Road to autonomous vehicles in Australia: an exploratory literature review

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Abstract

Autonomous vehicle technology and its potential effects on traffic and daily activities is a popular topic in the media and in the research community. It is anticipated that AVs will reduce accidents, improve congestion, increase the utility of time spent travelling and reduce social exclusion. However, knowledge about the way in which AVs will function in a transport system is still modest and a recent international study showed a lower familiarity with AVs in Australia compared to the USA and UK. Attitudes towards fully automated driving (or higher levels of autonomy) range from 'excitement' to 'suspicion'. The breadth of feelings may be due to the low level of awareness or reflect polarising attitudinal positions. Whilst experts appear to be more confident about the adoption of AV technology in the near future, public acceptance is key to AVs' market success. Hence, research that examines local contexts and opinions is needed.

This paper reviews existing scholarly work and identifies gaps and directions for future developments, with a focus on the Australian context. The review will address the following broad categories: investigation of AV features and mobility models, implications for road traffic and connectivity to infrastructure (especially in low to medium density urban areas), public attitudes and concerns, travel behaviour and demand, potential business models, and policy implications. The aims of the paper are to identify critical issues for the development of a focus group inquiry to understand attitudes of potential users of AVs and to highlight AV development issues for policy makers in Australia.

Peer reviewed paper

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1. INTRODUCTION

Autonomous vehicles (AVs) have been the subject of wide-spread attention over the last few years featuring in government reports, research studies, media articles, blogs, novels and even movies.

AVs have captured the imagination and interest of stakeholders through their potential implications for transforming personal mobility and society as a whole (Schoettle & Sivak 2014a,b; Howard & Dai 2014: Kyriakidis, Happee & de Winter 2015; Madigan et al. 2016). In a recently released Smart Cities Plan, the Australian Government (2016) advocates a 'technology first' approach to solve our planning challenges. It lists AVs as a transformational technology that will have fundamental impacts on our cities. Although few will argue against this, there are still many unknowns associated with AVs, from both social and technical aspects. For example, attitudes towards fully automated driving (or higher levels of autonomy) range from 'excitement' to 'suspicion' (Bazilinskyy, Kyriakidis & de Winter 2015; Kyriakidis et al. 2015). Some anticipate that AVs will reduce accidents, improve congestion, increase the utility of time spent travelling and reduce social exclusion, while others remain unconvinced. This is partly due to our limited understanding about the way in which AVs will function in an already complex transport system.

The uncertainty and divided opinions around AVs, together with general inertia in transport systems, suggests that significant time will be required before we see AVs running down city streets on a large-scale. For instance, in a recent study of 109 countries and 5000 participants, Kyriakidis et al. (2015) found that almost one-third of participants do not believe that fully automated AVs will reach 50% market share before 2050. Compounding this, Australia is a relative laggard in the AV space, with a handful of trials (discussed later in the paper) but as yet no firm direction from the federal level. Interestingly, a recent study suggests Australian respondents had the highest general positive opinion compared to those from the U.S. and UK (Schoettle & Sivak 2014a).

Given this context, this paper reviews recent experiences of AVs and speculates on what the future might hold for Australia. While there are a myriad of levels of automation, for this review we focus primarily on full-time automatic driving with no requirement for human intervention. Section 2 provides some historical milestones in the evolution of AVs, Section 3 presents the impact of AVs on traffic, followed by public acceptance and likely demand changes (Section 4). Potential business models are included in Section 5 with policy impacts covered in Section 6. Finally, we present an overview of current trials in Australia before drawing some concluding thoughts.

2. EVOLUTION OF AVs

While the terms *autonomous* and *automated* are closely related, they have been loosely used. The US National Highway Traffic Safety Administration (NHTSA) defines automated vehicles as those capable of actuating at least some mission-critical controls with no human intervention (NHTSA 2013), most of which are related to longitudinal and lateral movement of the vehicle (Le Vine, Zolfaghari & Polak 2015). NHTSA classifies five levels of automation (levels 0–4), ranging from no automation to full automation. By comparison, the Australian National Transport Commission (NTC 2016a) adopts Society of Automotive Engineers International Standard J3016 (SAE 2014) that defines six levels of automated driving (levels 0–5). Most people's understanding of the term autonomous vehicle would probably refer to the highest level in both definitions, which means vehicles can make end-to-end trips independently. Nevertheless, there are also partial AVs, which can perform autonomous driving under certain circumstances.

