ADVICE ON AUTOMATED AND ZERO EMISSIONS VEHICLES INFRASTRUCTURE

LITERATURE REVIEW

July 2018

INFRASTRUCTURE VICTORIA

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BACKGROUND

The Victorian Government has asked Infrastructure Victoria to provide advice on what infrastructure is required to pave the way for highly automated and zero emissions vehicles in Victoria.

These emerging technologies have the potential to radically change how the state's transport system operates. Whether or not this change is for the better depends on both private sector innovation and the preparedness of government at all levels.

Infrastructure Victoria is consulting with experts and gathering extensive evidence to determine what infrastructure is required to realise the potential benefits of automated and zero emissions vehicles in Victoria.

Our final recommendations will be delivered to the Victorian Government in October 2018.

This report presents key themes identified in literature from academia, industry, think-tanks and governments. This literature has contributed to our understanding of the uncertainties in enabling the introduction of automated and zero emissions vehicles. This review has also helped us understand where the gaps are in the current evidence and what further research needed to be done to inform our final advice.

This review is not intended to be a comprehensive analysis of all literature related to automated and zero emissions vehicles; instead it has targeted areas relevant to our advice. Further, as automated and zero emissions vehicle technology is a rapidly emerging field of research, it should be noted this is a review of the literature as of May 2018.

This report is not a formal consultation document. However, contributions from stakeholders are always welcome. To find out how to get involved, see page 36.

TERMINOLOGY

We're used to hearing automated and zero emissions vehicles being described as driverless and electric cars in the media. These terms are often interchangeable, but not always. For the purposes of this advice:

- **Vehicles** can be cars, trucks, buses or any form of motorised, road-based transportation. Automated trams and trains are not a primary focus of this advice (find out what's out of scope and why in our report 'Future Scenarios').
- **Zero emissions vehicles** emit no emissions from the tailpipe, charging or fuel source. Currently, vehicles powered by electric batteries and hydrogen fuel cells have the potential to be zero emissions.
- **Highly or fully automated vehicles** are capable of driving without the involvement of a human driver. They are likely to be cooperative, with connections to other vehicles, infrastructure and the internet.

The Society of Automotive Engineers (2016) has defined six levels of automation for motor vehicles ranging from no driving automation at level 0 to full driving automation at level 5. A summary of these levels is as follows:

- **Level 0:** No automation; the driver is always in control, but may be briefly aided by the vehicle (e.g. automated emergency braking).
- **Level 1:** Limited automation; the vehicle can control either side-to side (lateral) or forward-backward (longitudinal) motion at any one time, but not both (e.g. adaptive cruise control OR lane-keep assistance).
- **Level 2:** Partial automation; the vehicle can identify and respond to the environment in certain areas using a combination of driver assistance systems for both lateral and longitudinal motion (e.g. adaptive cruise control WITH lane-keep assistance).
- **Level 3:** Conditional automation; the vehicle can drive itself in certain areas, but expects the human driver to intervene on request (e.g. steering, speed and braking assistance at defined speeds).
- **Level 4:** High automation; the vehicle can drive itself in certain areas, without the need for a human driver to intervene (e.g. campus only or sealed roads only).
- **Level 5:** Full automation; the vehicle can complete an end-to-end trip anywhere with no expectation of driver intervention.

At levels 0 to 3, people are required to perform most of the driving and/or intervene if needed when the vehicle is in control. At levels 4 and 5, a human driver is not needed. The difference between levels 4 and 5 is that at level 5, the vehicle is capable of being driverless anywhere, under any conditions, whereas at level 4, vehicles are limited in where and when they can operate without a driver. Our advice focuses on the infrastructure required to support vehicles operating at levels 4 and 5. The infrastructure required for levels 4 and 5 is expected to be the same, so they are not differentiated in our analysis.

LITERATURE REVIEW

Introduction

The purpose of this literature review is to examine and analyse key literature on the potential implications of the introduction of automated and zero emissions vehicles to Victoria.

During our identification of key issues we noted that the introduction of automated and zero emissions vehicles has four key uncertainties which may have implications for Victoria. These four key uncertainties are:

- automated vehicle technology
- zero emissions vehicle technology
- market models
- regulation.

We recognise that these uncertainties may have widespread implications, and have identified ten focus issues which are likely to be significantly affected by automated and zero emissions vehicles. These ten focus issues were also selected for the value they could add to our understanding of current debates and beliefs when delivering the final advice. Some of these focus issues relate directly to our technical investigations for the advice, while others cut across many technical areas and scenarios. The ten focus issues of the literature review are:

- land use planning
- safety and ethics
- physical infrastructure
- digital infrastructure
- health and active transport
- governance
- energy systems and the environment
- human behaviour
- social inclusion and equity
- employment and economic outcomes.

Each section of this literature review will analyse the literature on the implications of the four uncertainties for each of these focus issues. The key themes which have emerged in the literature on these uncertainties will be examined, and the tensions and alternative viewpoints to these perspectives will be discussed. The key questions that have emerged from this literature review will be outlined, to indicate areas of future investigation on the introduction of zero emissions and automated vehicles to Victoria.

1. Land use planning

Automated vehicle technology and land use planning

Childress et al. (2015) modelled the effects of private automated vehicles on travel behaviour in Seattle, Washington, and found that automated vehicles are likely to result in increased speed and road capacity, facilitating increased travel distances. Studies by Meyer et al. (2017) analysing the effects in Switzerland, Gelauff, Ossokina and Teulings (2017) focusing on the Netherlands and Kim et al. (2015) examining effects in Korea all concluded that private automated vehicles were likely to increase development in urban fringe and rural areas. These changes have been influenced by estimated changes to the perceived value of travel time, as well as factors such as increased road capacity.

Under current ownership models, there may be changes to car parking, with Milakis, van Arem and van Wee (2017) highlighting that parking may be shifted to the periphery of the city, reducing the number of parking sites in the central city area. Zakharenko (2016) modelled that this may create a 'parking belt' in the area of the city just outside the commuter work area, where up to 97% of automated vehicles may park themselves. Henderson and Spencer (2016) contend automated vehicles are likely to increase road capacity by two to four times. Thus, Henderson and Spencer (2016) identify if current road capacity is maintained, significant portions of the road could be reclaimed for other uses. While Gelauff, Ossokina and Teulings (2017) confirm the finding that private automated vehicles would shift development from urban centres, it was found that if private automated vehicles were combined with automated public transport, which increased efficiency and frequency, there was a population shift into the major desirable urban centres, at the expense of other areas.

Zero emissions vehicle technology and land use planning

A key theme across the literature is the expectation that home and workplace charging will meet the major fuelling needs of electric vehicles. ClimateWorks Australia (2017) contend that while there is a significant focus on public charging infrastructure, the key role of this infrastructure is alleviation of consumer concern over the range capabilities of electric vehicles. Fast charging public infrastructure will also be necessary in rural areas (ClimateWorks Australia 2017).

Within urban areas, Riesz et al. (2016) have modelled that the number of public charging stations needed will be lower than the current number of fuelling stations, allowing those extra facilities to be repurposed for new land uses. The emphasis on private electric vehicle charging at homes and workplaces is challenged by Goetz (2017), who contends that the introduction of automated vehicles means factors such as cost or grid requirements may become more important than convenience for drivers. While the current literature concentrates on battery electric vehicles, the potential land use implications for hydrogen fuel cell electric vehicles is also being explored. The Hydrogen Council (2017) contends that as hydrogen vehicles take a similar time as petrol and diesel vehicles to refuel, sites of current petrol stations will be appropriate to repurpose for hydrogen refuelling. It is not clear in the literature if the number of sites could be reduced.

Market models and land use planning

A seminal text by Fagnant and Kockelman (2014) modelled the ability of shared automated vehicles to replace traditional vehicles in Austin, Texas at a ratio of one to 11, with Zhang et al. (2015) confirming similar findings and noting the potential for a 90% reduction in car parking demand in a simulation model. Ohnemus and Perl (2016) present two divergent land use futures that private and shared automated vehicles offer. The visions, also supported by work from the Bloomberg Aspen Initiative on Cities and Autonomous Vehicles (2017) and Henderson and Spencer (2016), highlight the opportunities for repurposing land currently used for car parking and road space, as reduced numbers of smaller, efficient and shared automated vehicles will use significantly less space. Henderson and Spencer (2016) present a real estate perspective on this future, contending this space can be used to increase density of productive uses, such as mixed use developments, which could relieve development pressure on greenfield sites.

The finding that shared automated vehicles can significantly reduce the number of required carparks has been modelled within a Melbourne context by Dia and Javanshour (2017). The converse option of private vehicle ownership is contended to result in increased urban sprawl and number of vehicles on the road with zero passengers by Ohnemus and Perl (2016) and the Bloomberg Aspen Initiative on Cities and Autonomous Vehicles (2017). Zhang et al. (2015) highlights that users' willingness to not only car share, but also ride share, will influence the degree to which car parking can be reduced. Zhang et al. (2015) modelled that under a shared ownership model carparks can be significantly reduced in the city's outer areas, however, to get similar levels of reduction in the inner city, more vehicles may cruise with zero passengers. Ohnemus and Perl (2016) also tapered the expected reduction in carparks and vehicles, due to anticipated electric vehicle charging time. The appropriateness of a ride sharing system in regional and rural areas was challenged by Zhang et al. (2015) and Gruel and Stanford (2016), as it is contended that a critical mass of population is required to attain the benefits offered by a ride sharing system.

Regulation and land use planning

Within the US context, Isaac (2016) outlines the need for planning control changes to enable car parking to respond to the potential for lower private vehicle ownership and adjust to pick up/drop off needs, strengthen urban growth boundary policies and further support creation of walkable, dense suburbs. This is supported by similar recommendations in a report by GTA Consultants (2017) within the Melbourne context.

