significant owners of private vehicles, despite fleet ageing.
- Significant sustained annual growth in levels of road congestion over time, as total vehicles in use increase, with public transport accounting for less than 14% of private trips by 2031, and likely to increase slowly to 16% by 2050 as road congestion levels continue to grow.
- Average time spent by private motorists in urban Melbourne looking for parking is likely to increase from 30% in 2016, to 50% by 2031, and to 60% by 2050 (an increasing user-cost in terms of the total cost of travel and the total costs of urban road congestion).
- No likely change in the average vehicle occupancy level for private vehicles used for work trips (1.2 in 2016 compared to 1.6 for OECD countries and 1.5 for USA motorists). It assumes that early trials of car-pooling will not be repeated, based on Plan Melbourne proposals.

- The likely acceleration in the costs and related environmental issues associated with increased road congestion, in the absence of:
  - increased levels of public transport use
  - increased vehicle occupancy levels
  - private car-pooling from the expansion of UBER-style transport scenarios
  - widespread introduction of electric vehicles
  - introduction of autonomous vehicles with primary emphasis on increased passenger capacities and more efficient utilisation of freeway and arterial road space, via road pricing and other demand management policies.

Table 10: Business as Usual Scenario results

BUSINESS AS USUAL (BAU) SCENARIO FOR VICTORIA AND GREATER MELBOURNE			
	2017	**2031**	**2050**
> Population (Victoria)	4.61 million	6.0 million 1/	7.8 million 1/
> Vehicle Registrations (Victoria)			
- Private	3.60 million	5.01 million 2/	7.10 million 2/
- Commercial	0.65 million	1.24 million 3/	2.41 million 3/
> Daily Vehicle Kms.			
- Private	107.8 million	134.5 million 4/	168.1 million 4/
- Freight	7.75 million	11.75 million 5/	14.81 million 5/
> Number of Households with 2 Cars	52% 6/	46% 6/	38% 6/
> Household Spending on Transport (%)	14.5% 7/	13.2% 7/	12.0% 7/
Source: Author' calculations			
> Private Vehicle Trips (As % of Total Trips)	90%	86.4%	80.2%
> Level of Road Capacity Utilisation (Freeway and Arterial)	70% 8/	78% 8/	88% 8/
> Amount of Time Spent by Motorists in Looking for Parking in Inner City 9/	30%	50%	60%
> Average Vehicle Occupancy for Work Trips	1.2	1.2	1.2

1/	Assumed 'median' annual growth rate of 2.2% to 2031, and 2.5% by 2050.
2/	Assumed 'median' annual growth rates of 2.45% to 2031, and to 2050 for private vehicles.
3/	Assumed 'median' annual growth rates of 4.75% to 2031, and to 2050 for light rigid trucks/ light commercial vehicles (40/60 split).
4/	Assumed 'median' annual growth rates of 1.7% to 2031, and to 2050.
5/	Assumed 'median' annual growth rates of 4.5% to 2031, and to 2050. (As for BAU).
6/	Assumes an ageing of the population (population born from 1946-1964), reducing from 48% in 2017, to 40% in 2031.
7/	Assumes minor reductions in transport expenditures, as a result of an ageing population.
8/	Assumes that at 70%, road congestion becomes the predominant condition (20% to 30% reduction in average speeds). At 78% to 88%, road congestion becomes a critical time and reliability constraints (40% to 80% reductions in average speeds).
9/	With increased vehicles on the urban road network, % of travel time increases in searching for car parking (leading to higher overall total travel times and total travel costs).

Alternative scenarios

Precise estimates of the cumulative positive impacts of the progressive introduction of AVs are not achievable with current data. However, it is possible to summarise the range of plausible changes in road system behaviour over the five levels of AV development, from Levels 1 and 2 (Driver Assistance and Partial Automation} to Level 5 (Full Automation.) Table 11 below sets out three alternative scenarios, based on University of Texas (Austin) research on AVs[xxxv]:

Table 11 Scenario outcomes compared

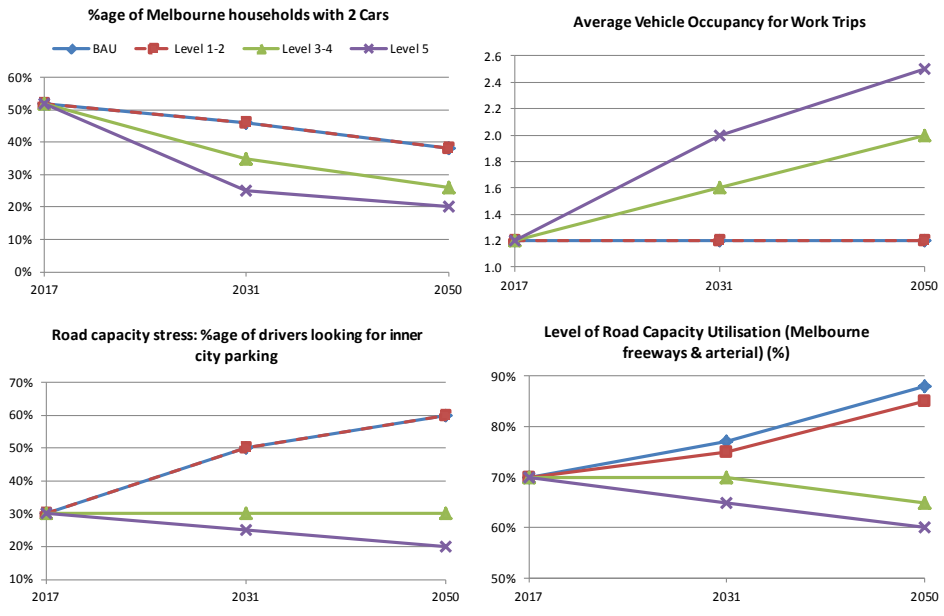
IMPACT OF AV-ENABLED TRANSPORT/MOBILITY SYSTEM									
Levels of Autonomy with AV Adoption Scenarios, 2017-2050									
				Level 0 (BAU)		Levels 1-2		Levels 3-4	Level 5
Key Transport Outcomes for Greater Melbourne						Emergent Technological Adoption		Accelerated Social Change	Full Automation
Proportion of As on road									
	2017			0		0		0	0
	2031			1		5-10		20-30	60
	2050			5		10-20		30-50	70
Vehicle occupancy (shared vehicle levels - persons)									
	2017			1.2					
	2031			1.2		1.5-1.8		2.5-3.0	3.5-4.0
	2050			1.2		2.0-2.5		3.0 -3.5	4.0-4.5
Average road congestion on freeways/arterial links (%)									
	2017			70					
	2031			70-80		65-70		55-60	<60
	2050			88-90		60-65		50-55	<50
Public transport demand (%age of total trips -%)									
	2017			12					
	2031			14		14		12	10
	2050			16		16		14	12

Source: University of Texas/Author' calculations

The three alternative scenarios 'flex' the rate of take-up of autonomous vehicle technologies in Melbourne and explore the potential directions for change arising from each. The first scenario reflects a gradual adoption of the technologies in accordance with conservative estimates, and the other two scenarios accelerate the rate of adoption to the levels suggested by more optimistic external analysis.