Shladover (2009) argues that autonomy and automation are two different and orthogonal concepts. He defines autonomous as the opposite to cooperative so a vehicle could be fully automated but not cooperative, i.e. it purely works on local information gathered by its sensors, with no vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication. In fact, Shladover and others suggest that AVs are likely to produce limited or no benefits to traffic performance without being connected, an issue which impacts dialogue attesting to their individual and societal benefits. On the other hand, autonomous driving provides the technical basis for unleashing their full potential of vehicular communication in the form of autonomous interaction between vehicles (Dresner & Stone 2008).

3. IMPACT ON TRAFFIC SYSTEM PERFORMANCE

One of the most highly anticipated benefits of AVs is improved traffic system performance. The potential improvements are expected to be achieved through stabilised traffic flow, increased vehicle platooning, intersection capacity, and reduced accidents. Each of these elements is considered in the following subsections.

Stabilising traffic flow

Imperfect human driving behaviour (Orosz & Stépán 2006; Zhang & Orosz 2013) often causes instable traffic flow so there is anticipation that robotic driving systems will reduce congestion on freeways by stabilising traffic flows. Currently, there is insufficient evidence on how driverless vehicles will behave, plus there will be natural variations between different vehicle brands. Nonetheless, their likely effect on freeway traffic can be estimated by looking into the relatively large body of research on Adaptive Cruise Control (ACC) systems. These systems perform lower levels of automation under NHTSA and SAE's definition. They control the vehicle's longitudinal motion based on local information gathered from the vehicle's forward-looking sensor, which monitors the movement of the immediately preceding vehicle and try to achieve the desired speed when it is safe to do so (Arnaout & Arnaout 2014). One would expect AVs will have similar driving characteristics to vehicles with ACC under certain conditions, especially on freeways.

Unfortunately, there have been contradictory conclusions on whether ACCs can improve traffic flow in mixed traffic with human drivers (Arnaout & Arnaout 2014). Assuming they can, there has to be a minimal market penetration in order to achieve a notable improvement – the same argument holds true for realising safety benefits, which will be discussed later. The estimates vary markedly from 10% of the vehicles being AVs (Kesting et al. 2008) to 60% (Vander Werf et al. 2002).

The limitation of ACCs is their total reliance on their local sensory inputs information. It is difficult to detect the preceding vehicle's acceleration with very high accuracy and low latency so typically a minimal headway of one second or higher is assumed (Shladover 2009; van Nunen et al. 2012). While this offers an improvement on human gap acceptance of about 1.6 seconds (Shladover 2009), it is arguably not as low as people imagined. Horn (2013) has proposed a bilateral ACC, which not only looks forward but also backwards, and claims it can stabilise traffic flow at high density. However, it requires most cars to be equipped with this system.

Consequently, cooperative adaptive cruise control (CACC) has been proposed (e.g. Davis 2007; Arnaout & Arnaout 2014) to overcome the limitations of ACC by vehicular communication, maintaining so-called string stable platoons (Ge & Orosz 2014; Davis 2004), which is difficult for human drivers due to their slow reactions (Zhang & Orosz 2013). In addition to higher level of service, stable traffic flows also have the benefit of reduced energy consumption through less stop-and-start.

Platooning

Another much publicised advantage of automated driving is the ability to form platoons, especially on the freeways. The main advantages of platooning include higher vehicle density and the reduction of energy consumption because of reduced air drag (Shladover 2009), which is not possible for human drivers at a high speed because they need large headways. Empirical data from California show that at the speed of 100 km/h, human driven vehicles can only achieve about 11% of longitudinal length utilisation (Shladover 2009). Platooning is hoped to increase throughput through higher vehicle density. However, research again suggests that isolated AVs will not be able to perform this task effectively without V2V communication (Liang & Peng 2000; van Nunen et al. 2012). There are also concerns on how platoons interact with non-equipped vehicles and the potential negative impacts on ordinary drivers in a mixed traffic (e.g. Gouy et al. 2014).

Intersection capacity and comfort

Intersections present more challenges to AVs than freeways because of more conflicting movements (Li et al. 2013). Researchers have envisaged new ways of intersections controls incorporating AV technology, which would improve intersection capacity (e.g. Li et al. 2013; Tachet et al. 2016; Lu & Kim 2016; Dresner & Stone 2008; Guler, Menendez & Meier 2014). Some require radical departure from the conventional signal controls such as the slot-based system (Tachet et al. 2016) and dynamic lane reversal (Levin & Boyles 2016), for which full market penetration is required and customer acceptance would be a challenge; others are designed to work with a mixed flow of human driven vehicles and AVs (e.g. Guler 2014). Most of these systems require V2V/V2I communication. Florin & Olariu (2015) provide a recent review on how vehicular communications can be used for signal optimisation. Much of the current research focuses on analysing single intersections, which is the necessary first step, but it will be interesting to see how much improvement they can achieve in a network where interaction and coordination of the intersections would have an impact.