The International Council on Clean Transportation (2017a) has highlighted that San Francisco, Los Angeles, New York, Shenzhen, Hangzhou, Beijing, Shanghai, Qingdao and London are all implementing electric vehicle friendly building and parking codes, with London requiring 20% of parking spaces in new residential developments to have an electric vehicle charge point. The consensus on the future of car parking is challenged by the disparate views raised by Ohnemus and Perl (2016) and Zhang et al. (2015) regarding the combination of electric and automated vehicles, and the trade-off relationship between empty cruising and car parking.

Areas for further research

The review of this literature has created the foundations of our understanding on the land use planning implications of automated and zero emissions vehicles, however it has also identified gaps where further research is necessary. Key areas of further research include the need to understand necessary changes to Victorian planning regulation and legislation, particularly with regards to parking, charging and integrated transport regulations. While significant overseas research has identified potential impacts on land use density and dispersion, research within the Victorian context is needed to understand whether areas may become densified, fringe development may increase, effects for people in regional, rural and low density areas and consequences for Victoria's current land use goals. Further, an analysis of future vehicle space allocation, including parking, road width and fuelling and charging space and location within the Victorian context is also needed.

2. Safety and ethics

Automated vehicle technology and safety and ethics

Cyber security, safety of automation and the ethics of autonomy are identified as key themes within the literature on automated vehicles. Automated and connected vehicles may present a number of cyber security risks. Thandeeswaran, Pawar and Rai (2017) identify that there are several types of potential threats, classifying them as threats to the communication links, threats to data validity, threats to access control, threats to privacy, threats to devices and threats to identity of vehicles, and note that while some security threats will be malicious, some security threats will be the result of unintentional actions. Automated vehicles are regularly associated with improved safety outcomes, with 94% of US crashes attributed to human error, and 90% of Australian crashes due to minor human mistakes. A common assumption is that these accidents could be prevented with vehicle automation (National Highway Traffic Safety Administration 2015; QBE 2017). The European Parliament's Committee on Transport and Tourism (2016) argues that this contention is so far unproven, and the safety implications of automated vehicles are currently unknown.

Sparrow and Howard (2017) posit that once automated vehicles become safer than human drivers, it will become unethical to allow humans to continue to drive, just as it is unethical to allow automated vehicles while they are less safe than human drivers. KPMG (2017a) highlights the challenges of the transition stage of level 3 autonomy, as drivers may be required to quickly take over and respond to an urgent situation with little notice. Coeckelbergh (2016) contends that once full autonomy is achieved the user morally separates from the responsibilities of a driver as they assume the role of passenger, with the responsibility now the duty of the manufacturers.

A considerable body of research, including Dignum (2017), Fleetwood (2017), Lin (2016) and Bonnefon, Shariff and Rahwan (2016), provide extensive discussion on the responsibility that will rest with developers to ensure that automated vehicles make moral decisions. It is argued by Fleetwood (2017) that merely requiring automated vehicles to follow the rules of the road is overly simplistic, when human drivers regularly make spontaneous, moral decisions. Fleetwood (2017) and Lin (2016) contend society will need to agree on an acceptable moral code, which automated vehicles will operate by, for when the vehicle needs to make a decision between two undesirable outcomes. Bonnefon, Shariff and Rahwan (2016) claim this creates a ‘social dilemma’, as people prefer a utilitarian automated vehicle for other people, however for themselves they prefer a vehicle which prioritises their own safety. This is disputed by Zhao et al. (2016) who argue that the emphasis on the ‘social dilemma’ and need for moral algorithms has been exaggerated and is an unnecessary barrier to the potential deployment of automated vehicles. Zhao et al. (2016) argue that the focus should be on ensuring that automated vehicles create moral outcomes through ethical decisions, such as attempting to avoid hitting humans, rather than being embedded with moral principles such as utility.

Zero emissions vehicle technology and safety and ethics

Research on the safety considerations of electric and hydrogen vehicles has been ongoing for the past three decades. Over this considerable period, the safety of hydrogen has been extensively researched. Adamson and Pearson (2000) and the US Office of Energy Efficiency and Renewable Energy (n.d.) provide an overview of the safety considerations, highlighting that while the chemical makeup of hydrogen presents a significant risk under certain circumstances, these are unlikely within its use as a vehicle fuel. The US Office of Energy Efficiency and Renewable Energy (n.d.) identifies that for a hydrogen fire to occur an adequate concentration of hydrogen, an ignition source and the right amount of oxidizer (like oxygen) must be present simultaneously, with an explosion unable to occur in a tank that contains only hydrogen. Further, Adamson and Pearson (2000) discuss that while hydrogen is highly flammable, it also rises very quickly and consequently areas with ventilation are unlikely to accumulate enough gas for fire or explosion. However, there is a disparate theme within the literature, with Cadwallader and Herring (1999), Hansel, Mattern and Miller (1993), Shinnar (2003) and Markert et al. (2007) discussing the increased risk that would arise from allowing unskilled people to handle hydrogen during refuelling. It is argued that while hydrogen can be used safely, accidents do occur, and these have the potential to become more likely and catastrophic through hydrogen's use as a fuel (Cadwallader & Herring 1999; Hansel, Mattern & Miller 1993; Shinnar 2003; Markert et al. 2007). Frequently cited Satyapal et al. (2007) contends hydrogen fuel storage, boil off and use of ammonia all need to be further investigated for their safety implications, while formative text DeLuchi (1989) contends that hydrogen risks are different, however likely no greater, than petroleum fuel.

Significant research has also been done on the safety of lithium-ion batteries, the battery technology commonly used in electric vehicles. A seminal paper by Balakrishnan, Ramesh and Prem Kumar (2006) discusses the importance of consumer education, with safe use dependent on compliance with advice on factors such as operation temperature, and over and under charging. Doughty and Roth (2012) and Wang et al. (2012) contend that lithium-ion batteries require a trade-off between performance and safety, with thermal runaway potentially causing explosion or fire. The Society of Automotive Engineers (2012) focuses on the risks presented by a potential electric vehicle crash, claiming that while the high voltage system is likely to be secure, an increased level of care and expertise will be required by first responders. However, Tan et al. (2016) outline a new solid state lithium-ion battery technology that is contended to deliver a higher level of safety. A significant number of media articles, such as Vandervell (2017) and Reisch (2017), discuss the potential utilisation of this technology by vehicle manufacturers.

Zero emissions vehicles are generally accepted as being ethical, however the review has highlighted concerns regarding the use of resources, such as cobalt in lithium-ion batteries, sourced from countries, primarily the Democratic Republic of the Congo, where labour and human rights issues are known (Amnesty International 2016). Amnesty International (2016) has raised concern over the lack of action by companies who use cobalt to identify whether child labour or unsafe labour was used in the resource extraction process.

Market models and safety and ethics

The uncertainty of market models for automated and zero emissions vehicles has not extensively been explored for its safety implications, although some research has considered the liability repercussions. KPMG (2017a) has identified that if automation results in a shift to shared fleets, the onus transfers to commercial from personal insurance and liability.

Regulation and safety and ethics

Minogue (2017) contends that a higher level of compliance testing is essential to ensure the safety of automated vehicle users, with current laws overlooking security needs. The literature on the different levels of government in achieving this has been further outlined in the section 'Regulation and governance'. The necessity for government involvement in automated vehicle algorithms is unclear, with Bonnefon, Shariff and Rahwan (2016) arguing that although regulation could require utilitarian moral algorithms to overcome the 'social dilemma' they identified, it is unlikely to be popular and may delay the adoption of automated vehicles, which would result in lost benefits. Prakken (2017) argues that although a considerable amount of attention has been given to moral arguments, a more desirable approach is for governments and industry to collaborate on creating guidelines and regulations for automated driving, with a focus on efficient, legally compliant and proactive driving behaviours. To confront the ethical issues related to resource extraction for electric vehicles, Amnesty International (2017) states governments should require companies to publicly report on their resource supply chains (Amnesty International 2017).

Areas for further research

The key area that requires further investigation is the safety implications of automated vehicles, with a specific focus on the extent to which government should have authority over vehicle safety. While there is significant speculation on the safety impacts of automated vehicles, further research is needed into the safety needs and implications within the Victorian context. The potential for safety gains to be undermined by a heightened period of unsafe driving during the transition stage, where vehicles with different levels of automation operate together, must also be understood. The role for government in potentially mandating automation features if improved safety is proved (or banning unsafe features), and the necessary balance of enabling a fast introduction and ensuring safety, needs to be investigated.

3. Physical infrastructure

Automated vehicle technology and physical infrastructure

Austroads (2017a) contends that the majority of automated vehicles are likely to be designed to operate on our current road infrastructure, however several characteristics may require reconsideration. Austroads (2017a) and Atkins (2016) highlight that the physical attributes of roads, such as intersection design; pavement and structures, such as bridges and road materials; sign and lines, in terms of readability; roadworks, which will require real time updates; and the potential for automated vehicle certification for certain roads, should be key infrastructure considerations for the introduction of automated vehicles. Further, Austroads (2017a) identifies that pot holes, edge wear, accident damage and debris may negatively affect the performance of automated vehicles, and highlights that automated vehicle development appears to focus on sealed roads, which represent only 56.8% of Australia's roads. Chen, Balieu and Kringos (2016) have discussed that while increased wheel accuracy and lane capacity could lead to increased road rutting, they contend that increased traffic speeds and decreased congestion could mitigate the rutting effect.

This raises the debate on whether automated vehicle technology will increase or decrease congestion, and the consequent infrastructure implications. Kockelman (2017) and Milakis et al. (2017) contend that improved vehicle communication could significantly decrease road congestion. This is because improved vehicle communication may facilitate reduced headways (the distance or time between vehicles), narrowed lanes and possible platooning (the technological linking of trucks to create a convoy) (Kockelman 2017; Milakis et al. 2017; Austroads 2017). Milakis et al. (2017) further state that platooning vehicles could relieve the need for costly congestion reducing infrastructure investments, such as high speed trains, as platooned vehicles in designated express lanes could provide an alternative option.