The relative impacts of the scenarios on proxy measures of car dependency and road congestion are shown in Figure 7. The key features and outcomes of these scenarios are set out in more detail below.

Figure 7: Scenario impacts on car dependency and congestion



Emergent Technological Adoption

Under this scenario, market penetration is projected to reach 20% by 2050. This will be reflective of increased acceptance of the technical reliability of automation, the benefits associated with increased speeds, declining accident levels, and reduced levels of on-road driver stress and fatigue. Congestion savings will become more significant as market acceptance grows (33% of total benefits of automation). MaaS will emerge and take up a share of travel, but preference for private ownership and driving are only mildly impacted. (see Table 12 below)

Table 12: Emergent Scenario details

LEVELS 1 - 2: EMERGENT SCENARIO FOR VICTORIA AND GREATER MELBOURNE			
	2017	**2031**	**2050**
> Population (Victoria)	4.61 million	6.0 million 1/	7.8 million 1/
> Vehicle Registrations (Victoria)			
- Private	3.60 million	5.01 million 2/	7.10 million 2/
- Commercial	0.65 million	1.24 million 3/	2.41 million 3/
> Daily Vehicle Kms.			
- Private	107.8 million	122.9 million 4/	140.1 million 4/
- Freight	7.75 million	11.75 million 5/	14.81 million 5/
> Number of Households with 2 Cars	52% 6/	46% 6/	38% 6/
> Household Spending on Transport (%)	14.5% 7/	12.5% 7/	11.5% 7/
> Private Vehicle Trips (As % of Total Trips)	90%	86.4%	80.2%
> Level of Road Capacity Utilisation (Freeway and Arterial)	70% 8/	75% 8/	85% 8/
> Level of Road Capacity Utilisation Looking for Parking in Inner City 9/	30%	50%	60%
> Average Vehicle Occupancy for Work Trips 10/	1.2	1.2	1.2

1/ Assumed 'median' annual growth rate of 2.2% to 2031, and 2.5% by 2050. (As for BAU).

2/ Assumed 'median' annual growth rates of 2.45% to 2031, and to 2050 for private vehicles. (As for BAU).

3/ Assumed 'median' annual growth rates of 4.75% to 2031, and to 2050 for light rigid trucks/ light commercial vehicles (40/60 split). (As for BAU).

4/ Assumed reduced annual growth rates of 1.0% to 2031, and to 2050.

5/ Assumed 'median' annual growth rates of 4.5% to 2031, and to 2050. (As for BAU).

6/ Assumes an ageing of the population (population born from 1946-1964), reducing from 48% in 2017, to 40% in 2031. (As for BAU).

7/ Assumes further reductions in transport expenditures, as a result of an ageing population.

8/ Assumes that at 70%, road congestion becomes the predominant condition (20% to 30% reduction in average speeds). At 78% to 88%, road congestion becomes a critical time and reliability constraints (40% to 80% reductions in average speeds). Assumes minor benefit from slight reduction in road congestion.

9/ With increased vehicles on the urban road network, % of travel time increases in searching for car parking (leading to higher overall total travel times and total travel costs). (As for BAU).

10/ Use of AV technology is assumed to be insufficient across the road network to improve vehicle occupancy levels.

Source: University of Texas/Author's calculations

Accelerated Social Change

Under this scenario, market penetration is projected to reach 50–55% by 2050. Major anticipated transport system changes, costs and benefits will be clearly evident, with some improvement in overall road safety. Community attitudes to private vehicle ownership will be fundamentally revised. MaaS will be extensive and competitive. Shared vehicle utilisation will be a major social change, with fewer vehicles per household. Late adopters of AV technology will benefit from accelerated technological change, with shifts from conventional vehicle forms to new era vehicles, and with lightweight/streamlined chassis/seating and neither pedals nor steering wheels (see Table 13 below)

Table 13: Accelerated Adoption scenario details

LEVELS 3 - 4: ACCELERATED ADOPTION SCENARIO FOR VICTORIA AND GREATER MELBOURNE			
	2017	**2031**	**2050**
> Population (Victoria)	4.61 million	6.0 million 1/	7.8 million 1/
> Vehicle Registrations (Victoria)			
- Private	3.60 million	4.4 million 2/	6.2 million 2/
- Commercial	0.65 million	1.24 million 3/	2.41 million 3/
> Daily Vehicle Kms.			
- Private	107.8 million	121.1 million 4/	137.9 million 4/
- Freight	7.75 million	11.75 million 5/	14.81 million 5/
> Number of Households with 2 Cars	52% 6/	35% 6/	26% 6/
> Household Spending on Transport (%)	14.5% 7/	11.4% 7/	9.8% 7/
> Private Vehicle Trips (As % of Total Trips)	90%	86.4%	80.2%
> Level of Road Capacity Utilisation (Freeway and Arterial)	70% 8/	70% 8/	65% 8/
> Amount of Time Spent by Motorists in Looking for Parking in Inner City 9/	30%	30%	30%
> Average Vehicle Occupancy for Work Trips 10/	1.2	1.6	2.0

1/ Assumed 'median' annual growth rate of 2.2% to 2031, and 2.5% by 2050. (As for BAU).

2/ Assumed 'median' annual growth rates of 2.0% to 2031, and 1.5% to 2050 for private vehicles. (Reduction on BAU level).

3/ Assumed 'median' annual growth rates of 4.75% to 2031, and to 2050 for light rigid trucks/ light commercial vehicles (40/60 split).

4/ Assumed reduced annual growth rates of 0.9% to 2031, and to 2050.

5/ Assumed 'median' annual growth rates of 4.5% to 2031, and to 2050. (As for BAU).

6/ Assumes an ageing of the population (population born from 1946-1964), reducing from 48% in 2017, to 40% in 2031. AV technology will have a significant influence in vehicle ownership.

7/ Assumes significant reductions in transport expenditures, as a result of an ageing population and smaller fleets.

8/ Assumes that at 70%, road congestion becomes the predominant condition (20% to 30% reduction in average speeds). By 2031, congestion levels will be contained to 2017 level, and improved conditions by 2050. Road congestion no longer becomes a critical time and reliability constraint.

9/ With reduced vehicles on the urban road network and car pooling with AVs, % of travel time decreases in searching for car parking (leading to higher overall total travel times and total travel costs).

10/ With increased AV utilisation, average vehicle occupancy level can be expected to increase.

Source: University of Texas/Author's calculations

Rapidly Maturing AV Technology

This scenario assumes near saturation of the AV technology, reaching between 70% – 90% of all on-road passenger vehicles by 2050. It also assumes penetration of 40%– 50% in the light commercial vehicles sector, interacting with increased utilisation of drone technology for small/home freight deliveries. MaaS will dominate and car ownership will be very limited (see Table 14 below).