Infrastructure investment aside, V2V/V2I communication implementation would require a significant transition time. In the interim, how disconnected AVs (that purely reply on local sensors) would interact with the conventional signalised intersections' capacity is less clear. Le Vine et al. (2015) cast doubts on the potential impact of AVs at existing signalised intersections, if they are not integrated with V2V/V2I communication.

This could be also extrapolated at the link level and the road network. Le Vine et al. (2015) also concluded that if AVs are designed to prioritise passenger comfort, they might actually decrease intersection capacity and cause longer delays to vehicles (compared to the all human-driving base case).

The issue of passenger comfort of AVs has been mentioned by several authors. There are some possible technical solutions to the problem, such as tilting the vehicle to counter the longitudinal and lateral accelerations (Le Vine et al. 2015), but how much cost they would add is unknown, especially for large vehicles. In addition, the potential for AVs to enable more productive or enjoyable time use, raises questions around potential trade-offs between 'smoothness' of the ride and quicker reaction times.

Accidents

Clearly, reducing accidents will increase travel time reliability and reduce congestion (NHTSA 2013; Fagnant & Kockelman 2015). As pointed out by Fagnant and Kockelman (2015), while there is the potential for machine failures and hacking, AVs do not drink and drive, do not drive tired, get distracted, or use drugs, and do not speed or break laws. Given that the U.S. National Highway Traffic Safety Administration attributes the driver as the critical reason in 94% of the total crashes (Singh 2015), it is reasonable to assume AVs will be generally safer. However, the benefits would depend on the proportion of AVs in the traffic mix and the communication between vehicles and infrastructure (Petit & Shladover 2015), because while an AV can be programmed to be logical, conventional traffic cannot. On-road trials of AVs in mixed traffic in the U.S., attest to this issue with higher crash rates (on a per kilometre basis) reported for AVs, largely from being hit by human-operated conventional vehicles (Schoettle & Sivak 2015a). It is also worth noting, that at the time of this study, there were no instances of AVs being at fault in any of the reported crashes. However, on May 7th, 2016, the first fatality directly attributed to a system failure in an AV was reported although it must be stressed at the time of writing the exact cause of the accident is still under investigation.[1]

4. ISSUES, PERCEPTIONS AND ATTITUDES

Any study assessing the future of new technologies should evaluate the determinants of the adoption process. Given that consumer preferences, socio-economic factors and social interactions all influence the pathway and speed of adoption, we start by considering what some of the potential issues are with AV adoption before considering, more broadly, what has been reported to date around public perceptions and attitudes towards AVs.

Potential issues with AV adoption

AV uptake is a complex issue and a highly convenient mobility option comes with negative impacts as well, some of which are hard to anticipate at the moment, including: greater obesity, loss of competencies and skills (Bazilinskyy et al. 2015), and over reliance on machines (Trimble et al. 2014; Howard & Dai 2014). The range of individual concerns already expressed include: lack of trust in the capabilities of AV and their networking (Fraedrich & Lenz 2014); specific risks for crashes (Daziano, Sarrias & Leard 2016) that may be generated by non-AV traffic participants (Bazilinskyy et al. 2015), hacking of the systems (Fagnant & Kockelman 2015), data transfer to third parties, and deprivation from the joy of driving (Fagnant & Kockelman 2015; Kyriakidis et al. 2015).

Carlson et al. (2014) report that trust increases with the past performance of the system, with research on reliability or validation of the system, and through the reputation of the designer and manufacturer of the system; still, numerous trust issues remain unresolved and under review (Howard & Dai 2014; Kyriakidis et al. 2015). The classical dilemma of 'who is the AV saving?' in a crash produced by a fallen object or an inattentive cyclist on the road, suggests that the public is equally unlikely to leave this decision in the hands of a computer scientist incorporating rules of operation for AV or of a machine, learning from itself how to drive safely.