The National Association of City Transportation Officials (2017) support designating high volume transit lanes, and discuss the possibility that decreased congestion offers the opportunity to increase road space allocation towards public transport, pedestrians and cyclists, and the need for curb management to facilitate pick-ups and drop-offs. However, KPMG (2016a) argues that automated vehicles will decrease the cost of car travel, while also making it more convenient and easy, leading to a possible 29% increase in average car trip time and 23% increase in average car trip distance, growing congestion levels. SMEC Australia (2016) supports this, arguing that automated vehicles will reduce the perceived value of time spent outside of commuting, and contend that reduced value of time has a greater impact on increasing congestion than a proportional increase in arterial road capacity. Puylaert et al. (2018) supports this, arguing that automated vehicles are likely to increase car trips, and exacerbate congestion, while MRCagney (2017) found if all non-car based commuters in Auckland, New Zealand switched to automated vehicles, vehicles accessing central Auckland during peak hour would immediately increase by 50%, and double by 2043, increasing congestion and severely impacting road capacity. If automated vehicles are also able to communicate with other vehicles and road management systems, Puylaert et al. (2018) contends this could further increase car trips, therefore increasing congestion, although increased vehicle speeds may moderate this increase. Ivanchev et al. (2017) and Glancy (2015) proposed introducing separate automated vehicle lanes during the fleet transition period, although Ivanchev et al. (2017) found that while the lane would reduce travel time for automated vehicles, it would do so at the expense of delaying traditional vehicles. Parkin et al. (2016) argues that the logic which previously advocated for traffic efficiency has been replaced with a more nuanced understanding of movement and place, which avoids prioritising traffic flow at the expense of place making and active and public transport.

The relationship between automated vehicle technology and public transport is another major area of investigation. Milakis, van Arem and van Wee (2017) argue that automated vehicles may induce car travel demand, through increasing trip length, frequency, and mode shift, however identify that high capacity public transport could reduce the size of the vehicle fleet. Fishman and Davies (2016) predict a significant increase in vehicles on the road as a consequence of automated technology, and advocate for a restructure of the current transport pricing structure, contending that dynamic road pricing will offer a transparent revenue source and potentially increase sustainable transport use. This is supported by Arcadis, HR&A Advisors and Sam Schwartz (2017) who suggest numerous infrastructure adaptations to be made in conjunction with automated technology introduction, including transport pricing options, high frequency and high capacity public transport, first and last mile transport connections using driverless shuttles and expansion of mobility hubs. It is argued that automated vehicle technology presents an opportunity to offer a continuous, point-to-point transport service (Arcadis, HR&A Advisors, & Sam Schwartz 2017). The possible benefit of automated vehicle technology to public transport is further extended by MRCagney (2017) who found that if public transport in Auckland, New Zealand was automated, service levels could increase by approximately 80% and subsidies could be reduced by 30%. Tettamanti, Varga, and Szalay (2016) contend that automating public transport vehicles for operation on fixed routes offers a simple and direct application of automated technology.

Zero emissions vehicle technology and physical infrastructure

The International Council on Clean Transportation (2016) (2017b) (2017c) contends that high levels of charging infrastructure is correlated with high rates of electric vehicle market penetration. This is supported by AEMO and Energeia (2016) who state that, along with a limited product range, underdeveloped public charging infrastructure is constraining electric vehicle uptake. ClimateWorks Australia (2017) have argued that the perceived availability of public charging infrastructure is key to reducing range anxiety and increasing electric vehicle uptake. Greaves, Backman and Ellison (2014) counter that charging infrastructure and range are only likely to become factors in electric vehicle uptake once the cost of batteries is reduced, as currently price is the key constraining factor. Further, there is considerable debate in the literature regarding the most appropriate type of charging infrastructure for electric vehicles. ClimateWorks Australia (2017) identified that there are currently AC chargers, which charge at approximately 50km an hour, and DC chargers, which provide considerably faster charging with the potential to charge to 80% battery capacity in 20 minutes (Wager, Whale & Braunl 2016). Bakker, Leguijt and van Lente (2015) recognise there are incompatible standards across AC and DC chargers, with vehicles generally manufactured to fit only one of four major charger plug types. Further, the International Council on Clean Transportation (2017d) have highlighted that there are several other charging infrastructure options including catenary (overhead) and in-road charging, which may be appropriate particularly on high use or freight corridors, or battery swapping.

It has also been recognised that hydrogen fuel cell technology is a potential zero emissions vehicle fuel, particularly for long distance freight vehicles (International Council on Clean Transportation 2017d). Hydrogen acts as an energy carrier, with infrastructure necessary for the energy production, storage and power conversion processes (International Council on Clean Transportation 2017e). Hydrogen can be produced on distributed sites, or at a centralised facility, with International Council on Clean Transportation (2017e) arguing centralised production is the more efficient option (International Council on Clean Transportation 2017e). The International Council on Clean Transportation (2017e), Schoettle and Sivak (2016) and Offer et al. (2010) identify the current lack of hydrogen refuelling infrastructure internationally, with ABMARC (2016) discussing the high cost of the infrastructure, and the challenges for reaching adequate supply within the context of Australian low density cities. Stiller et al. (2010) analysed the potential for hydrogen fuel in Norway, and contend that low population density may mean that distributed production is the most efficient method. Alazemi and Andrews (2015) argue that the introduction of hydrogen refuelling infrastructure must be timed simultaneously to the introduction of hydrogen fuelled vehicles, as neither is viable without the introduction of the other.

Market models and physical infrastructure

Gruel and Stanford (2016) investigated three different automated vehicle introduction scenarios and found that if the introduction of automated vehicles does not cause people to change their travel behaviour, traffic volumes may increase, however likely only at rates which could be offset by increases in vehicle and traffic efficiency. Gruel and Stanford (2016) also present two alternative scenarios, where automated vehicles increase the attractiveness of car travel, reducing public transport use, while car use and congestion rise; and where automated vehicles are shared, which reduces the number of vehicles, incentivises a compact city through the pay-per-kilometre system and potentially positively affects public transport use. Modelling of Lisbon, Portugal by the International Transport Forum (2015) found if all vehicles were configured as a ride sharing fleet supported by high capacity public transport, 90% of vehicles could be removed and all mobility needs would still be met. If only 50% of vehicles were part of the automated shared fleet, and there was no public transport, vehicles would increase. While vehicle kilometres travelled increased in every scenario, under the 100% ride sharing supported by high capacity public transport scenario the increase was only 6%, while conversely, if only cars are shared and there is no public transport, vehicles kilometres travelled increased by 89% (International Transport Forum 2015). However, even in this scenario, 23% fewer vehicles were required during peak hour (International Transport Forum 2015). This is supported by Fagnant and Kockelman (2014) and Dia and Javanshour (2017) who found that if automated vehicles operate in a shared on-demand market the number of vehicles required to meet a region’s mobility needs is likely to be significantly reduced, although overall vehicle kilometres travelled are likely to increase, with Fagnant and Kockelman (2018) contending that ride sharing is crucial to avoiding increasing congestion. In the Victorian context, Truong et al. (2017) found that car occupancy would need to increase by at least 5 to 7% to offset the increase in trips automated vehicles are likely to generate.

SMEC Australia (2016) and Ohnemus and Perl (2016) contend that a shared market model of automated vehicles could provide support to public transport networks by providing feeder services to public transport, particularly from low density suburbs which currently lack quality public transport services. SMEC Australia (2016) argues that this approach, combined with transport pricing to increase the cost of car access to the city, could make public transport the most viable transport option. Chen, Kockelman and Hanna (2016) investigated the relationship between market models of automated vehicles and electric vehicle technology, and found that shared automated vehicles reduce many consumer concerns about electric vehicles, as fleets would have access to charging infrastructure and manage their own charging schedule. However, Chen, Kockelman and Hanna (2016) identify that one electric, shared, automated vehicle can only replace 3.7 private vehicles, while one non-electric, shared, automated vehicle could replace 7.3 private vehicles, as electric vehicles will have time dedicated to charging. However, International Transport Forum (2017) contend that electric vehicles are only likely to increase required shared automated vehicle fleet size by 10%, while International Transport Forum (2015) estimated an increased fleet size of only 2%.

Regulation and physical infrastructure

Austroads (2017a) contends that in the medium term it will be prohibitively expensive to upgrade all roads to a standard acceptable for automated vehicle use. Austroads (2017a) proposes a road certification process should be developed that would require an evaluation of roads, which could then be certified as appropriate for automated vehicle use.

Areas for further research

The main areas which require further investigation include the impact of automated vehicles on Victorian road networks, such as network needs, impacts to capacity and human behaviour, and the effects of interventions, such as transport network pricing. The implications of automated and zero emissions vehicles for physical infrastructure, such as lanes, lines, signage, motorway management, road surface and charging need to be investigated further, and further research is needed on the interaction of automated vehicles with public transport, particularly within the Victorian context. The impacts of different vehicle market models should be analysed further, particularly with a view to the challenges and opportunities for physical infrastructure, and the role for government in influencing market choices.

4. Digital infrastructure

Automated vehicle technology and digital infrastructure

Austroads (2017a), Atkins (2016), Institute for Public Administration (2017) and Kockelman (2017) contend that the current technologies for enabling connected and automated vehicles are vehicle to vehicle (V2V), vehicle to infrastructure (V2I), vehicle to personal device (V2P) and the all-encompassing vehicle to everything (V2X). V2V enables communication between vehicles and is likely to create increased safety, while V2I and V2X could allow road and traffic control, with signs and intersection signals potentially able to be updated in response to new information, and advise vehicles of changes and information (Atkins 2016; Institute for Public Administration 2017). Wuthishuwong, Traechtler and Bruns (2015) simulated that V2I could successfully produce an accident free intersection, and Najm et al. (2010) contend V2V could reduce 76% of all crashes, while V2V and V2I systems combined could potentially address 81% of all vehicle crashes.

