VENTURER

Introducing Driverless Cars to UK Roads

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Understanding the Socioeconomic Adoption Scenarios for Autonomous Vehicles: A Literature Review

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1 Introduction

There is great and growing interest in autonomous vehicles (AVs), both in relation to rapid technological developments and the trialling of these developments, and the potential for their far reaching impacts on transport systems and society. The present report examines scenarios and policy and practice challenges for the adoption of AVs. Whilst it has broad relevance for societies, in the industrialised democracies at least, there is a particular focus on the UK context.

The report begins with an overview of the historical development of AVs. This is followed by a summary of two theoretical perspectives which frame the various processes through which new innovations can enter the mainstream and be adopted by individuals: i. the multi-level perspective (which is illustrated through a case study of the transition from horse drawn carriages to automobiles); and ii. the technology acceptance model (which deals with individual intentions rather than societal diffusion). The frameworks highlight the importance of government leadership, support from powerful professional bodies and positive public perceptions as necessary (but not sufficient) conditions for new innovations to achieve significant market share. Accordingly the report moves on to review the academic and grey literature on government, expert and public perceptions of AVs in turn. The theoretical and empirical insights are then synthesised in a discussion which considers two competing but plausible future operating scenarios for AVs. The first sees AVs as supporting 'business-as-usual', with road transport remaining an essentially private 'owner-user' set of practices, with more cars and traffic resulting from the removal of constraints on who can use vehicles and when. The other presents AVs as a key element in achieving 'collective efficiency' in the use of transport assets, with different and emerging ownership and use models.

2 A history of autonomous vehicles

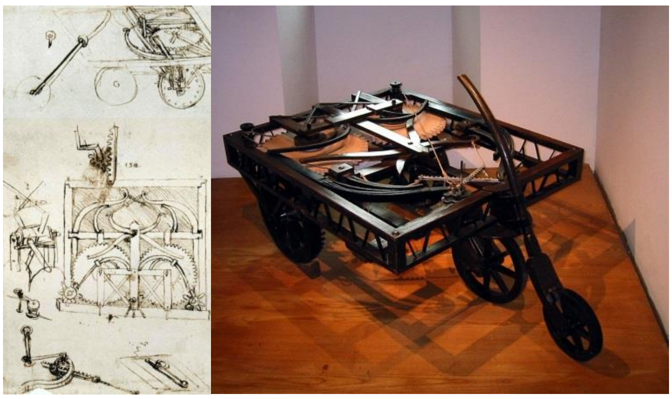
Autonomous: 'having self-government, independent of others'

Vehicle: 'Any conveyance in or by which people or objects are transported'

Collins (1989)

The first human ridden horses, untamed and therefore uncontrolled, provided the earliest examples of 'autonomous vehicles' as far back as 10,000 years BC (autonomous cars 2013). A first *man-made* 'programmable cart' was designed and built by the Greek inventor Hero, in 60 years AD. The cart was powered by a falling weight which unwound a string wrapped around its axles. By winding the string in different directions, Hero was able to programme the cart to move forwards, backwards and to turn in a pre-defined sequence limited in duration only by the length of the string (New Scientist 2007). Leonardo di Vinci later conceived of his 'programmable cart' in the 15th century AD (Figure 1). This design was powered by coiled springs (tightened and hence energised by pulling the cart backwards) and followed a pre-set route that was programmed using an arrangement of gears and springs (thelistcafe date unknown).

Figure 1: Leonardo Di Vinci's driverless cart



Source: Wikipedia (2014)

The 'driverless vehicles' [1] that are under development today are, of course, an incremental evolution of the modern day motor car, with its origins in the late 19th century, and brought to the masses by Henry Ford in the first decade of the 20th century. By the end of this 'century of the car', a global system of 'automobility' (Urry 2004) had emerged and the majority of households in developed

[1] 'driverless cars' are *programmed* rather than *autonomous* (i.e. acting independently)

economies had access to a privately owned car (Dennis and Urry 2009). The complex, inter-dependent systems of automobility and the implications for transitioning to an alternative dominant form of mobility are considered later, in the review of theoretical perspectives (in Section 3).