Trimble et al. (2014) argue that two of the three types of trust (overtrust and distrust as opposed to calibrated trust) may affect the uptake of AVs. Whereas calibrated trust (match of individual beliefs and system capabilities) supports appropriate application, overtrust can lead to misuse and distrust to disuse, which are equally damaging. Extended periods without performing driving may also lead to losing this skill, as memory fades and driving reactions may be less efficient. This is seen as problematic, especially if there is a need to override an AV. Related to this, AVs may erode the internal locus of control (Howard & Dai 2014), or the perceived possibility to control events. Schoettle & Sivak (2015b) showed that 96% of their sample expressed the desire that steering wheels, brake pedals, and some controls remain available in AV cars.

1 https://www.theguardian.com/technology/2016/jun/30/tesla-autopilot-death-self-driving-car-elon-musk

Many members of the community have raised issues of privacy, likely to increase once data sharing and V2V/V2I communication become mainstream operation. Using current examples of intelligence collected on purchasing preferences and searches, or from monitoring of personal activity patterns, apprehensions about 'who would own and control the data' and 'with who is shared and for what purpose', are well founded.

Finally, electronic security concerns are also at the top of the list of issues to be resolved (Schoettle & Sivak 2014b,c; Kyriakidis et al. 2015).

> *Computer hackers, disgruntled employees, terrorist organizations, and/or hostile nations may target AVs and intelligent transportation systems more generally, causing collisions and traffic disruptions. (Fagnant & Kockelman 2015: 177).*

Their study distinguished between the acts of espionage (information gathering) vs sabotage (compromising the system's normal operation). Whereas for the individual the former gets more prominence (responsibility for good operation of the system is seen as an organisational aspect), tampering with the system could have long lasting repercussions.

Public opinion and AVs

Several large sample public opinion studies have highlighted positive attitudes (Payre, Cestac & Delhomme 2014), as well as *'non-negligible level of reluctance'* (Kyriakidis et al. 2015: 128). This mixture/ambivalence towards AVs is expected considering the uncertainties surrounding the technology (Daziano et al. 2016). However, levels of awareness and cultural differences, have led to a wide range of attitudes around the globe. For example, people in Germany and China are reportedly more aware of AVs compared to those in Japan (Sommer 2013) and more US respondents have heard about AVs compared to their UK and Australian counterparts (Schoettle & Sivak 2014a). Evidently, there may also be considerable heterogeneity in preferences for automation. For instance, using a nationwide online panel, Daziano et al. (2016) found a substantial share of the sample willing to pay more than $10 000 for automation, with an equally large number unwilling to pay any amount. This suggests that flexible policies may be required for a successful adoption of the technology.

This may be associated with the more positive attitudes towards AV: more positive responses and fewer negative responses were received from the Australian sample, than UK and US (Schoettle & Sivak 2014a); similarly, respondents in China and India are substantially more interested in acquiring AVs than the Japanese respondents (Schoettle & Sivak 2014b).

Comparable differences are shown when expert opinion is elicited. A survey of London transport professionals showed hesitation that the timing for level 3 and 4 AVs to become commonplace would be earlier than 2040 (Begg 2014), whereas participants in the Automated Vehicles Symposium 2014 saw 2030 as feasible for full automation freeway driving (Underwood 2014).

Coming back to studies focusing on Australian respondents, a number of benefits were cited in Schoettle & Sivak (2014a): safety, as AVs would lead to reduced crashes (72.3%); reduced severity of crashes (73.5%); improved emergency response to crashes (68.7%); less traffic congestion (47.5%); shorter travel times (44.8%); lower vehicle emissions (62.3%); better fuel economy (70.1%); and lower insurance rates (54.6%). Despite these positive results, only 12.7% of the Australian sample indicated that they would not be concerned at all about driving or riding in a level 3 AV or 11.5% in a fully automated vehicle (Schoettle & Sivak 2014a, Table 3, p.9).

In summary, education and exposure may encourage the public to have a more positive attitude towards AVs, but concerns about liability, control, security represent a hurdle and will take some time before AVs will be accepted.

5. IMPACT ON TRAVEL BEHAVIOUR AND DEMAND

A key argument for AVs is that overall they will provide greater mobility for more people and if managed appropriately through vehicle sharing and optimal routing, lead to greater system efficiency. However, the potential attractiveness of AVs has also generated concerns over the potential to generate more car-based demand, leading to more congestion on city streets. This section considers the main drivers of this 'induced demand'.