Connected and automated vehicles are not automatically synonymous with each other, however, Austroads (2017a) contends that connected vehicles are a prerequisite to full autonomy, as connected vehicles provide support for drivers to make decisions through receipt of information through communication technologies. Austroads (2017a), Atkins (2016), Institute for Public Administration (2017) and Kockelman (2017) discuss the digital infrastructure requirements to enable vehicle connectivity, with 802.11p the wireless technology standard repeatedly discussed, to enable a real time, secure network connection between vehicles and other systems. Atkins (2016) contends that this standard is only the lower layer of required connectivity, with an upper layer needed to create the system known as wireless access in vehicular environments (WAVE), arguing WAVE is synonymous with V2X. When analysing Delaware, US, the Institute for Public Administration (2017) notes the type of technology to enable this V2X connectivity is still uncertain, however current dominant options appear to be dedicated short-range communication (DSRC) and cellular technology similar to that used in smartphones, such as 5G. DSRC acts similar to WiFi and would require specialised roadside infrastructure which could receive and transmit communication to vehicles, while cellular technology could utilise infrastructure currently used by mobile phones (Institute for Public Administration 2017).

Currently, some vehicles have a private SIM-based connectivity service, operated through the cellular network (WSP 2017). Milakis et al. (2017) argue that cellular technology suffers from latency and bandwidth constraints, and that DSRC requires significant infrastructure investment, advocating for a combination of vehicle sensor and communication technologies to cover more situations through the mix of technologies. WSP (2017) highlights the emerging belief that vehicle based sensors will not be sufficiently safe without supporting digital communication infrastructure, although noting that trials from the US are suggesting that this may not be true. The Society of Motor Manufacturers and Traders Limited (2017) argues that while vehicles will be able to operate without connected technologies, the addition of connectivity will increase vehicle safety and functionality. This is supported by Parkin et al. (2016) who contend that while vehicle sensors should attempt to recognise and respond to pedestrians, communication between the vehicle and roadside infrastructure monitoring pedestrian movements is likely to reduce the probability of collision.

Austroads (2017a) and Milakis et al. (2017) discuss the importance of positioning technology and high resolution mapping, noting that Global Navigation Satellite System (GNSS), particularly Global Positioning Service (GPS), will not be sufficient to accurately provide navigation, with vehicles also needing to rely on their on-board sensors for positioning. Austroads (2017a) highlights this is also likely to be a relevant factor for automated vehicles in regional and rural areas, which often lack digital infrastructure, including cellular communication coverage. Further, most automated vehicle technology is being developed using satellite-based augmentation systems (SBAS) enabled GNSS, which is not yet freely available in Australia. However, the 2018-2019 Australian Government budget has allocated funding to improve GPS capability, which could mean the availability of higher accuracy GPS in the future (Australian Government 2018). Atkins (2016) argues that digital communication of information currently conveyed through visual signals will be significantly more reliable than relying on machine vision. Similarly, Austroads (2017a) contends vehicles need to access up-to-date information on accidents and roadworks to make appropriate responses when real world road conditions differ from maps. This supports the contention by Austroads (2017a), Australia and New Zealand Driverless Vehicle Initiative et al. (2017), Atkins (2016), National Association of City Transportation Officials (2017), Intelligent Transport Systems Australia (2016) and KPMG (2017b) that data collection, access and management are key digital infrastructure considerations for automated vehicle technology. Austroads (2017a) contends that while private companies will be responsible for maps and map data, road infrastructure agencies are the main source for up-to-date information of several road data attributes, such as speed limit changes and road works.

The National Association of City Transportation Officials (2017) contend that this data sharing should be mutual between public and private organisations, with public agencies receiving the aggregated and anonymised data through a secure third party platform. It is contended that this data should be collected by in-vehicle technologies where possible, or otherwise on street sensors, in order to undertake kerbside and street management, vehicle occupancy pricing and strategic planning. Intelligent Transport Systems Australia (2016), KPMG (2017b) and the National Association of City Transportation Officials (2016) highlight the importance of interoperability for exchange of this data within the digital infrastructure, including between public and private organisations and across regional boundaries. Austroads (2017a) contends that this shift to a real time digital infrastructure focused workplace may require organisational changes for road operators, as the roles and emphasis may alter significantly. Accenture Digital (2014) highlights this shift to a data driven digital based infrastructure is likely to significantly increase data consumption, potentially requiring cellular service providers to build new products and infrastructure.

Another significant aspect of digital infrastructure which may be an implication of automated vehicles is the development of new transit apps, including the potential for those similar to Mobility as a Service (MaaS) app, Whim, in Helsinki (KPMG 2017b). Arcadis, HR&A Advisors and Sam Schwartz (2017) argue that it is essential to leverage technology such as open data, universal apps and smartcards to improve mobility, with Shaheen, Cohen and Martin (2017) reporting that 39% of multimodal transport app users stated they drove less due to the app. Lindsay (2016) highlights that an app could also be utilised to offer real time information and incentives in response to transport conditions.

Zero emissions vehicle technology and digital infrastructure

Masoum et al. (2011) and Ma and Mohammed (2014) discuss the need for smart grid infrastructure, such as bi-directional charging converters, real time monitoring of the grid and smart metres which can coordinate the energy demand, to support future electric vehicle charging. Jian et al. (2013) also advocate for smart grid infrastructure and algorithms, but caution against use of the information to create dynamic pricing, arguing instead for governments and energy companies to focus on benefiting from increased efficiency and decreased emissions. The media, including eMotorWerks (2017), has highlighted new digital infrastructure approaches for electric vehicles, discussing a combination of companies in the US who are providing a networked smart grid of electric vehicle public chargers that are supported by on-charger advertising. The digital infrastructure implications of hydrogen fuel have received minimal research, and the future needs and technologies of zero emissions vehicles are largely still unexplored.

Market models and digital infrastructure

Iacobucci, Hovenkotter and Anbinder (2017) contend that most private mobility companies are not currently required to share information, and that data sharing between private and public entities is essential to coordinate and understand the impact of shared mobility on the broader transport network. Further, Intelligent Transport Systems Australia (2016) argues that real time data sets must be shared between governments and commercial transport operators, to create multimodal transport information tools and achieve MaaS. Iacobucci, Hovenkotter and Anbinder (2017) extend this, arguing that the transport process must be simplified, advocating for a universal payment system that utilises common technologies such as contactless payment, and a transport planning app that allows users to make comparisons between modes and plan multimodal trips. Iacobucci, Hovenkotter and Anbinder (2017) argue that if real time vehicle location data was accessible through digital infrastructure, multimodal trip tools could actively arrange connections between modes, including pooling riders headed to similar destinations into shared vehicles.

Regulation and digital infrastructure

Iacobucci, Hovenkotter and Anbinder (2017) and Intelligent Transport Systems Australia (2016) advocate for regulation requiring data sharing between private and public entities to be a prerequisite for allowing private transport operators within a government's legislative boundaries. Haratsis (2017) identifies that Finland has made changes to regulation in order to shape the types of MaaS services available, require open availability of data and deregulate where needed to encourage new market operators. The US National Highway Traffic Safety Administration (2016) has been investigating regulation to require new vehicles to have V2V technology that would allow standardised communication between vehicles, and advice to governments on enabling V2I technologies and embedding them in infrastructure.

Areas for further research

Significant further evidence is required to understand the connectivity requirements, changes and investments necessary to enable automated vehicles in Victoria, with research particularly needed into digital connectivity options and needs, as well as any specific challenges for Victoria, such as unconnected rural areas. There is also a gap in the research on opportunities and challenges of an integrated planning and payment, or MaaS style service, and any barriers that may exist within Victoria's current transport systems. This gap also illustrates a wider question on the division of responsibility for digital infrastructure between government and the private sector, with the ideal level of control and information sharing to be investigated further. Similarly, the balance of data sharing, ownership and privacy, particularly with regards to fleet operators, will need further analysis.

5. Health and active transport

Automated vehicle technology and health and active transport

Fleetwood (2017) contends that automated vehicles may significantly reduce vehicle injuries and fatalities, but also raise many health related questions, including the potential for increased car use and decreased active transport, diverted public transport funding and equity of access. The Altarum Institute (2016) contends that automated vehicles are likely to reduce emissions through improved efficiency in driving, expand access to healthcare and healthy choices for those whose mobility is currently restricted, and contribute to creating a more compact city which supports active transport. Crayton and Meier (2017) describe the benefits of increased mobility for the elderly, and explain that the shift from the role of driver to passenger is likely to reduce stress, a leading cause of hypertension.

The effect on urban form and activity is corroborated by Millard-Ball (2016) who argue that the cautious nature of automated vehicles means the urban environment will become people orientated, as pedestrians, cyclists and children, can walk, ride, and play without safety concerns. Millard-Ball (2016) suggests this may lead to an increase in urban density, which can further contribute towards increasing active transport numbers. Stevenson et al. (2016) supports this contention, outlining that compact cities support modal shifts from private vehicles towards active and public transport. Further, Davidson and Spinoulas (2015) argue that even in scenarios where automated vehicles lead to congestion, this congestion may shift transport users to active or public transport, as they become more attractive options. However, Truong et al. (2017) and Gelauff, Ossokina and Teulings (2017) contend that the introduction of automated vehicles is likely to divert trips currently taken via public and active transport to automated vehicles, with Gelauff, Ossokina and Teulings (2017) highlighting factors such as perceived reduction of travel time cost, reduced parking costs, vehicle market penetration and increased road capacity as likely to influence this shift. The Altarum Institute (2016) identifies that this shift may result in a reduction in government investment in public transport, which would restrict the mobility and opportunities of people who cannot access automated vehicles.

Despite the literature supporting the increased safety and freedom for pedestrians and cyclists due to automated vehicles, Parkin et al. (2016) and Fairley (2017) highlight the current issues automated vehicles are encountering in detecting and communicating with cyclists, identifying that increased safety and cyclist confidence is uncertain. Similarly, Banks, Stanton and Harvey (2014) contend that at levels of automation lower than full automation, there may be negative health effects, as monitoring automation features may be more stressful for users than current driving practices.