Table 14: Full Automation scenario details

LEVEL 5: FULL AUTOMATION SCENARIO FOR VICTORIA AND GREATER MELBOURNE			
	2017	**2031**	**2050**
> Population (Victoria)	4.61 million	6.0 million 1/	7.8 million 1/
> Vehicle Registrations (Victoria)			
- Private	3.60 million	3.5 million 2/	3.4 million 2/
- Commercial	0.65 million	0.8 million 3/	1.0 million 3/
> Daily Vehicle Kms.			
- Private	107.8 million	105.8 million 4/	103.2 million 4/
- Freight	7.75 million	10.25 million 5/	12.64 million 5/
> Number of Households with 2 Cars	52% 6/	25% 6/	20% 6/
> Household Spending on Transport (%)	14.5% 7/	10.5% 7/	10.0% 7/
> Private Vehicle Trips (As % of Total Trips)	90%	86.4%	80.2%
> Level of Road Capacity Utilisation (Freeway and Arterial)	70% 8/	65% 8/	60% 8/
> Amount of Time Spent by Motorists in Looking for Parking in Inner City 9/	30%	25%	20%
> Average Vehicle Occupancy for Work Trips 10/	1.2	2.0	2.5

1/ Assumed 'median' annual growth rate of 2.2% to 2031, and 2.5% by 2050. (As for BAU).

2/ Assumed reduced annual rates of ownership to 2031, and to 2050 for private vehicles.

3/ Assumed reduced annual rates of ownership to 2031, and to 2050 for light rigid trucks/ light commercial vehicles (40/60 split). (As compared to the BAU).

4/ Assumed reductions in vehicle use to 2031, and to 2050.

5/ Assumed reduced 'median' annual growth rates of 3.5% to 2031, and to 2050.

6/ Assumes an ageing of the population (population born from 1946-1964), reducing from 48% in 2017, to 40% in 2031. A major reduction in vehicle ownership per household.

7/ Assumes significant reductions in transport expenditures, as a result of an ageing population and AV utilisation.

8/ Assumes that at 70%, road congestion becomes the predominant condition (20% to 30% reduction in average speeds). By 2031, congestion levels will be significantly reduced, further reducing by 2050, with no further investment in road capacity after 2025. Road congestion no longer becomes a critical time and reliability constraint.

9/ With reduced vehicles on the urban road network and car pooling, % of travel time decreases in searching for car parking

10/ A major benefit of AV utilisation will be the significant increase in average vehicle occupancy levels, in line with decreased road congestion.

Source: University of Texas/Author's calculations

Under this scenario, the effective road capacity of all freeways and arterial roads will be significantly increased, especially through vehicle 'platooning', leading to virtual cessation of new road capacity construction and radically improved commuter times within Greater Melbourne. Intercity highway travel will be able to utilise AV technology, the savings in Greater Melbourne road network construction being allocated to intra-state road infrastructure modifications to suit AVs for Victoria, and for improved links to the other major capital cities. Greater Melbourne road congestion savings should account for 60% of all benefits, with road accident benefits accounting for a further 30% of all direct AV user benefits.

Limitations and Qualifications

Need for economic and social evaluation of alternative futures

The Boston Consulting Group/World Economic Forum project and our Melbourne scenarios discussed above are illustrative only. They do not purport to be comprehensive technical, let alone full economic and social, evaluations of differing implementation profiles of AV mobility services. Government and public understanding of the interaction of technical and economic and social issues will clearly be a critical first step in ensuring that AV based mobility services enable Melbourne's strongly growing population to live productive and fulfilling lives, wherever they live, work, study, or recreate.

Social equity and access objectives will be important in framing the optimal use of AV technology and mobility services. Currently, there is stark contrast between the mobility options available to people living in Melbourne's inner core (within, say, a 10km radius of the CBD), characterised consistently as one of the world's 'most liveable' cities, and those in Melbourne's rapidly expanding outer suburbs. The former have access to a wide range of mobility infrastructure and services. The latter, often facing much longer journeys to work, have fewer and less frequent services and hence are forced to default to multiple car ownership. Once established, the resulting pattern of mobility becomes entrenched. The challenge, and opportunity, offered by AV enabled mobility will be to ensure that any new services are integrated with, and support, the development of land use and activities that promote equitable economic and social wellbeing.

Evaluating all mobility options on a consistent basis

Scenarios for Melbourne's mobility futures with AV need to evaluate the comparative technical, economic and social attributes of all transport options. This is particularly true for a rapidly growing population. As with Melbourne's nineteenth century development, how and where transport services are provided can have a decisive influence on where people live and work. Traditional public transit modes – rail and bus – have a massive starting advantage over car-based transit in terms of carrying capacity (see Figure 8 below). It is not clear whether AV-based road transport can cost-effectively overcome this capacity gap. For example, it has been pointed out that AVs one metre apart and travelling at 100 kph might transport 25,000 people per hour down a freeway lane, a movement capacity that is only half that of a train.[xxxvi] Moreover, the application of artificial intelligence and machine learning to rail signalling and management systems could further increase the timeliness and capacity of Melbourne's rail services.[xxxvii]

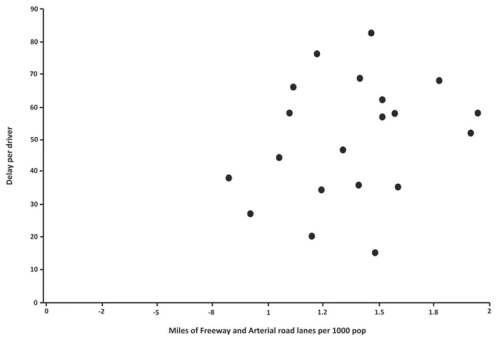
Figure 8: Comparative capacity of different transport modes [xxxviii]

Mode	Number of people carried in the space of one road lane per km per hour
Car on normal street lane	800
Car on freeway lane	2,500
Bus on normal street lane	5,000
Tram on street	10,000
Light rail on separate right of way	20,000
Heavy rail on separate right of way	50,000

Source: Professor Peter Newman

The interaction of AV-based mobility and road pricing also needs careful consideration from a resource allocation and social equity perspective. The data intense nature of AV and CAV services provides the basis for an extensive system of road pricing. For example, the external congestion costs imposed by road users travelling at peak periods can be calculated and charged in real time. This would assist greatly in optimising the use of existing road capacity and thereby ameliorating pressure for yet more road construction where there is a strong body of evidence suggesting that continuing to build high capacity roads does not reduce road delays over the long term (see Figure 9 below).

Figure 9: High Capacity road provision and traffic delays in 20 US cities [xxxlx]



Clearly, the social equity issues also need to be addressed when evaluating road pricing options, an important element of which would need to be much greater provision of integrated mass transit services for Melbourne's outer suburbs (a point made strongly by a wide range of reviews of congestion management and road and transport funding).

AV everywhere or focus on the 'first/last mile'?