Induced demand

Given their potential to provide personal independence and an appealing travel option for many, AVs may generate substantial new demand for car travel. AVs may facilitate travel for segments of the population currently excluded, and offer comfortable travel conditions, conducive to a more productive and/or enjoyable time use. This could change the perceived value of time (VOT), i.e. reduce the 'time cost' of travel, which in turn may induce higher demand in terms of numbers of trips and longer distances than before. There is also a less desirable effect that may be associated with the new demand: empty runs or long parking times for vehicles that are doing only point-to-point services, further urban sprawl by relocating to more attractive or less expensive areas (because travel cost decreases and utility increases). These issues are considered in more detail.

Uptake by people with mobility restrictions

One of the main appeals of AVs is their ability to offer car-based mobility for a number of currently disadvantaged groups, such as the elderly (with notable decline in vehicle license holding and age-related impaired driving aptitudes) and individuals with disabilities (which preclude them from driving) (Howard & Dai 2014; Fagnant & Kockelman 2015; Anderson et al. 2016). This was consistently highlighted as a 'plus' for AVs, because enhanced mobility is associated with a positive quality of life and health outcomes.

In addition to individuals unable to drive, AVs create mobility solutions for those unwilling to drive or prohibited from driving for various reasons. Thus, regardless of the circumstances that lead to losing the privilege to drive, AVs provides a corrective solution for the lack of mobility, which may hinder social interaction and participation in community life. Lack of independent mobility could result in critical reductions in wellbeing and negative symptoms, and although public transport and other on-demand solutions may alleviate the situation, they are not seen as being as flexible as AVs.

Eliminating negotiation between family members

Autonomous vehicles also enable those too young to drive by themselves to be taken to their activities, with or without an accompanying adult. This may resolve some of the challenges of trip chaining and sequencing of activities for parents who are often forced to organise their own work at other hours than the children's school program and to negotiate their schedules. As indicated, this is expected to have positive impacts for individual and family wellbeing (Wight, Raley & Bianchi 2009).

AVs may also solve some of the 'disruptions' of family routines (Wight et al. 2009) by either allowing all family members to be together during the AV ride (having family time, relaxing together, or conducting other activities, separately), or freeing up adults to undertake work and non-work activities at other locations than that of their children. The latter case assumes that parents and carers would be comfortable to let their children be 'free range' in the company of a robotic vehicle, with various degrees of monitoring for the trip, an assumption that clearly needs further scrutiny. Furthermore, by eliminating the joint travel, these new movements generate extra road capacity demands, especially if they are not spread evenly during the day.

Better/more productive time use

A fully automated vehicle, by releasing the driver from the driving task, potentially opens up the opportunity for other activities to be conducted during the trip. Combined with the likelihood of a transformed layout of the vehicle, AVs offer the benefit of converting travel time to reach various locations into productive and/or more enjoyable activities: working, resting, eating meals, watching movies, reading books or magazines, making phone calls, and socialising (Schoettle & Sivak 2014a; Fagnant & Kockelman 2015). In the context of an increasingly 24/7 economy and with the diffusion of work hours outside standard 9 a.m. to 5 p.m., the potential to conduct other less stressful or demanding activities during driving could potentially improve social interaction and work-life balance for many individuals (Wight et al. 2009).

In their three-country comparison, Schoettle & Sivak (2014a) showed that after 'watching the road', the next top choices of activity while riding the AV were: 'reading' (#1 in US and UK and #3 in Australia); 'text or talk with friends/family' (#1 in Australia, #2 in the US and #3 in the UK); and 'sleep' (#2 in the UK and Australia and #3 in the US) (p.18). This in turn has the potential to substantially decrease the VOT due to productivity gains and or higher utility of travel, with policy implications for evaluating alternative transport projects (where VOT savings is a core element in cost-benefit evaluations).

Secondary demand (extra movements, empty runs)

AV operation, not requiring human presence, facilitates delivering freight and unlicensed individuals reaching their destinations. However, if AVs do not serve multiple demands (as in a shared program), the empty runs after deliveries and drop-offs may increase the number of vehicles on the road and the vehicle-mileage (e.g. if the AVs are self-parking in less expensive areas). These extra movements and distances depend heavily on the level of AV penetration. Fagnant and Kockelman (2015) estimate an excess of 20% at 10% AV market share, but only 10% at 90% market share (p.172). This suggests that a shared mobility model (on-demand services) holds great promise for traffic conditions, despite the concerns around loss of personal space and loss of control (a demand for travel is not considered in isolation, so dependency on others is not removed). We consider shared mobility models in the next section.