Zero emissions vehicle technology and health and active transport

Sovacool (2010) highlights that currently emissions present a greater risk to human health than vehicle accidents in the US. It is argued that shifting to electric vehicles, particularly with electricity generated through clean methods, and more efficient vehicles, the burden of pollution will be lightened and respiratory illnesses and cancers rates will be reduced (Sovacool 2010). Xunmin et al. (n.d.), Jacobson, Colella and Golden (2005) and the American Lung Association in California (2016) find the health benefits, costs and climate effects of vehicle use could be substantially improved through the use of zero emissions vehicles, including both electric and hydrogen fuel cell vehicles. Xunmin et al. (n.d.) contends that modelling of electric vehicles adoption in China could create a decrease in emissions and consequently increase public health outcomes, with thousands of avoided mortality cases by 2030. Similarly, Jacobson, Colella and Golden (2005) state that a shift to wind or natural gas hydrogen fuel cell vehicles could save 3,700-6,400 lives each year in the US. Woodcock et al. (2016) highlighted that while reducing vehicle emissions creates better health outcomes, this is lower than the benefits that could be gained from increasing active travel and reducing car use. Woodcock et al. (2016) outline that the greatest health benefits occur from a combination of lower emissions vehicles and increased active transport and decreased car use.

Market models and health and active transport

Kent (2014) states that currently car sharing members walk, cycle and use public transport at higher rates than the general population. Similarly, Shaheen, Cohen and Martin (2017) contend that users of multimodal apps reduce their car use, which supports research by Iacobucci, Hovenkotter and Anbinder (2017) who argue that emphasising the compatibility between active, sharing and public transport modes will reduce overall car use. Dowling and Kent (2013) and KPMG (2016b) expect vehicle sharing market models to emerge prominently within inner city areas which have a strong range of available transport options, including public transport, walking and cycling. Crayton and Meier (2017) argue that while shared automated vehicles may create better health outcomes than private automated vehicles, this will not reduce the negative health effects of sedentary time inside vehicles, which may increase if transport patterns change and people accept longer travel times. Further, Milakis, van Arem and van Wee (2017) and Truong et al. (2017) discuss the possibility that short distance trips that people currently walk or cycle for, including feeder trips to public transport, may shift to shared automated vehicles. Childress et al. (2015) found that while generally automated vehicles are likely to decrease public and active transport types, a shared automated vehicle system with high user costs produced shorter trip lengths and an increase in public transport and walking. Additionally, Fagnant and Kockelman (2014) and Dia and Javanshour (2017) have highlighted that while a shared mobility market of automated vehicles would significantly reduce the number of vehicles, the overall vehicle kilometres travelled would increase or hold steady, indicating that alone it is unlikely to produce the health benefits of reduced emissions.

Regulation and health and active transport

Millard-Ball (2017) identifies that the potential pedestrian supremacy which may emerge from the cautious nature of automated vehicles could be developed and supported by governments, however there are also regulatory responses that would assist in avoiding this outcome. Regulation could enforce and strengthen current legislation which separates pedestrians from the road, including potentially with physical barriers (Millard-Ball 2017). Millard-Ball (2017) also suggests this approach could be applied to only some roads, while others could be shared. Iacobucci, Hovenkotter and Anbinder (2017) contend that regulation must impose appropriate fees on automated vehicle fleets, to incentivise public and active transport and higher occupancy vehicle trips. Woodcock et al. (2009) also support incentivising a reduction in vehicle use, including under higher proliferation of lower emissions vehicles. Xunmin et al. (n.d.) advocate for local air targets to encourage electric vehicle uptake, and for the government to encourage a shift from fossil fuel to renewable energy sources to gain the highest health benefit from the shift to zero emissions vehicles.

Areas for further research

This review highlighted several gaps in the literature on the broad health implications of automated and zero emissions vehicles within the Victorian context, including the health risks and benefits for other road users and any expected shifts in transport mode. Further, Victorian context evidence is needed to understand the impacts of automated and zero emissions vehicles on transport and land use patterns, and the required infrastructure to ensure active transport numbers are not reduced.

6. Governance

Automated vehicle technology and governance

The literature has identified potential effects of automated vehicles on governance assumptions and structures. In this review, governance can be understood as an evolving partnership and sharing of responsibility between public and private organisations (Dowling & Kent 2013). The Australian Government (2016) identifies the importance of achieving consistency through collaboration with state governments. The Institute for Sensible Transport (2016) identifies that any objectives that City of Melbourne aims to achieve from the introduction of automated vehicles will depend not only on their local government policy, but also on Victorian and Australian government policy. It is highlighted that certain policies, such as road user pricing, are beyond the sole prerogative of local government, and collaboration across government levels is necessary (Institute for Sensible Transport 2016). Smith (2017) contends that a comprehensive strategy directing the introduction of automated vehicles, and a coordinator who can work across different government levels as well as liaise with the private sector, is essential. Infrastructure Partnerships Australia (2017) argues that automated vehicles will ideally operate across state boundaries, necessitating Australian Government involvement to ensure consistency, education and safety standards for the state governments.

In a paper on the preparedness of transport planning agencies to address automated transport, Stone et al. (2018) contend that transport governance within Victoria is fragmented, a claim echoed within the US context by Iacobucci, Hovenkotter and Anbinder (2017). Iacobucci, Hovenkotter and Anbinder (2017), when analysing the relationship between traditional fixed route transport systems and emerging shared mobility systems, argue that this governance fragmentation means that coordination across and between transport modes is challenging, with Stone et al. (2018) contending that planning for automated vehicles must navigate industry and consultancies, as well as other government efforts. Stone et al. (2018), Infrastructure Partnerships Australia (2017) and Roads Australia (2017) discuss the fundamental question of the appropriate level of government involvement in the introduction of automated vehicles to Victoria. Stone et al. (2018) highlight that there are uncertainties within the transport governance of Victoria on the role of government as either an 'enabler' or a 'shaper' of the private sector.

Infrastructure Partnerships Australia (2017) argues that a 'middle road' of government intervention is preferable, whereby government reacts promptly in response to community choice. This is contrasted to a significantly delayed response which could constrain positive outcomes, or pre-emptive government action which may result in investment in the wrong technology or infrastructure (Infrastructure Partnerships Australia 2017). Roads Australia (2017) identified that the Swedish Government, in preparing for the introduction of automated vehicles, has prioritised societal goals and then collaborated with the private sector to meet those needs. This contrasts with the US and UK who have focused on strengthening the industry first (Roads Australia 2017). Roads Australia (2017) argues that government should identify key goals and potential collaborations with the private sector, which will assist in enabling suitable and timely regulation.

Zero emissions vehicle technology and governance

Zero emissions vehicle technology is currently uncertain, however zero emissions vehicles will impact current governance structures. ClimateWorks Australia (2017) contends that Australia lacks a comprehensive framework for the introduction of electric vehicles, with the Australian Government currently providing some enticements and variation between the incentives offered by the state governments. International Council on Clean Transportation (2017c) argues that all cities that have had significant success in introducing electric vehicles have been supported by major national level policies. It is highlighted that the success of each region in introducing electric vehicles will be constrained or supported by policies from other levels of government, with

Australian, Victorian and local government policies all influential in affecting electric vehicle adoption (International Council on Clean Transportation 2017c). This supports the contention of ClimateWorks Australia (2017) that one comprehensive policy across government levels is crucial. Further, if zero emissions vehicles technologies mean that tax is no longer collected from fuel, a key issue is the future funding models and structures (Bloomberg Aspen Initiative on Cities and Autonomous Vehicles 2017). The Bloomberg Aspen Initiative on Cities and Autonomous Vehicles (2017) identifies that a congestion tax is a likely response, but questions which level of government will collect these funds and their ability to return the tax to where it was collected from. In a further analysis of the role of government, Dowling and Kent (2013) argue that government is reliant on partnerships with private actors to achieve their goals in electric vehicle policies.

Market models and governance

Future ownership and market models of automated and zero emissions vehicles are currently uncertain, however they present implications for governance. KPMG (2017c) has analysed different MaaS offerings based on government intervention and coordination. It is contended there are open MaaS markets, light MaaS regulation markets and full MaaS regulation markets (KPMG 2017c). Open MaaS markets have minimal regulation with users taking direct responsibility for their mobility, reducing reliance on public transport (KPMG 2017c). Light MaaS regulation markets involve government intervention and planning in the transport eco-system, such as requirements for visibility and transparency of MaaS systems, although the systems may still be operated by private sector organisations (KPMG 2017c). A full MaaS regulation market represents a situation where the government operates the MaaS system itself, with private sector operators potentially governed by this scheme, or operating their own systems with pricing and service provision highly regulated (KPMG 2017c). KPMG (2017c) argues that different levels of government intervention are appropriate under different circumstances, with locations where there are many transport players and elevated congestion and pollution risks requiring higher levels of intervention.

Regulation and governance

The uncertainties of regulation for the introduction of automated and zero emissions vehicles will have implications for governance. In Victoria, the Australian and Victorian governments currently share regulatory responsibility for vehicles (Austroads 2017b). Infrastructure Partnerships Australia (2017) and Austroads (2017b) identify the Australian Government has responsibility up to the point of first supply and has obligations to numerous international regulations, however does not have jurisdiction over road rules which differ across the states. Austroads (2017b) highlights that automated vehicles will, therefore, need to follow local road rules. National Transport Commission (2017a) advocates for a safety assurance system that can enable government oversight of how automated driving system entities manage automated vehicle safety. National Transport Commission (2017a) argues this system should be administered by one federal body, with responsibility also for vehicles which may progressively increase their automation functionality after initial use. This would be a shift from the current arrangement, where the states have responsibility following first supply (National Transport Commission 2017a). Following this recommendation, the National Transport Commission (2018) has proposed several options for this safety assurance system, with their preferred option consisting of a safety assurance system with a dedicated national agency for automated vehicle safety, with specific offences and compliance and enforcement tools, as well as a general duty on automated driving system entities to ensure safety. KPMG (2017d) also highlights the importance for strong governance structures within private sector automated vehicle actors. It is discussed that the increased regulatory focus on automated vehicles means it is crucial vehicle manufactures build trust through strong data, software, hardware, security, integration, and compliance governance (KPMG 2017d).