As noted above, failure to provide a fully integrated mobility service for Melbourne's rapidly expanding outer suburbs risks locking families into multiple car ownership, resulting in increased pressure and congestion on both local and arterial roads. Careful consideration therefore needs to be given to the interaction of AV-based mobility services and 'traditional' forms of public transport: heavy and light rail and buses. One approach would be to allow all types of AV mobility services to compete for a share of the mobility markets across Melbourne. An alternative would be to focus such services on the 'first and last mile' i.e.:

> "The new urban economics movement shows that cities can save time and reduce road accidents if they spend their precious infrastructure resources on fast rail that can go around, under or over traffic, and create highly walkable, pedestrian-friendly city centres and sub-centres. It means that new rail lines and new centres need to be built deep into car-based suburbs struggling to find a disruptive transport system. We need to think about how autonomous vehicles can help in this transition.
>
> Autonomous vehicles will need to be banned from city centres that are prioritising pedestrians. But, out in the suburbs, there will be increasing numbers of people who need help getting to the nearest train station so they can travel quickly across the city, then at the other end with the short distance to a destination. This is the 'last mile' or 'first mile' issue in public transport planning. Solutions have involved buses, bikes and car drop-offs but could include autonomous vehicles. Autonomous vehicle 'taxis' could find an important niche with their demand-responsive system. Such vehicles could be electric, along with the trains making an oil-free, equitable and efficient system"[xli]

Risk profile of the scenarios

Qualitative risk profiles of the above four scenarios are shown in Attachment 1. The key points are:

- Technical risks of vehicle design lie with private original equipment manufacturers and software suppliers. To the extent that these suppliers deliver safe autonomy that is very largely or wholly independent of road infrastructure, there is a correspondingly lower need for road infrastructure investment and upgrades, and therefore lower commissioning and operational risk for governments
- Overly onerous or inconsistent Federal and State safety standards for vehicle design and operation will reduce or delay AV penetration, with attendant additional social and economic costs generated by forgone reductions in deaths and serious injuries
    - More generally, system governance is critical is setting design and operational parameters that will deliver a more efficient and less congested road transport system. This includes:
    - leading and educating public opinion and understanding about costs and benefits of alternative AV futures for a sustainable and liveable Melbourne
    - developing a clear but flexible strategy for providing transport services and options that complement and integrate AV-based services
    - establishing design and operational incentives and rules that promote safe, secure shared AV services and allocate scarce road space to highest value uses (including road and congestion pricing)
    - guiding the establishment of an appropriate high capacity data network to enable an integrated transport system

6. HOW DOES PLAN MELBOURNE FARE UNDER DIFFERENT AV FUTURES?

What does Plan Melbourne aim to achieve?

Plan Melbourne 2017–2050, released in 2017, aims to be a 'blueprint' for Melbourne's development over the life of the Plan. The Plan is described as being "a blueprint to ensure Melbourne grows more productive, sustainable and liveable as its population approaches eight million."[xlii]

The Plan poses six 'challenges' the city faces in this context:

- Managing population growth
- Growing the economy
- Creating affordable and accessible housing
- Improving transport
- Responding to climate change, and
- Connecting communities

This is a fairly orthodox and unsurprising view of a future that is pretty much 'business as usual, but just a lot bigger'.

This set of 'challenges' could be related to almost any phase of the city's past eight decades, with the exception of climate change. The principles, outcomes, directions and policies that comprise the Plan continue this orthodoxy, as do observations on future transport issues

In relation to transport, Plan Melbourne comments that:

> "Although the city's transport system has sound foundations, it is coming under increased pressure from growth. By 2050, Melbourne's transport network will need to handle an extra 10.4 million trips per day. Congestion and overcrowding is already an issue on parts of the road and public transport network, particularly at peak times. Major investment in transport infrastructure will boost rail and road capacity to meet the transport challenge, boost productivity, conserve energy, curb greenhouse gas emissions and protect liveability."

In planning for an 'integrated transport system', Plan Melbourne proposes four directions:

3.1 Transform Melbourne's transport system to support a productive city

3.2 Improve transport in Melbourne's outer suburbs

3.3 Improve local travel options to support 20-minute neighbourhoods

3.4 Improve freight efficiency and increase capacity of gateways while protecting urban amenity

There are seven Outcomes defined in the Plan, and thirty-two Directions to give effect to them. There are also detailed policies arising from the proposals to implement the directions. In Attachment 2, we have evaluated the impact of the introduction of autonomous vehicles, under different scenarios, on Plan Melbourne's Directions. The conclusion of this evaluation is summarised in Table 14 below, which shows that the faster autonomous vehicles are adopted in Melbourne, the greater the chance of achieving Plan Melbourne's Directions.

This is especially the case if TaaS/MaaS services have high acceptance, because the affordability, accessibility and flexibility of mobility within Melbourne will be transformed. Benefits will be spread widely across the community and the business sector, and the competitiveness of the city, as the annual costs of congestion and traffic harm are progressively reduced. At the same time, Melbourne's population will gain increased access to more diverse jobs, and job location will become more flexible, supporting the principle of 20-minute neighbourhoods.

How will Plan Melbourne be impacted by AV development?

A significant missing link in the business-as-usual view is the lack of recognition of technology change associated with AV technology. The CAV and AV markets will increasingly open up new opportunities and challenges for all economic sectors of greater Melbourne. The technologies will challenge existing business models and create new models. Community expectations will continue to change as new technologies, sustainability, changing demographics, and increased urban densities evolve.

Many consumers will re-think their attitudes and relationships to vehicles, and hence their travel and vehicle ownership choices. Access, rather than ownership, will be a key move, particularly among the young urbanites, but also for older drivers and those with disabilities or other limitations to their access to personal mobility.

The static Business-As-Usual model underpinning Plan Melbourne's vision will be affected by the following array of changing 'business' activities:

- Government (State and Local) – new policy and regulations, new traffic management systems, parking, road infrastructure investment
- Technology – shared mobility platforms, new data centres, vehicle/infrastructure data links, data analytics, new skill requirements, new job training centres/on-line training
- Suppliers – new forms of freight delivery, new data transfer and storage systems, vehicle retrofitters, new vehicle distributors and maintenance staff
- Finance – new forms of car insurance, device-to-device payments for AV technology on specified routes, re-investment with new technologies in existing vehicles
- Health care – emergency service responses, new forms of mobility for the elderly, decentralised healthcare facilities
- Public ground transport – new forms of taxis, new forms of public transport access points and vehicles, new forms of car parking, new public transport pricing and payment systems, new forms of bus subsidies for urban routes
- Dramatic change in the criminal justice system as infringements reduce (and disappear) with adoption of AVs with major social and revenue impacts for the State. New laws will be necessary for the effective operation of AVs, along with new types of infringements.

These effects are likely to require changes to planning policy, even without any accelerated introduction and adoption of AV technologies. As the pace of AV technology increases, especially if it is at the rapid end of the spectrum, changes will be dramatic.

Analysis of the majority of the thirty-two directions (some were deemed to not have an urban structural dimension) in the light of our scenarios is presented in Attachment 2. The high-level findings are presented in Table 15.