First, returning to the evolution of modern day driverless *vehicle technology*, Anderson et al (2013) in their review of AVs (from a predominantly American perspective), identified three phases in their development to date: i. foundational research conducted by universities in partnership with the major motor manufacturers (e.g. General Motors (GM)) and state agencies, ii. the so-called 'Grand Challenges' which were initiated in the U.S. by the Defense Advanced Research Projects Agency (DARPA), and lastly, iii. commercial development, in which major corporations like Google and the motor manufacturers have begun investing in their own research and development programmes in seeking to position themselves as AV market leaders.

A chronology of the evolution of AV technology from the early 20th Century is summarised in Table 1:

Table 1: Chronology of developments in AVs

1939:	The World's Fair: GM's exhibit 'Futurama' predicts personal car ownership and highway platooning (the interstate system was yet to be developed) (Wired 2007).
1940s:	Military technology like RADAR and other electronics are developed during the war years. These are later employed in civilian contexts, including in driver assistance technologies such as adaptive cruise control (Wetmore 2003).
1958:	GM develop a Chevrolet vehicle that steers automatically by detecting (through inductance coils mounted on the vehicle) AC currents in wires embedded in the road (Vanderbilt 2012).
1960:	Dr Vladimir Zworykin develops an intelligent highway system that senses vehicle speeds and locations, processes this in a central computer, and sends back control instructions to vehicles to avoid collisions (Wetmore 2003).
1970s:	Development in automated highways in the USA is halted. Motor manufacturers are forced by state legislation and technological limitations to focus innovation on safety improvements and emissions controls (Wetmore 2003).
1977:	Tsukuba Mechanical Engineering Lab equips a car with cameras and an analogue computer, enabling the vehicle to automatically track white road markings at speeds of up to 30 km/hr. (Forsyth date unknown)
1980:	Ernst Dickmanns, working with a team at Universität der Bundeswehr (Munich), fits various sensors to a Mercedes Van. Throttle, brakes and steering are automatically controlled on traffic-free streets. No road side infrastructure is required (Forsyth date unknown).
1986:	The van is later developed into what became known as VaMorRs ("Versuchsfahrzeug für autonome Mobilität und Rechnersehe" or "test vehicle for autonomous mobility and computer") which drove at up to 96km/h over a not-yet-opened 20km stretch of German autobahn (Weber 2013).
1987-95:	The EU fund the pan-European PROMETHEUS project (PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety). Dickmanns develops the VaMP autonomous car as part of the project – a Mercedes 500 SEL with automatic control of throttle, brakes and steering (Chiafulio date unknown).
1994/5:	Enhancements to the image processing algorithms enable the VaMP car to be demonstrated in simulated traffic in Paris as part of the PROMETHEUS project. In 1995 it is piloted automatically in real traffic for the majority of a 1,600 km journey between Munich, Germany and Odense, Denmark (Chiafulio date unknown). In the USA, researchers from Carnegie Mellon University used the 'Rapidly Adapting Lateral Position Handler' algorithm to automatically control the steering of a Pontiac Trans Sport on a journey between Pittsburgh and San Diego. Throttle and brakes were controlled by the researchers (Carnegie Mellon University data unknown).

1996-2001: The University of Parma, Italy (also involved in PROMETHEUS) equip a Lancia Thema 2000 with low cost black and white cameras, under the ARGO research programme (University of Parma data unknown). Image processing algorithms are successfully able to keep the vehicle within white lines and to regulate speed. The vehicle is successfully demonstrated in automatic mode on extra-urban rural roads in Italy over a tour of 2000km (Vanderbilt 2012).