Areas for further research

The review of this literature has formed the foundation of our understanding on the governance implications of automated and zero emissions vehicles, however it has also identified gaps where further research is needed. The role for the Victorian Government in the introduction of automated and zero emissions vehicles requires further investigation, including the most appropriate level of cooperation and responsibility sharing between different levels and entities of government and private organisations. Specifically, issues of road rule standardisation, transport governance structures which may affect integrated planning and payment options and the required future interaction between Victorian, Australian and local government and private sector organisations requires further analysis and research.

7. Energy systems and the environment

Automated vehicle technology and energy systems and the environment

Miller and Heard (2016), Jun and Markel (2014) and Milakis, van Arem and van Wee (2017) contend that automated vehicles are likely to drive more efficiently than human drivers through improved communication and driving behaviour, consequently reducing fuel use. Conversely, Miller and Heard (2016) argue that automated vehicle user behaviour will significantly impact emission outcomes, as vehicle kilometres travelled may increase. Brown, Gonder and Repac (2014) support this, stating that vehicle fuel efficiency is likely to have a significant impact on emissions outcomes, with automated vehicles predicted to more than double present vehicle energy use if demand and speeds rise without increased efficiency. However, fuel use could be reduced substantially through achieving maximum efficiency gains, such as vehicle electrification, even with an increase in demand and vehicle speed (Brown, Gonder & Repac 2014).

Zero emissions vehicle technology and energy systems and the environment

Electric vehicle charging technology is currently categorised as level one to three, with level one analogous to a standard home outlet, level two requiring a separate connection and equipment that is typically installed in a garage or public charge point, and level three being a fast, high power charger (Potter 2017). Rushlow et al. (2015), McLaren et al. (2016), International Council on Clean Transportation (2017b) and Ustun et al. (2013) state that level one charging is insufficient to meet the needs of high use electric vehicles. However, Ustun et al. (2013) highlight that level one charging is the only level that will not require an upgrade of existing electrical infrastructure, illustrating a potential need for infrastructure upgrade if high electric vehicle use is desired.

An analysis of charging behaviour by Morrissey, Weldon and O'Mahony (2016) in Ireland found that electric vehicle owners consistently plug their vehicles in to charge when they arrive home from work. Consequently, significant numbers of vehicles may be charging during the evening peak of electricity use, which Azadfar et al. (2015) contends may have implications for the reliability of the grid (Morrissey, Weldon & O'Mahony 2016). This is supported by Lemoine, Kammen and Farrell (2008) and Ma, Callaway and Hiskens (2013) who contend that an increase in demand during the evening peak may create a need for additional electricity generation capacity. The Commonwealth Scientific and Industrial Research Organisation (2012) and Azadfar et al. (2015) state that this increase in peak time demand could be reduced through the introduction of incentives for off-peak charging. This is contested by Ma, Callaway and Hiskens (2013) who argue that time-based and fixed-schedule pricing strategies may have trouble shifting demand into the night-time period of low electricity use. Alternatively, Ustun et al. (2015) note that vehicles plugged in during the evening peak could be used to discharge and provide energy to the grid, thus lessening the evening peak, although this would require the presence of V2G technology.

Ustun et al. (2013), Andersen, Mathews, and Rask (2009), Jian et al. (2013) and the International Council on Clean Transportation (2017f) contend that V2G technologies permit battery aggregation, which allows batteries to act as distributed storage devices, thereby creating capability for distributed controlled load, frequency and voltage control services. Conversely, Azadfar et al. (2015) found that technical restrictions on load levelling the grid mean V2G proposals require careful assessment, while Speidel and Bräunl (2014) contend that V2G technologies are not viable due to high infrastructure costs, and additional wear and tear of the vehicle battery through the added recharge and discharge cycles. The impact on energy capacity has been further analysed, however there is divergence in the estimations on the impact of zero emissions vehicles on Australian generation needs, with Ustun et al. (2013) estimating energy demand would increase by less than 0.1% of 2011-2012 demand, while Maniatopoulos, Andrews and Shabani (2015) have argued that a 57% increase in generation would be required. Timelines, exclusion or inclusion of freight trips and type of vehicles were key differences between the variables in the research by Ustun et al. (2013) and Maniatopoulos, Andrews and Shabani (2015), with longer timelines, inclusion of freight and complete transport shift to battery electric and hydrogen fuel cell electric vehicles included in the research by Maniatopoulos, Andrews and Shabani (2015) where the greatest increase in generation need was observed. While transmission networks are expected to be minimally impacted by the uptake of zero emissions vehicles, Ustun et al. (2013), Azadfar et al. (2015), the Commonwealth Scientific and Industrial Research Organisation (2012), Wagner and Reedman (2010) and the International Council on Clean Transportation (2017f) highlight the issues present for distribution networks, and illustrate that mass uptake of electric vehicles will require changes to distribution networks and may require management, protection and possible mitigation strategies.

The energy implications are closely tied to the environmental impacts of zero emissions vehicles. The Victorian Government (2012) states that electric vehicle disposal is predicted to have minimal environmental implications, with the source of energy, efficiency of energy conversion and vehicle use expected to have the most significant environmental effects. Andersen, Mathews and Rask (2009), McLaren et al. (2016), Robinson et al. (2014) and the Union of Concerned Scientists (2012) argue that the mass penetration of electric vehicles will provide a net reduction in emissions, including a reduction in particulate matter. However, Mills and MacGill (2017) and Wagner and Reedman (2010) contend that emissions from electric vehicles increase when they are charged overnight due to high coal and emissions intensity in the overnight National Electricity Market mix. Mills and MacGill (2017) further argue that without a cleaner generation mix the greenhouse gas benefits of electric vehicles are unlikely to exceed those of a hybrid vehicle. This finding is supported by ABMARC (2016), which highlights how in Victoria, which has a significant reliance on coal for electricity generation, electric vehicles charged from the grid can produce higher CO2 emissions than internal combustion engine vehicles. Aside from battery electric vehicles, Balta-Ozkan and Baldwin (2013) contend that a 75% reduction in emissions could be achieved in the UK through a 70% uptake of hydrogen technology in the fleet. However, McKay (2009) argues that hydrogen is unsuitable as a sustainable technology for the UK due to inefficiencies and practical challenges of converting energy to, and from, hydrogen. Hydrogen is capable of aiding with the temporal challenges of renewable energy with power-to-gas technologies, however, the International Council on Clean Transportation (2017f) states that most fuel hydrogen is currently generated from fossil fuels, further illustrating the importance of renewable sources of energy.

Market models and energy systems and the environment

Fagnant and Kockelman (2014) highlight through modelling in a simulated city that a shared market model of automated vehicles could produce a significant reduction in vehicle numbers, with one vehicle able to replace approximately ten conventional vehicles. Bischoff and Maciejewski (2016) also state that Berlin's 1.1 million cars could be replaced by 90,000-110,000 automated vehicles at a similar ratio of approximately one automated to ten conventional vehicles. While it is contended that the shared market model would increase vehicle kilometres travelled, the overall emissions impact would be reduced due to the decrease in vehicle numbers (Bischoff & Maciejewski 2016; Fagnant & Kockelman 2014). Greenblatt and Saxena (2015) state that even with an increase in vehicle kilometres travelled, automated shared vehicles are expected to reduce emissions, especially if lower emission vehicle types are adopted. Further, Fagnant and Kockelman (2014) argue that the increased frequency of vehicle turnover under a shared market model is likely to increase new vehicles with more fuel efficient technologies, as older vehicles are replaced more frequently.

Regulation and energy systems and the environment

The Institute for Sustainable Futures (2011) advocates for a policy connection between renewable energy targets and electric vehicles, to ensure that any increase in energy demand from electric vehicles is sourced from low carbon energy. It is argued that the renewable energy targets could be adjusted annually from anticipated electric vehicle energy consumption, rather than the current target system which is fixed to 2020 (Institute for Sustainable Futures 2011). The Institute for Sustainable Futures (2011) contends that this change is of particular importance for Victoria, due to the current carbon intensive electricity generation system.

Areas for further research

The three main gaps which have been identified in the literature relate to charging patterns and methods, the impact to the capacity of the energy system particularly within the Victorian context and the influence of automated and zero emissions vehicles on emissions and environmental outcomes. Further research is necessary on potential Victorian electric vehicle charging patterns, including an understanding of preferences and techniques to adjust behaviour. There is also a significant gap in evidence on the impact that the uptake of zero emissions vehicles would have on the energy grid, at the generation, network, distribution and transmission levels, including the consequences of different ownership and market model scenarios. While some research has investigated the impact of zero emissions vehicles on environmental outcomes, minimal research has been done on this within the Victorian context on hydrogen, with further analysis needed on the different forms and requirements of hydrogen fuel generation. Environmental effects of electric vehicles should also be investigated, particularly with a view to understanding the levels of renewable energy needed to create truly zero emissions vehicles. Further evidence should also be gathered within the Victorian context to confirm the well-to-wheel impacts of zero emissions vehicles, and how automation may affect environmental impact findings.

8. Human behaviour

Automated vehicle technology and human behaviour

Choi and Ji (2015), Lee et al. (2015) and Howard and Dai (2013) discuss the human factors that are likely to influence uptake of automated vehicles. Choi and Ji (2015) and Lee et al. (2015) highlight that the vehicles user's subjective perspective of usefulness, trust and self-evaluation of hands-on experience may impact their intention to use automated vehicles. Howard and Dai (2013) note that safety benefits, parking convenience and multitasking abilities are viewed as attractive features of automated vehicles. Howard and Dai (2013) also note that there are concerns about automated vehicles regarding liability, cost and loss of vehicle control. Abraham et al. (2016) contend that this concern regarding loss of vehicle control is strong among older adults, who are comfortable with innovations to assist drivers, but not with relinquishing control. Bloom et al. (2017) has identified that use of data from automated vehicles for purposes such as tracking and identification caused study participants a significant amount of discomfort, while uses such as continuous data gathering for navigation analysis created more moderate concern. Bloom et al. (2017) found that the more likely a participant believed a data gathering situation to be, the more comfortable they were with it. Further, Nees (2016) contends that if expectations of the level of automation in vehicles are unrealistic, trust and acceptance in the vehicles will be damaged.