6. BUSINESS MODELS

The current high price of AVs raises questions around the feasibility of whether people will own vehicles or share them. The notion of sharing vehicles is already being embraced with a recent report suggesting that worldwide around 5.8 million people are members of formal car-sharing entities with a total shared vehicle fleet of 86 000 vehicles (Bert et al. 2016). The same source suggests that the number of car-sharing participants is expected to grow dramatically by 2021 to 35 million participants, which in turn will reduce vehicle sales by 550 000 cars in an industry worth €4.7 billion per annum. While these figures do not refer to AVs specifically, it is expected that in the future they may represent a non-trivial proportion. The shift to diverse mobility solutions may mean that up to 1 out of 10 new cars sold in 2030 are likely to be used as a shared vehicle (McKinsey & Company 2016) and this expansion of car sharing models will progress without the advent of fully automated vehicles. However, the prospect of a completely self-navigating vehicle, sometime in the future, will continue to encourage investment in mobility sharing technologies. This is because an AV is potentially cheaper than models that require a human driver.

In addition, AVs offer a more streamlined business model in that transferring vehicle insurance could be avoided. Insurance is a particular concern for public and private companies increasing their ridesharing activities, such as Uber. A new hybrid model may replace the driver-partner sharing model to an entrepreneur-sharing model, which eliminates the driver. This would significantly change the car sharing landscape. The Uber's CEO, Travis Kalanick has reportedly made frequent reference to the fact that the driver is the most expensive part of its operations, compounding challenges to the business model associated with legal questions around whether drivers are employees or contractors (della Cava 2016). These issues may be alleviated by removing the driver from the service.

Operationally, the AV lends itself to ride sharing because it potentially solves the relocation problem faced by one-way sharing models (Firnkorn & Müller 2015). Relocating AVs will involve some degree of empty running. However, the amount of empty kilometres could potentially be halved under a system of dynamic ride sharing, whereby more than one passenger destination can be serviced on the same trip (Fagnant & Kockelman 2015). To achieve this, passengers would need to be somewhat more flexible in their schedule and accept longer trip times.

In a recent stated choice exercise, younger travellers who identified themselves as being multimodal stated a higher intention to participate in dynamic ride sharing (Krueger, Rashidi & Rose 2016). Furthermore, these respondents were more likely to be currently using ride sharing and car sharing applications. Not limited by the discussion being on AVs, there is strengthening evidence that the next generation of independent travellers may not purchase their own car and may be more willing to pay for mobility services. Over recent years, younger people in Australia appear less likely to obtain a driver's licence (Delbosc & Currie 2013) and seem less influenced by the status and hedonic qualities of vehicle ownership than their parents (Delbosc & Currie 2014).

As indicated at the beginning of this section, fully autonomous vehicles can improve the outcomes for the segments of the community that are unable to drive. However, Anderson et al. (2016) point out that public authorities already provide paratransit services, but at a considerably higher cost than fixed route public transport services. From the point of view of sharing or flexible mobility models, the delivery of an affordable service seems to come down the cost savings made by removing a professional driver from the equation.

The role of AVs may extend into the regular public transport space. There is much less research on autonomous public transport networks than on driverless vehicles, with the exception being output from the City2Mobile project (e.g. Alessandrini et al. 2014). The concentration of research on the private vehicle may be counter intuitive because finding dedicated lanes – avoiding interactions with human drivers – is far easier for existing public modes. Alessandrini et al. (2015) indicate that different urban types would benefit from different automated public transport models. More dense corridors would benefit from high–tech buses, capable of platooning, but lower density suburbs would lend themselves to shared vehicles and on demand public transport acting as feeder services.

It is evident that the shared mobility models will continue to grow before AVs become mainstream. However, the prospect of driverless vehicles will reassure investment in this sector because of the cost savings. At present car sharing has its strongest hold in inner city Sydney and Melbourne (Dowling & Kent 2015). However, this is predominately due to the car-club models being affordable to households who need to make fewer trips by cars (Castle 2015). New business models of peer-to-peer sharing, such as Car Next Door, also demand monthly fees and high per use charges making them suited to the inner city, car free culture. The advent of driverless vehicles will blur the line between taxis and car sharing companies and may indeed undermine the club membership model. Furthermore, public authorities need to decide what role they will play in this market and whether the first and last mile is left to the private market or whether driverless on demand public transport will provide feeder services in low density Australian cities. Yet, driverless rail and busways offer lower technology options than fully autonomous vehicles that need to share the lane with human drivers. Mass public transport links appear to be an obvious entry point for driverless technology on our networks.