Table 15: Evaluation of scenarios against Plan Melbourne Directions

Plan Melbourne Direction	*Business As Usual*	*Emergent technologies*	*Accelerated Social Change*	*Rapidly maturing AV technology*
City structure that strengthens Melbourne's competitiveness	✸	✸	✸✸	✸✸✸✸
Improve access to jobs across Melbourne	✸	✸	✸✸	✸✸✸✸
Create development opportunities at urban renewal precincts	✸	✸✸	✸✸✸	✸✸✸✸
Support productive use of land and resources in Melbourne's non-urban areas	✸	✸	✸✸	✸✸
Manage the supply of new housing in the right locations	✸	✸	✸	✸✸
Deliver more housing closer to jobs and public transport	✸	✸	✸✸	✸✸✸
Increase the supply of social and affordable housing	✸	✸	✸	✸✸
Transform Melbourne's transport system to support a productive city	✸	✸✸	✸✸✸	✸✸✸✸✸
Improve transport in Melbourne's outer suburbs	✸	✸✸	✸✸✸✸	✸✸✸✸✸
Improve local travel options to support 20-minute neighbourhoods	✸	✸✸	✸✸✸	✸✸✸✸✸
Improve freight efficiency and increase capacity of gateways	✸	✸	✸✸✸	✸✸✸
Create more public spaces across Melbourne	✸	✸	✸✸✸	✸✸✸✸
Create a city of 20-minute neighbourhoods	✸	✸	✸✸✸	✸✸✸✸✸
Transition to a low-carbon city	✸	✸✸	✸✸✸	✸✸✸✸✸
Make Melbourne cooler and greener	✸	✸✸	✸✸✸	✸✸✸✸✸
Improve air quality and reduce the impact of excessive noise	✸	✸✸	✸✸✸	✸✸✸✸✸
Improve connections between cities and regions	✸	✸	✸✸	✸✸✸

These evaluations are at a high level, and the most significant impacts are in the transport characteristics of the city, obviously, and in the changed social and environmental impacts of the transformed transport sector. Land use changes are less obvious and need a finer-grained analysis, but some of the more obvious include:

- Reduced need for car parking as a land use, with major potential for re-use for housing. business, and public amenity
- Reduced need to provide on-site parking in new developments of all kind, making the use of sites potentially much more intensive (especially for such land uses as shopping centres, sports venues, transport interchanges, housing of all kinds, industry campuses, universities, airports and other categories of travel origin and destinations. Of course, there will need to be AV car parks, but these are likely to be more like train and bus depots, with mixed-use capabilities along with vehicle maintenance, trading, and storage.

- Capacity to alter intersection designs and street layouts as high-grade GPS, external awareness and safety software in autonomous vehicles makes many of our current traffic management technologies and infrastructure redundant.
- Potentially much higher density development in MaaS-rich locations like the CBD and inner suburbs, but also with greater potential for pedestrianisation and bicycle access, as well as new public spaces.
- Potential pressure for more low-density urban development beyond the urban fringe, as travel times in AVs, and ease of travel, increases the attractiveness of peri-urban living in semirural or coastal settings.
- Improved street amenity throughout inner Melbourne where narrow streets and the lack of on-site parking are today heavily congested by on-street parking. Such streets will no longer need their parking provisions and hence will not only improve in amenity but may also become the locations for higher density development.
- Increased potential for footpaths and cycle ways to make up a greater share of public space throughout the city, along with more parks and recreation areas.

All such changes, of course, will require significant amendments to planning schemes, municipal regulations and standards relating to road and parking requirements, and design of buildings where car parking is unnecessary.

In summary

Plan Melbourne clearly has a 'missing link' in its lack of recognition of the potential impacts of technological change associated with AV/CAV technology. Our assessment strongly suggests that Plan Melbourne 2017–2050 is much more likely to be achieved if there is strong and rapid adoption to AV technologies across the entire vehicle fleet.

Even with the risk of increased pressure for urban sprawl, the other potential gains would still be significant. This is particularly the case for the growing number of elderly people who no longer have or trust their driving skills, as well as for people with disabilities.

However, the entire community will benefit from faster, safer, cleaner, more responsive and flexible transportation that maximises the use of existing road capacity and reduces the need to construct major new roads. The impact on established public transport systems is unclear, but our scenarios suggest that travel by traditional public transport could be a reducing share of total travel.

If community concerns about losing personal control of vehicles are very strong, to the point where there is active opposition to the adoption of autonomous technologies, then the pace of take-up may be slowed significantly. This is where government leadership and community engagement on these important issues are vital. Our assessment is that a mixed fleet of autonomous and human-driven vehicles could be chaotic, depending mostly on human driver behaviour and the safety-conscious performance of AVs. In this case achieving Plan Melbourne's ambitions becomes more difficult.

In a recent essay, Mike Scott set out principles to guide the introduction of AVs from a city planning perspective. In summary, they are:

- Regulations, policies and infrastructure investment that encourage the evolution of MaaS
- A comprehensive approach to travel demand management
- Specific measures to favour access by shared AVs
- Not curtailing access to shared streets for pedestrians, cyclists and other non-vehicular road users
- Funding of education, enforcement and infrastructure investment programs supporting increased safety for pedestrians and cyclists in the AV environment.

We have recommended a plan of action that would give effect to these high-level principles

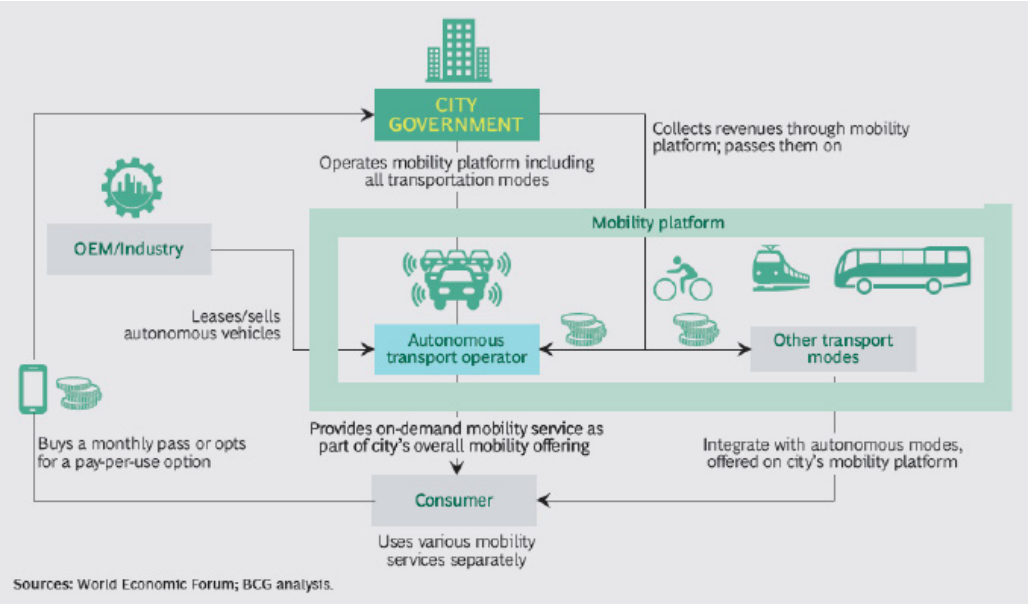
7. CONCLUSIONS

No one currently knows with any degree of certainty or precision how, when, and where AV based-transport services will be introduced on an economically sustainable basis. Both technology enablers and business model developments are very largely in the hands of a broad range of private-sector players, and thus outside the control of governments. Government's role, nonetheless, as an enabler and facilitator is important for:

- setting and enforcing transport objectives in relation to service standards, mode share, and investment needs, as part of overall urban governance responsibilities
- engaging the community in dialogue about the potential implications of AV services for transport service provision
- managing the overall transport systems and infrastructure
- establishing policy and regulatory settings that encourage experimentation that broadly aligns with the established urban policy objectives.