Zero emissions vehicle technology and human behaviour

Greaves, Backman and Ellison (2014) and Cocron et al. (2011) have identified that electric vehicles with short battery ranges are appropriate for the majority of metropolitan trips, as most trips are short, with considerable time parked between trips. Further, Cocron et al. (2011) highlighted that range anxiety was reduced with experience. Bockarjova and Steg (2014) contend that the environmental advantages of electric vehicles, and the negative effects of traditional vehicles should be emphasised to increase public acceptance. This is supported by Moons and Pelsmacker (2012) who contend that those who are environmentally concerned or active are likely to adopt electric vehicles when they become widely available. However, Heffner, Kurani and Turrentine (2007) identify that while hybrid electric vehicles originally symbolised a tool for environmental benefits for liberal environmentalists, there are now a diversity of connotations attached to hybrid vehicles including economy, technological progress and energy independence.

Skippon and Garwood (2011) and Wesche, Plötz and Dütschke (2016) contend that low personal connection with traditional vehicles is a factor that raises interest in electric vehicles, although the papers disagree on whether higher wealth is likely to increase or decrease the likelihood of electric vehicle uptake. Kim, Rasouli and Timmermans (2014), Moons and Pelsmacker (2012) and the Institute for Sustainable Futures (2011) highlight the importance of cultural attitudes in the adoption of electric vehicles, with Kim, Rasouli and Timmermans (2014) stating that the opinions within social networks can increase or decrease the desirability of electric vehicles. Bockarjova and Steg (2014) argue that collective customs must change to influence individual behaviour change, with a shift that sees electric vehicle uptake as part of an integrated effort towards a more sustainable society. Further, the International Council on Clean Transportation (2017b) and ClimateWorks Australia (2016) highlight the opportunities of government education and awareness campaigns for increasing electric vehicle uptake. The Institute for Sustainable Futures (2011) contends that while people may hold environmental concerns this does not necessarily equal a shift in individual behaviour, as social conventions lock in existing technologies and lock out new technologies.

This lock out is compounded by the high cost of electric vehicles, and the considerable shift from established routines and behaviours required to undertake the shift (Institute for Sustainable Futures 2011). Graham-Rowe et al. (2012) in the UK and Delang and Cheng (2012) in Hong Kong identify further barriers to electric vehicle uptake; concerns about infrastructure and technology obsolescence, the impact of battery waste, and emissions caused by fossil fuel energy production.

These barriers are slightly varied from the barriers for hydrogen fuel cell vehicle uptake, which are the lack of hydrogen infrastructure, the source of hydrogen, the inability of fuel cell vehicles to be recharged from home, cost issues and concerns about hydrogen safety (Hardman et al. 2017). Further, Schulte, Hart and van der Vorst (2004) highlight that a focus on the environmental benefits of hydrogen vehicles may connect them to the connotations of lower performance and range associated with electric vehicles, and instead the capabilities of the vehicles should be emphasised. Further, hands-on experience is expected to be highly important in increasing public acceptance, as people will understand the benefits for their own lives (Schulte, Hart & van der Vorst 2004). Contrary to negative safety perceptions raised by Hardman et al. (2017), Iribarren et al. (2016) conducted a Spanish study which found people were broadly accepting of hydrogen within the energy and transport sectors.

Market models and human behaviour

The market models of automated and zero emissions vehicles are currently uncertain, with implications expected to influence, and result from, human behaviour. Haboucha, Ishaq and Shiftan (2017) have highlighted that if a service were to offer free shared automated vehicles, only 75% of surveyed individuals would use them. Variations were also found between countries studied, with study participants in Israel more likely to adopt shared automated vehicles than participants from the US, suggesting cultural behaviour may also have an influence. Abraham et al. (2016) have identified that while many older people are open to the idea of using emerging transport alternatives to private car ownership, very few are making the change, potentially due to technological barriers to access.

Regulation and human behaviour

National Transport Commission (2017b) contends that governments must understand customer behaviour and adjust to better predict and prepare for changes that may occur. National Transport Commission (2017b) states this can be done through focusing on real changes in choice by consumers and business offerings. The Institute for Sustainable Futures (2011) suggests that if cultural shifts and choices are not delivering desired outcomes for electric vehicle uptake, governments should set targets, to create a behaviour shift.

Areas for further research

As the literature has illustrated there is significant research on the human behaviour implications for the introduction of zero emissions vehicles. However, within the Victorian context there is a gap in the evidence on Victorians' perspectives and expected responses to the introduction of automated vehicles, particularly with regard to car and ride sharing and any projected changes to the perceived value of travel time.

9. Social inclusion and equity

Automated vehicle technology and social inclusion and equity

Das et al. (2017) identify that retirees over 75 years old spend 50 minutes less outside of the home each day than younger retirees, with time spent travelling, shopping and socialising the most reduced. Das et al. (2017) notes that this may suggest that automated vehicles could increase shopping and socialising activity among retirees aged 75 years and over. Griffith Law Reform Research Team (2017) contends that elderly Australians can experience anxiety, depression and decreased quality of life from surrendering their licences, with automated vehicles potentially offering independence to homebound elderly people. Concerns regarding the acceptance and uptake of automated vehicles by elderly Australians was raised in the House of Representatives Standing Committee on Industry, Innovation, Science and Resources (2017) submissions.

However, the Australia and New Zealand Driverless Vehicle Initiative (2017) contends that when compared to other demographic groups, older people are more positive and trusting of automated vehicles, and have higher acceptance and willingness to pay, although they also have higher concerns regarding safety and privacy and lower awareness. A UK study by the Society of Motor Manufacturers and Traders Limited (2017) states that disabled people, the old and the young are the most mobility restricted. The Society of Motor Manufacturers and Traders Limited (2017) indicate that the biggest barrier of public transport for young people is cost, for the elderly it is flexibility, and for people with a disability it is reliability. Griffith Law Reform Research Team (2017) argue that public transport is often unequipped or may be too far away to service people with disabilities. Further, while people with disabilities may be unable to drive or face high costs due to required vehicle modifications, transport provision is crucial as it allows people to access medical treatment, employment and provides a sense of freedom and independence (Griffith Law Reform Research Team 2017).

The House of Representatives Standing Committee on Industry, Innovation, Science and Resources (2017) found that automated vehicles are expected to bring many benefits to people in regional and rural who are elderly, disabled and sick, however it was highlighted that infrastructure and costs needs may mean automated vehicles are unsuitable for these areas. This is supported by Australia and New Zealand Driverless Vehicle Initiative (2017) who contend that the uptake of automated vehicles in rural areas may be unpredictably different to uptake in other areas, due to the isolation and lack of supporting infrastructure in these areas. The KiM Netherlands Institute for Transport Policy Analysis (2015) highlights that under certain uptake scenarios affordability of automated vehicles may create concerns for social inclusion and equity, and questions whether there are steps that the government can take to reduce costs as a barrier. Griffith Law Reform Research Team (2017) contends that if costs remain high, any pressure for uptake of vehicles would place an economic burden on people, particularly those who have existing economic pressures, such as the disabled or elderly.

Zero emissions vehicle technology and social inclusion and equity

Newman et al. (2014) contend that the lack of quality public transport and car dependency in rural areas means that they may be ideal areas for the introduction of electric vehicles, as they will offer a viable sustainable transport option. However, Newman et al. (2014) note that the current high upfront costs of electric vehicles may be prohibitive for many people who live in rural areas. While Newman et al. (2014) conducted this research within the UK context, similar concerns regarding the ability of lower income groups to access electric vehicles have been raised by ClimateWorks Australia (2017), the Royal Automobile Club Foundation for Motoring (2011), Wells (2012) and Harrison and Shepherd (2014). Wells (2012) and Harrison and Shepherd (2014) have criticised the inequity of current electric vehicle costs and policies. It is argued that the high upfront cost of electric vehicles, as well as the barrier for renters, particularly in multi-unit buildings, to install chargers, means that low income people are unable to obtain the benefits of lower running costs, as well as any potential subsidies, preferential access or tax breaks (Wells 2012; Harrison and Shepherd 2014). DeLuchi (1989) examined the cost of hydrogen vehicles and contends that in all scenarios examined, hydrogen vehicles were not cost-effective vehicle options, although significant uncertainty within the assumptions was noted.

Market models and social inclusion and equity

The Royal Automobile Club Foundation for Motoring (2011), the Technology Law and Policy Clinic (2013) and the International Transport Forum (2017) argue that shared mobility market models under most circumstances will produce lower cost mobility options, increasing mobility for those who are unable to drive and unable to afford other mobility options. The Royal Automobile Club Foundation for Motoring (2011) contend that the large upfront costs which are associated with private vehicle ownership exclude people who are unable to afford these costs, with hired automated vehicles offering a lower cost option. Similarly, the International Transport Forum (2017) conducted a study in Europe and found that shared, automated taxi-buses could be offered at a lower price than public transport if public subsidies were removed, and shared automated taxis could be operated at approximately one-third of the current price of a taxi. The reduction in cost that could be gained from switching from private vehicles to shared taxis was influenced by the efficiency of the vehicle and the amount of kilometres driven each day (International Transport Forum 2017).

Arcadis, HR&A Advisors and Sam Schwartz (2017), Grush and Niles (2017) and Shaheen, Cohen and Martin (2017) have highlighted the importance of ensuring that technology for new shared automated systems does not act as an exclusionary measure to those who may not have the skills or income to utilise the data reliant smartphone apps that current shared transport networks rely on. Shaheen, Cohen and Martin (2017) outline several measures such as pay-as-you-go smart cards, dial-a-ride services and regulation and incentives to create more equitable access and uptake. As well as potential cost barriers to technology access, Shaheen, Cohen and Martin (2017) argue that availability and speeds of data in rural locations may also limit access. Further, the International Transport Forum (2017) found that the type of vehicle and distance travelled influenced the cost savings of shared taxis, with higher distances travelled resulting in high viability for private ownership, highlighting the difference in suitability between urban and rural areas for shared mobility from an equity standpoint.