The previous discussion has indicated that AVs could have direct impacts on personal mobility, travel demand, system efficiency, reduced externalities, parking, public transport and other types of shared transport services. In addition, effects may be felt in other sectors of society due to the lowering of marginal costs (largely because there will be less need to own a vehicle) and opportunity costs that is likely to accompany large-scale introduction of AVs. For instance, people may choose to live further from work and other activities where housing is more affordable and make longer trips. A further impact could be the loss of many jobs in the professional driving sector, as drivers are replaced with robots. All these issues create challenges for policy-makers, without whose support AVs will likely remain confined to fiction.

7. POLICY CONSIDERATIONS

Regulatory issues

The introduction of AVs, will require significant changes in regulatory frameworks and liability regimes. The Australian National Transport Commission recently identified 716 potential legal barriers in the current federal, state and territory legislation (NTC 2016a,b,c). Among the most pertinent issues for consideration are if/how AVs should be regulated, what types of vehicles should be allowed on the road, safety standards, liability regimes, and privacy issues. An additional consideration in Australia is what elements of AV regulation should come under federal and/or state legislation. Clearly, a coordinated approach is needed to ensure consistency across the country and to international standards (NTC 2016c). This is particularly so when considering V2V/V2I communication plays an important role in unleashing the full potential of AVs. Commentators have recently cautioned Australia not to repeat the same mistake made on rail gauges (Retter 2016).

As a relative laggard in the AV space, Australia does have the (comparative) advantage of learning from regulatory efforts overseas. In the U.S., several states have passed legislation permitting on-road trials of AVs under specific circumstances (although equally interesting is that several have failed to do so), and federal policy guidelines have recently been published to provide assistance for testing, licencing and registration of AVs (NHTSA 2013). Within Australia, most of the federal push for legislation is coming from the NTC, although ANCAP as the main regulator of new vehicle standards is also clearly a key player. A critical issue, as with the U.S., is that while testing of vehicles is a federal level prerogative, testing of drivers is done at the state level. As Anderson et al. (2016) point out, this could cause complications for AVS because essentially the driver is now the vehicle.

Liability and insurance

If AVs result in the levels of safety benefits alluded to earlier in this review, then insurance costs should go down. However, as yet, this is a big unknown, particularly if operating in mixed traffic as seems a probable scenario initially at least. Irrespective, it is unlikely current insurance models will work with AVs as it seems unreasonable to have the individual underwrite a vehicle that is operating autonomously. Suggestions are that the manufacturer of the vehicle and/or makers of the software components themselves could bear a larger brunt here, which could in turn stifle the introduction of new technology (Anderson et al. 2016). Further complexity is introduced for various reasons. First, the decision on what to do in the event of a possible crash now shifts from the driver to the machine and/or programmer. In turn, this could result in challenging decisions around, given a choice, whether the vehicle occupants are the priority or other road users. Second, it is probable that there will still be some level of human override as we transition to total automation, which raises questions around shared liability. Third, even under a fully automated regime, it is probable an AV will still be responding to user directions to some extent in terms of directives to pick them up/drop them off under specific conditions. For instance, if it is raining heavily, will the pricing regimes change and/or will there be certain conditions when the vehicle is programmed not to come and pick up a passenger?

Broader policy issues

As alluded to in this review, AVs could have many tangential effects on mobility, location choice and others, which we cannot yet anticipate. One area that has received recent press is that of the potential impacts of AVs on parking requirements (Anderson et al. 2016). Provision of sufficient parking capacity in dense, urban areas is a perennial issue. It is a constant source of angst for both private travellers and businesses with parking-related searching contributing significantly to wasted VKT and associated negative externalities. Parking provision is also expensive both for the authority and consumer, but it provides a significant source of government revenue, both indirectly through taxation and directly through payments and fines. In theory, AVs should reduce parking demand because, once a passenger has been dropped off, the vehicle can then go on to pick up another passenger. With estimates as high as 30% of vehicles on city roads searching for a parking space, the potential impacts of the removal of this traffic are clearly significant (Shoup 2005). Looking further ahead, if AVs take off on a large-scale, this could reduce the demand for dedicated parking space, which could be converted to other land-uses of a more amenable nature such as parks and pedestrianised areas. However, this change is unlikely to happen without significant pain as many car-parks (e.g. multi-storey) are difficult to repurpose; moreover, car parks represent a significant source of revenue, implying that councils may have to look to make up the revenue shortfall through other charging mechanisms. In addition, AVs would also make parking an ineffective travel demand management tool. Owners might order AVs to seek cheaper parking or even roam or return to the base, especially if the roads are not priced (Sun, Gladstone & Taplin 2016).