The Boston Consulting Group/World Economic Forum project indicates the potential breadth of these responsibilities (Figure 10).

Figure 10: An integrated city wide mobility platform [xlv]



Source BCG/WEF

As ultimate steward of greater Melbourne's transport system, government will need a high level of leadership, knowledge and capability in understanding system design requirements and contract commissioning and administration. Previous experience with Victorian Government performing such a role has been mixed, suggesting the need for a major focus within government on ensuring clarity of objectives, accountability and capability in steering this important transition.

Government responses to major uncertainties

The wide range of factors that need to be addressed to facilitate transition to AV-based systems large enough to deliver substantive public benefits argues for caution in taking actions based on assuming a rapid deployment of AV/CAV technology across Greater Melbourne. Policy settings, resource allocation and investment priorities should be based on a clear set of decision-making principles that identify and manage risk while encouraging, where appropriate, controlled and carefully evaluated experimentation. Recent experience with the costs of the failure to develop and implement an effective, integrated energy policy in Australia provides a clear warning on the need for such clarity and adaptability.

Victoria's capacity to lead, plan and manage an uncertain AV transition

In the context of the ineradicable uncertainties currently associated with AV technologies, how well-equipped is Melbourne/Victoria to address the challenges and opportunities offered by the advent of AV/CAV? The picture is mixed. There are individual areas of good practice, but also a lack of clarity, accountability and capability across important areas of policy development and administrative agencies that have critical roles to play in facilitating and managing the development of a framework that might most effectively leverage the potential benefits of AV/CAV technologies and services (see, for example, the Victorian Auditor General's report on managing traffic congestion[xlvi]). The results of in depth interviews with officials responsible for urban and transport planning also suggest a significant degree of concern about the degree of political engagement and capacity to shape the introduction of AV-based services consistent with the public interest.[xlvii] If this results primarily in a reactive mode by government, the potential for purely commercial interests to dominate increases, with attendant detrimental impacts on access and social equity (e.g. 'cherry picking' high demand areas and eroding the viability of public transport services to more disadvantaged communities).

Suggested Government decision making principles

In effectively discharging the responsibilities listed above, decision-making in relation to the transition to an AV-enabled transport system by the Victorian Government should be based on:

- Clear and measurable goals based on:
  - Pursuit of the long term public interest of all citizens - equity, effectiveness, safety, competitive neutrality in relation to modal choices and service providers
  - Treating Greater Melbourne as a sustainable ecosystem for delivering citizens' well-being
  - Meaningful and timely citizen involvement and consultation
- Integration across all transport modes, including walking and cycling, facilitated by real time data capture/management/information/billing systems
- Transparency of decision-making, facilitated by the publication of the evidence/data on which all major policy and commercial decisions are based
- Adaptability and flexibility to meet changing circumstances, facilitated by experimentation based on clearly specified learning outcomes supported by data capture and evaluation
- An independent and highly capable system governance and administration.

These principles are intended to address a number of problematic issues with the current policy framework and administration of Melbourne's transport system. In relation to the policy framework, neither Plan Melbourne nor Victoria's Infrastructure Plan address in detail the possible implications for investment, modal choice, community and customer (dis)benefits of the widespread deployment of AV-related services.

While sensible in its own right, the IV study commissioned by the Government is, not surprisingly, focused on physical infrastructure. And, because of the large degree of flux around all the key technological commercial drivers, it is unlikely to add precision to the AV deployment path beyond the uncertainties already amply laid out in the KPMG/Arup/Jacob modelling commissioned for the 30-year strategy and the range of other studies referenced in this paper.

More importantly, the terms of reference do not address the exhaustively documented issues of governance and decision-making that have bedevilled major public infrastructure investment decisions across Australia.[xlviii] In Victoria, governments of all political persuasions have selected major transport infrastructure investments with highly marginal economic benefits, often in a non-transparent way that favours particular commercial interests, driven by problematic financing structures to meet short term fiscal objectives (e.g. avoiding reduced revenue/increased operating deficits of existing public transport services).

Adoption and adherence to the proposed principles would go some way to facilitating competition within an integrated planning framework, mitigating winner-takes-all problems, and managing risks of sunk costs. In doing so, it would help ensuring that, in confronting the potentially major transition in Melbourne's transport system, there is even-handed and transparent evaluation of all possible approaches to government facilitation and overall management of that transition.

Possible system-wide actions

The preparation for CV and AV technologies, which have already arrived and will come in greater force, will need to involve collective actions on the part of all government agencies with transport and planning responsibilities, local government authorities, private road network operators, and private companies providing CV and AV vehicle technologies. These collective actions may include:

- The development of a clear legal framework within which AV technologies can be quickly and flexibly deployed and tested, drawing on the increasing number of overseas models (e.g. recently enacted legislation in Georgia and other US states)
- Appropriate investment in road infrastructure – traffic lights, lighting posts, bridges, signage, and road markings. Much of this infrastructure investment will be to replace or improve existing infrastructure (not all required in the 'do-nothing' AV scenario). Rather than replacing like-for-like, road agencies (VicRoads and local Councils) should consider how future AV-related infrastructure can be introduced to limit the maintenance of existing infrastructure. This includes investment in additional digital infrastructure – allowing fast and secure connections between vehicles and traffic management systems. Much of this investment is yet to be identified in detail.
- Data capture and exploitation. CVs and AVs will generate extensive data. Data brokerage to ensure the road authorities have access to appropriate data, how data will be stored, and how the mobile phone of drivers will be connected to the new road technology:
- Currently, Melbourne has no integrated data capture, information and evaluation system for Greater Melbourne's transport tasks. Whatever form and timing of AV introduction, such an integrated system is an essential tool for government to discharge its responsibilities for overall system planning and smooth operation and risk management
    - The urgent need for such a system is demonstrated elsewhere e.g. BCG/WEF Boston work (see Figure 10 above)
    - The specification and project management of the introduction of such a system demands leadership, skills, and capabilities of a high order
    - Cyber security – secure cyber systems will be necessary. The security of networks will be vital to avoid threats and illegal system interference.
- Leadership and management of change. Road authorities will need to consider their roles in leading the development and introduction of CV and AV technologies. They will need to challenge themselves as to the right strategic and technical roles to play. Careful distinction will need to be drawn as to who pays for the necessary infrastructure i.e. the identification of the public interest in supporting the introduction of the new technologies. Agencies will need to have developed appropriate performance indicators to guide their decision making as to the appropriateness of investment in new infrastructure i.e. to avoid the inefficiencies associated with cross-subsidising investments (otherwise to be made by the private sector and vehicle owners).
- The following KPIs can be developed by the road authorities, in advance of the introduction of further CV and new AV technologies:
    - Travel time reliability and reductions in congestion levels for specific corridors – major potential user savings
    - Traffic volumes – the impact is unknown at this stage
    - Road safety – reductions in crash levels from reductions in human error
    - Safety of the more vulnerable road-related users – reductions in accidents associated with the elderly motorists, pedestrians, and cyclists
    - Contribution to economic growth – more efficient road network operations for passenger and freight vehicles, with reduced penalties associated with congestion
    - Carbon emissions – the impact is unknown as more vehicles movements may result, and new vehicles may not be able to deliver overall reductions in air quality conditions
    - Freight activity – optimisation and streamlining of freight logistics movements should be achievable, with shortened and improved delivery times, increased vehicle efficiency with connected freight vehicle 'platooning', and increased customer satisfaction, with more just-in-time deliveries.
    - Active modes of transport (walking, cycling) – the impact of the new technologies is not known. People currently walking may have access to AVs. Conversely, with improved road conditions (less traffic, safer conditions), more people may cycle or walk.