Regulation and social inclusion and equity

Diamond (2009) and Wells (2012) argue that any government regulation or financial incentives which aim to encourage zero emissions vehicle uptake reinforce privilege, as the high upfront costs inhibit low income buyers from purchasing vehicles. Diamond (2009) contends that monetary incentives provide financial support for those who need it the least, and Wells (2012) highlights that any incentives, such as tax breaks and preferential parking or road use laws, for zero emissions vehicles penalise those who were unable to afford one of these vehicles. The National Transport Commission (2017c) has also raised a regulatory issue of social inclusion, as a person would be excluded from current driving restrictions such as drug and alcohol use or fatigue if the vehicle was highly automated, however any vehicle which allows, or requires, people to take over the driving task would not be exempt and they could be penalised if they choose, or were required, to take over driving tasks.

Areas for further research

The review has highlighted that there is a research gap within the Victorian context on the role of automated vehicles in increasing social inclusion through expanding accessibility, with further investigation required to understand impacts on mobility impaired, young, old and low income people. With regards to mobility impaired people, further research is also required to understand any specific needs and impacts that should be understood to ensure accessibility is increased. Further analysis is needed to understand the ideal role for government, specifically with regards to the costs and benefits of subsidising or mandating specific charging, vehicles or standards.

10. Employment and economic outcomes

Automated vehicle technology and employment and economic outcomes

The Australian Driverless Vehicle Initiative (2016), Clements and Kockelman (2017) and Karpilow and Winston (2016) argue that automated vehicles can provide economic benefits to a country. The Australian Driverless Vehicle Initiative (2016) argues that the government will gain economic benefits through the introduction of automated vehicles as road safety will increase, pollution and noise will decrease, congestion may be reduced, public transport can be lower cost and more connected, transport can be better priced and more efficient, and vehicle ownership may decrease. The Australian Driverless Vehicle Initiative (2016) contends that the private sector will also receive economic benefits through increases in time saving, productivity and personal safety, ability to reduce travel time or increase productivity during travelling, and increased accessibility for those unable to currently drive. The Australian Driverless Vehicle Initiative (2016) highlights that while the direct economic impacts will depend on future supply chain and infrastructure requirements, there may be indirect impacts on vehicle numbers, legislation and regulation, the need for new systems, impacts on active and public transport, benefits for the environment and health and the potential for increased land efficiency.

Further, MRCagney (2017) illustrates that the government could gain savings through automation of the public transport system, which could allow for increased service delivery at a lower cost. KPMG (2017b) contends that government investment is key in influencing investment in new technologies and supply chains to support the introduction of automated vehicles and achieve the potential benefits. However, contrary to the research by Australian Driverless Vehicle Initiative (2016) that travel time in automated vehicles may be used more productively, Cyganski, Fraedrich and Lenz (2014) contend that only a minority of study participants in Germany confirmed this as an intention, with most participants expecting to continue activities they undertake in traditional cars. Further, the Office of the Chief Economist (2017) in the US and Frey and Osborne (2017) state that automated vehicles may eliminate some occupations, with the Office of the Chief Economist (2017) highlighting that this will particularly affect jobs where driving constitutes the main feature of the role, as they will have few transferable skills. Clements and Kockelman (2017) contend that while some individual businesses may suffer if they do not adapt, overall the economic effects will be savings for society.

Zero emissions vehicle technology and employment and economic outcomes

The Electric Vehicle Council et al. (2018) contend that economic savings and better economic conditions can be achieved through the introduction of electric vehicles to Australia. This is supported by Chatzikomis, Spentzas and Mamalis (2014) who state that Greece would achieve economic benefits through the introduction of electric and hybrid vehicles to their fleet. The Electric Vehicle Council et al. (2018) highlight that numerous economic benefits can be gained from the introduction of electric vehicles, including new industries, a boost for GDP through construction investment, lower cost of meeting Australia's emissions obligations thus lowering cost of production and increasing spending and employment. Further, the lower ongoing costs associated with electric vehicles allow production and consumption in other areas of the economy (Electric Vehicle Council et al. 2018).

The Electric Vehicle Council et al. (2018) also contend that reduced reliance on imported fuel will improve the terms of trade for Australian businesses and benefit consumers. In New Zealand, Leaver and Gillingham (2010) found that battery electric and fuel cell vehicles would increase electricity prices, and highlighted that government priorities and consumer preferences will influence future fuel choice outcomes. However, Beer et al. (2012) state that plug-in electric vehicles can create high monetary value through a secondary application to extend their lifecycle as distributed stationary energy storage. The Electric Vehicle Council et al. (2018) contend that although some roles may be lost due to productivity gains in transport and lowered fuel demand, it is expected employment will increase in other sectors, and lowered costs through increased efficiency for businesses will result in expansion and increased employment. This illustrates the possibilities and expectations in the literature for the uncertainty of zero emissions vehicle technology.

Market models and employment and economic outcomes

Strategy Analytics (2017) contends that vehicle automation will cause a shift from private vehicle ownership to a new type of service offering with a focus on car sharing services. MRCagney (2017) argues that this will lower costs of mobility for those who drive infrequently, as the fixed costs of vehicle ownership will be shared. However, Ostrovsky and Schwarz (2018) state that the number of riders within the car has the highest impact on cost, with an increase in passengers producing a significant decrease through cost sharing. Ostrovsky and Schwarz (2018) highlights that further to this benefit, there are also expected benefits from the reduction in congestion that ride sharing would create.

Deloitte Access Economics (2016) examined the possible impacts of ride sharing in Greater Adelaide and found in a cost-benefit analysis that the costs would be approximately $1.1 million and the benefits would total around $3.4 million. The benefits were mainly achieved through a reduction in congestion, road maintenance and carbon emissions (Deloitte Access Economics 2016). Wadud (2017) highlights that mobility service providers will gain the greatest economic benefits from automated technology, with private vehicles gaining a smaller benefit. However, Wadud (2017) also notes that the shift of commercial vehicles, such as mobility providers, to automated technology may face opposition, due to the significant job losses which may arise from this change.

Regulation and employment and economic outcomes

Fishman and Davies (2016) recommend a change to the current transport pricing system, by replacing vehicle registration fees and the fuel excise with a road user charge. It is argued that this may assist in management of the transport network, and provide a new source of revenue for funding sustainable transport options, as the fuel excise revenue will be lost due to the shift to electric vehicles (Fishman & Davies 2016). However, Clark, Parkhurst and Ricci (2016) contend that governments have focused on benefits that may come from manufacturing, arguing that they have been reluctant to intervene in creating specific outcomes for automated vehicles.

Areas for further research

While some research has addressed the economic and employment effects of the introduction of automated and zero emissions vehicles, the economic impact on vehicle consumers and the impact on jobs in Victoria requires further investigation. There is also a need for analysis on the impact of, and for, government, with an increased understanding needed of the influence and economic tools government can use to shape outcomes. The financial impacts to all levels of government caused by the introduction of automated and zero emissions vehicles should also be investigated.

Assumptions

All literature reviewed on the implications of automated and zero emissions vehicles contained some level of assumptions. A full report on every assumption within each item of the literature will not be presented, however some of the key themes are examined.

Assumptions regarding the relationship between automated and zero emissions vehicles have recurred through the literature, with some literature assuming that automated and zero emissions vehicle technology will inevitably develop simultaneously. Conversely, many pieces of literature on zero emissions vehicles have ignored the impact of automated vehicle technology, partially in regards to the implications of a potential change in ownership models. Similarly, the literature on automated vehicles often assumes that current fuels are in use, with little acknowledgment of the implications zero emissions fuels may have on fleet size and vehicle use.

There is also a common assumption across some of the literature that current trends and patterns are appropriate indicators of future outcomes, which does not account for revolutions or disruptions to current practices.

Numerous demographic assumptions and extrapolations have occurred across the literature, as suppositions have often been made about human behaviour at a population level, which has not accounted for nuances and divergences in behaviour across demographic groups. These assumptions regarding population heterogeneity have also been used to make assumptions regarding socioeconomic uniformity and have not accounted for how implications of automated and zero emissions vehicles may be influenced by socioeconomic inequality. Similarly, increasing mobility choices has been assumed to increase activity among elderly people and reduce active transport, however these assumptions have not accounted for factors such as health concerns, values, lifestyle changes and patterns which may also influence travel choices.

Across the literature on automated vehicles there has been the significant and common assumption that automated vehicles will inevitably create positive outcomes. There are assumptions that automated vehicles will make driving safer, the price of use will be low enough to be accessible to all, that mobility will be increased for disabled and elderly people and that there will be broad economic benefits from the introduction of automated vehicles. These assumptions have not accounted for the unknown outcomes of technological development, potential monopolies in the market, a lack of disability access compliant vehicles and infrastructure, or the uncertain consequences for and role of Victoria in the economic development of automated vehicles.

Conclusion

The literature on the uncertainties of automated and zero emissions vehicle technology, market and ownership models and regulation have provided a foundation for understanding the implications for land use planning, safety and ethics, physical infrastructure, digital infrastructure, health and active transport, governance, energy systems and the environment, human behaviour, social inclusion and equity and economic and employment outcomes.

There is significant debate over many aspects of the predicted implications, and many assumptions have been made throughout the literature. This has highlighted gaps where further research and analysis is needed in order to provide advice on infrastructure to enable automated and zero emissions vehicles in Victoria.

Infrastructure Victoria has commissioned technical studies to resolve many, although not all, of the gaps in the evidence identified within this report, particularly areas where further information was needed to understand the implications within the Victorian context. These technical reports and our report discussing this evidence base have been published concurrent with this review in August 2018.

NEXT STEPS

In October 2018, we will present our final advice to the Victorian Special Minister of State.

Our findings and recommendations will in turn influence the next update of Victoria's 30-year infrastructure strategy in 2019.

HOW TO GET INVOLVED?

Infrastructure Victoria invites any stakeholders with an interest or expertise in automated and zero emissions vehicles to provide input to the development of the advice. Visit our consultation website or contact us for further information.

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