8. SNAPSHOT OF AV RESEARCH AND TRIALS IN AUSTRALIA

In Australia, other than the National Transport Commission leading the legislative review, the Australian Driverless Vehicle Initiative (ADVI) plays a significant role in coordinating AV activities at the national level. This started from the Driverless Vehicle Roundtable held in Sydney in 2014 at the 26th ARRB Conference, the result of which was summarised in a workshop report (Hillier, Wright & Damen 2014). However, most of the actual research and trials are in a state of competitive federalism featuring a healthy contest between states and territories governments and institutions located in their boundaries. In this section we provide a snapshot on the AV research and trials around the country at the time of writing. Given the scattered nature of the activities, this is by no means a complete list and we acknowledge this may not cover all projects.

The Queensland government is cooperating with Bosch and QUT's Centre for Accident Research and Road Safety (CARRS) to test retrofitted AVs in its road network (Galvin 2016). The government also commissioned an independent review, 'Opportunities for Personalised Transport (OPT)' in October 2015, looking into a range of future trends in personal mobility including shared AVs (Washington et al. 2016). Tranter (2016) has concluded that much of Queensland's road and criminal laws can be adjusted to accommodate AVs and he also identified areas needing reform.

In NSW, the UNSW Research Centre for Integrated Transport Innovation (rCITI) partnered up with car sharing company GoGet to develop AV technology (UNSW 2014). Krueger et al. (2016) have used stated preference surveys to investigate the likely adopters of shared autonomous vehicles and their willingness to pay in terms of critical service attributes.

The ACT government and its opposition have both shown strong support for attracting AV trials (ABC 2016). In Victoria, the government is funding AU$4.5 million to the development of Intelligent transport Systems which presumably include AV technology (Victoria State Government 2016). In October 2016, Bosch unveiled what was claimed to be 'the first self-driving car developed in Australia', with AU$1.2 million support from the Victoria government (Lamacraft 2016). The car is highly but not fully autonomous (level 4 by SAE International Standard J3016).

The neighbouring state, South Australia, has hosted the International Driverless Cars Conference and its first AV trial with Volvo in 2015. In 2016, it became the first state to pass legislation that allows AV trials subject to approval by the transport minister (Tucker 2016). Subsequently, a significant announcement was made in late 2016 that the SA government had committed AU$10 million in developing, demonstrating and deploying Connected and Autonomous Vehicles in the next three years (DPTI 2016), with a condition that all projects must happen in South Australia (Conway 2016).

In Western Australia, RAC (2016a), with the support of the state government, has purchased a French-made driverless electric bus, which can carry 11 passengers with the maximum speed of 45 km/h and average speed of 20-25 km/h (RAC 2016b). The trial, which is the first of its kind in Australia, has obtained government's approval and been running on public roads in South Perth since 31 August 2016 (RAC 2016c). The bus appears to operate at lower speeds than its capacity, possibly due to safety precautions. The UWA REV Project has also developed robotic vehicle control technologies, including a self-driving Formula SAE racecar and a retrofitted semi-autonomous BMW X5 (UWA 2016).

9. CONCLUDING COMMENTS

This review, while by no means comprehensive, indicates several key issues and unknowns if Australia is to embark on a journey to automation. First, while vehicle automation is a 'hot topic' and several 'trials' are being conducted both overseas and in Australia, there are clearly many unknowns and barriers around why, how and when this should happen. Second, technologically speaking, automation of vehicles itself is not a new concept, with examples in other sectors, particularly rail, being around for decades. The difference here is that (unlike rail) and other instances where the environment can be constrained and controlled, roadways present a myriad of additional challenges for AVs to negotiate, particular within mixed traffic, pedestrians, cyclists etc. Third, Australia does not currently we have the legislative or regulatory framework in place to deal with AVs and it is likely to lead to fundamental changes in liability models. Fourth, dialogue around AVs seems to be accompanied by dramatic changes in the way mobility will be provided in the future with the implicit assumption that vehicles will be used more efficiently, through shared models. Evidence suggests in Australia (and elsewhere) that breaking the 'love affair' with a personal vehicle and the control it offers is likely to be a long, hard journey. Finally, if we look historically at road transport systems, inertia is a key feature and change happens very slowly. AVs may be coming, but there is a great deal of uncertainty around exactly when.

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