Attachment 1: Scenario Risk Profiles

Risk Type and Level	Scenario/Level of Autonomy			
	Business As Usual (Level 0)	Emergent Technological Adoption (Levels 1 – 2)	Accelerated Social Change (Levels 3 – 4)	Full Automation (Level 5)
Demand/Market Penetration – High Owner(s): OEMs, vehicle suppliers	Limited to 5% of vehicle demand	Increased sales of conversion technologies; emergence of purpose-built AVs (5%– 20% of market)	Major market penetration, with both conventional and purpose-built AVs in demand (20% – 50% of market)	60% – 70% market penetration, with a broad range of AV technologies in service
Automation Design Risk - High Owner(s): OEMs, vehicle suppliers	Restricted with few manufacturers – no Australian conversion suppliers or AV manufacturers	Limited international participation in AV technology; growing R&D expenditures by vehicle manufacturers	New forms of existing vehicle conversion technologies; new purpose-built vehicles tested and operational	Most design risks/ technical constraints are identified and resolved; accelerated R&D spending
Infrastructure Design, Provision/ Network Completion Risk – High Owner(s): Governments for commissioning/overall system performance; suppliers for execution	Dependent on selected trialled routes within urban Melbourne	Emergent roll-out of guidance systems on designated freeways	Major requirements for infrastructure investment across Greater Melbourne; infrastructure plans are significantly upgraded	Near full roll-out of infrastructure to support full AV utilisation
IT/Electrical Services Risk – Medium/High Owner(s): Private sector suppliers	Minimal - due to limited demand for AV technology	Significant localised pressures on NBN facilities and electricity utilities to maintain adequate services Growing risk to system credibility acceptance from major hacking incidents and/or system failure	Specific IT system investment needed to ensure cyber security/privacy with new providers; major electricity system redevelopment across Greater Melbourne/Victoria Major risks to system credibility acceptance from major hacking incidents and/ or system failure	Periodic IT/energy system upgrading to keep AV utilisation at required levels and security standards Major risks to system credibility acceptance from major hacking incidents and/or system failure

Institutional/Governance Risk – High Owner(s): Governments; to shape shared service PT/ AV model	Significant planning issues to be resolved at State/Local Government level New approach to road funding needs to be agreed between Federal/State Governments	Growing insecurity among state and local agencies as to future public sector investment requirements and funding sources New approach to road funding required between Federal/ State Government	New dedicated agency players; major restructuring of Local Government responsibilities New approach to road funding agreed between Federal/ State Governments	Integrated agency responsibilities for AV utilisation across Victoria and other states New approach to road funding required between Federal/ State Governments
Road Safety Risk – Medium/High Owners – Government: Standards/regulations/social outrage: OEM/service operator – operational performance	Uncertain – minor level of public investment involved with selected urban routes	Awareness of the need for road congestion pricing to fully reflect AV investment	New congestion pricing models linked to new AV technology investment and maintenance funding	Congestion pricing is fully linked to AV utilisation to achieve satisfactory cost recovery of public sector infrastructure investment
Environmental Risk – Medium Owners – Government/suppliers	Minimal – due to limited market penetration	Emerging evidence of CO2/ emission benefits	Major contribution of AVs to emission reduction	Full recognition of the gains from AV utilisation with climate change targets
Transport system performance – Medium/High Owner - Government	Rising congestion/higher road & PT investment requirement/ continued significant accident costs	Some amelioration of growing congestion pressures. Enhanced PT investment to meet demand response to road pricing	Reduced congestion supported by effective road pricing and effective PT systems	Reduced congestion supported by effective road pricing and effective PT systems
Community Stakeholder Risk – Medium/High Owner – Governments	Minimal – due to limited awareness and participation	Emerging community interest and support; increased Local Government funding issues	Widespread acceptance of AV technology and the benefits from congestion & road pricing reduction, improved road safety, and costs of private vehicle ownership	Sustainable acceptance of the roles and benefits of AV technology and the benefits from congestion & road pricing reduction for road transport; quantum change in the role of passenger vehicles in Greater Melbourne functions

Attachment 2: Evaluation of the impact of autonomous vehicles on Plan Melbourne's key directions, under different scenarios

Overview

Plan Melbourne Direction	*1. Business As Usual*	*2. Emergent technologies*	*3. Accelerated Social Change*	*4. Rapidly maturing AV technology*
City structure that strengthens Melbourne's competitiveness	✸	✸	✸ ✸	✸ ✸ ✸ ✸
Improve access to jobs across Melbourne	✸	✸	✸ ✸	✸ ✸ ✸ ✸
Create development opportunities at urban renewal precincts	✸	✸ ✸	✸ ✸ ✸	✸ ✸ ✸ ✸
Support productive use of land and resources in Melbourne's non-urban areas	✸	✸	✸ ✸	✸ ✸
Manage the supply of new housing in the right locations	✸	✸	✸	✸ ✸
Deliver more housing closer to jobs and public transport	✸	✸	✸ ✸	✸ ✸ ✸
Increase the supply of social and affordable housing	✸	✸	✸	✸ ✸
Transform Melbourne's transport system to support a productive city	✸	✸ ✸	✸ ✸ ✸	✸ ✸ ✸ ✸ ✸
Improve transport in Melbourne's outer suburbs	✸	✸ ✸	✸ ✸ ✸ ✸	✸ ✸ ✸ ✸ ✸
Improve local travel options to support 20-minute neighbourhoods	✸	✸ ✸	✸ ✸ ✸	✸ ✸ ✸ ✸ ✸
Improve freight efficiency and increase capacity of gateways	✸	✸	✸ ✸ ✸	✸ ✸ ✸
Create more public spaces across Melbourne	✸	✸	✸ ✸ ✸	✸ ✸ ✸ ✸
Create a city of 20-minute neighbourhoods	✸	✸	✸ ✸ ✸	✸ ✸ ✸ ✸ ✸
Transition to a low-carbon city	✸	✸ ✸	✸ ✸ ✸	✸ ✸ ✸ ✸ ✸
Make Melbourne cooler and greener	✸	✸ ✸	✸ ✸ ✸	✸ ✸ ✸ ✸ ✸
Improve air quality and reduce the impact of excessive noise	✸	✸ ✸	✸ ✸ ✸	✸ ✸ ✸ ✸ ✸
Improve connections between cities and regions	✸	✸	✸ ✸	✸ ✸ ✸

Create a city structure that strengthens Melbourne's competitiveness for jobs and investment

Under those scenarios where the growth of autonomous vehicles as a share of the vehicle fleet is rapid but government responses are slow, Melbourne's competitiveness could well diminish due to increased congestion as driverless and driver-driven cars try to operate on established road networks.

On the other hand, if there is rapid growth in demand for AV technology and MaaS services (Scenarios 3 and 4) facilitated by government leadership and investment, Melbourne could add to its competitiveness through lower overall costs of mobility for households, and freight handling. In the area of e-commerce, the rapid adoption of drone delivery technologies would add to competitiveness.

Improve access to jobs across Melbourne and closer to where people live

Scenarios that lead to effective MaaS could improve access to jobs, while scenarios that added to congestion would not. High congestion scenarios may bring jobs closer to where people live, but MaaS may lead to people living further from their work in order to obtain more lifestyle services.

On the other hand, the reduction in private car ownership associated with Scenarios 3, and especially 4, will free up garaging space and facilitate residential development in or near employment centres. It will also enable some businesses to be more footloose, bringing jobs closer to homes, especially in the fields of e-commerce and logistics

Create development opportunities at urban renewal precincts across Melbourne

Scenarios 3 and 4 with high MaaS adoption would intensify the development options and opportunities in urban renewal precincts through lower needs for parking, potentially vehicle-free, walkable precincts, and higher density development. All urban renewal precincts should be designed to accommodate autonomous vehicles regardless of their rate of uptake.

Support the productive use of land and resources in Melbourne's non-urban areas

High adoption of autonomous vehicles could make this strategic direction harder to implement, as urban sprawl encouraged by ease and speed of travel extends the demand for conversion of land to urban uses. Scenarios 3 and 4 are therefore risky in this regard and will require strong land use policy responses at the metropolitan fringe.

Manage the supply of new housing in the right locations to meet population growth and create a sustainable city

High adoption of autonomous vehicles could also make this strategic direction harder to implement, as urban sprawl encouraged by ease and speed of travel extends the demand for conversion of land to urban uses. However, MaaS services and modular vehicles may encourage greater development around dense AV routes or locations, much as Transit-Oriented Development (TOD) does with transit systems. However, there is likely to be little direct impact on the volume of housing supply.

Deliver more housing closer to jobs and public transport

Scenarios 3 and 4 could free up land used to garage and park cars for new housing developments close to jobs and public transport (eg industrial car parks might become available, as could shopping centre car parks providing for more jobs and/or more housing in those locations within the existing city). At the same time, the flexibility of MaaS services would bring housing and jobs 'closer together' through improved travel times and greater convenience.

Increase the supply of social and affordable housing

Land use and accessibility changes associated with high adoption scenarios could be helpful in supporting the increased supply of affordable housing. In addition, reductions in household investment in cars would free up resources that could be devoted to housing, increasing the potential for families to access housing they can afford. However, none of the scenarios is assessed as having a major impact.

Transform Melbourne's transport system to support a productive city

The Baseline and Scenario 2 risk long periods of conflicting road space demands between human-driven and driverless vehicles, with high risks of increased congestion and accidents. Scenarios 3 and 4 will significantly improve productivity through the adoption of MaaS services, but may make the use of public transport less attractive and, possibly, even less affordable. Certainly, the high-adoption scenarios will be transformative and disruptive in many ways, but will deliver substantial benefits far earlier that the more conservative take-up scenarios.

Improve transport in Melbourne's outer suburbs

Scenarios 3 and 4, with high MaaS adoption, will achieve this readily through competitive service provision offering full market area coverage, especially in outer suburbs where transport choices are limited. High MaaS adoption will dramatically reduce the current outer-suburban dependence on private cars and the need to own vehicles. MaaS services will provide much more convenient and flexible services (even with autonomous route buses) than can be made available at present. The rise of Uber has demonstrated the benefits of more readily available and responsive services using present-day smart-phone and auto-pay technologies.

Improve local travel options to support 20-minute neighbourhoods

Scenarios 1 and 2 will do little to achieve the '20-minute neighbourhood' Directions in Plan Melbourne. However Scenarios 3 and 4, with high MaaS adoption and competitive services will achieve this, increasing flexibility and availability of local travel services and improving access to jobs, facilities and services. e-commerce businesses may be able to relocate to activity centres and still access a diverse labour force and, if AV drones are strongly adopted, will readily service their markets from such locations.

Improve freight efficiency and increase capacity of gateways while protecting urban amenity

The introduction of autonomous freight vehicles of many different types is likely to improve the productivity of the whole logistics sector. Scenario 4 will have the strongest impact, with advanced technologies facilitating 'platooning' of freight vehicles resulting in significant efficiency and safety advantages. If electric autonomous vehicles, such as Tesla's current electric truck, become favoured or mandated, urban amenity will be offered significant protection.

Create more, great public spaces across Melbourne

Scenarios 3 and 4, that see high MaaS adoption and lower car ownership, will need less car parking and less kerbside parking, offering numerous opportunities for new public spaces through the conversion of parking to public spaces, greater pedestrianisation of streets, and similar changes. This could become especially attractive in inner city streets where car ownership may be lowest, with young residents, apartment buildings without car spaces, and attractive street spaces for transformation.

Create a city of '20-minute neighbourhoods'

Scenarios 4, with its high MaaS scenario and high-level autonomous technology, has the strongest potential to make this direction achievable. More flexible and accessible local transport services, especially if they are community-operated, will provide extensive opportunities for short and localised trips of all kinds. However, widely available, accessible and relatively cheap MaaS services in vehicles with digital entertainment and similar facilities could encourage longer trips, and work against the concept of '20-minute neighbourhoods'.

Transition to a low-carbon city to enable Victoria to achieve its target of net zero greenhouse gas emissions by 2050

Scenarios 3 and 4 assume high levels of electric-powered vehicles in the increasingly autonomous vehicle fleet, and having few hydrocarbon-powered vehicles and sustainable zero-emission power-generation technologies (electricity from renewables, hydrogen) will be of enormous assistance in meeting this objective. Under Scenario 4, the environment of Melbourne could be radically transformed.

Make Melbourne cooler and greener

Scenarios 3 and 4 make the strongest contribution to this direction, assuming high levels of adoption of AEVs and renewable energy generation. The spaces previously used for car parking can, under high MaaS adoption, also be converted to parks and plantings.

Improve air quality and reduce the impact of excessive noise

High MaaS Scenarios 3 and 4 are likely to have the greatest impact on air quality improvement where renewable energy powers vehicles, and excessive noise from truck engines will be significantly reduced if trucks move to dominance of electric power and autonomous operations.

Improve connections between cities and regions

Autonomous vehicles should make inter-regional travel quicker and much safer, while high MaaS Scenarios 3 and 4 might also offer improved inter-regional connections. Rural areas are, however, likely to be slow adopters of autonomous vehicles, so there may be a longer period of conflict between autonomous vehicles and human-driven vehicles of all types in rural areas.

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xl. See notes 24, 40, 41

xli. ibid

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