2002: This year sees the launch of DARPA's 'Grand Challenge' in the US. Teams are challenged to develop an autonomous vehicles that can traverse a 150km off road and unmarked route in the Mojave desert. The route is pre-planned and GPS waymarked. Funding is available to take part in the challenge, with a further $1m in prize money on offer to the winning teams. The objective of the programme is to stimulate innovation in autonomous vehicles which can then be developed for use by the military (Vanderbilt 2012).

2004: The first 'Grand Challenge' race is held, but no teams completed the route and the race is repeated in 2005. This is completed by five teams and won by Stanford University with a modified Volkswagen Tourag (Vanderbilt 2012).

2007: The third 'Grand Challenge' requires teams to complete a 96km urban course which is set up on the disused George Air Force Base. Vehicles were required to comply with traffic laws and to negotiate other traffic and obstacles. The challenge was won by Carnegie Mellon University with a modified Chevrolet Tahoe (Vanderbilt 2012).

2009-12: Google enter into the development of self-driving cars employing researchers that had previously been involved in the DARPA Grand Challenges (including Stanford's Sebastian Thrun). Self-driving technology was initially fitted to a Toyota Prius and later a Lexus which by 2012 had completed over 300,000 test miles on inter-urban free-ways in California and Texas. Testing then began in more complex urban environments (Vanderbilt 2012).

2014: Google unveil their first bespoke self-driving car with no steering wheel or pedals (Google date unknown).

Hence, in terms of technological development the broad principles of automation have been demonstrated in real-world scenarios. The outstanding technical challenges are in terms of the flexibility and resilience of the systems, for example, to the unexpected, the full range of possible weather, and the management of system failures. However, two major challenges remain beyond technical feasibility and reliance: first, to decide what socio-legal-regulatory environment AVs should be designed for, or indeed whether that environment needs to be modified to make AVs a realistic mass-adoption option, and second, whether there is a commercially-viable market model for the production and adoption of AVs, and whether that model would also be a socioeconomically desirable one. The report now turns to examine how theoretical perspectives can inform these questions.

3 Theoretical perspectives on the adoption of AVs

To speculate on how the transportation system may evolve in the *future*, it is informative to examine the nature of *present* day transportation systems and how these emerged through *past* technological innovations and system transitions. Transportation systems may be interpreted through a number of theoretical perspectives. Here, we consider the relevance of two such frameworks to the question of how AVs may come to be widely adopted across society, namely: The multi-level perspective and the technology acceptance model.

3.1 The multi-level perspective and socio-technical transitions

Geels (2005, 2012) and others have used the *multi-level perspective* (MLP) as a framework to explain historic transitions from one (dominant) transportation system to another (e.g. the transition from horse drawn carriages to automobiles). Transitions are examined through the MLP by considering the inter-relationship between processes occurring in three nested levels: i. niches, which are nested below ii. socio-technical regimes, which are nested below iii. landscapes.

Socio-technical regimes: The dominant transportation system of a time may be conceived as a *socio-technical regime* - the middle layer of the MLP. Dominant regimes (e.g. the current system of automobility (Urry 2004)) emerge when technologies (e.g. vehicles), infrastructure (e.g. roads for vehicles), regulations (e.g. the rules and legal framework for operating vehicles on roads), user patterns (the adoption of vehicles for mobility) and cultural discourses (e.g. the notion that roads are predominantly for automobiles rather than other modes or uses) converge to reinforce one way of doing things over alternatives. The system is 'reproduced, maintained and changed' by different social groups and actors. The term 'regime' is used rather than the term 'system' to capture the idea that there are 'deep structural rules that govern and guide' how different actors perceive how the system ought to be used and altered. The concept of a *socio-technical regime* also incorporates processes of 'lock-in' or path dependency that stifle innovation and make it difficult to transition from one (dominant) system to another.

Niches: New innovations are considered in the MLP to develop in 'niches', which are nested in the bottom level of the framework beneath the socio-technical regime. In the initial phases of innovation, niches may be thought of as 'protected spaces' such as research and development laboratories, demonstration projects or the military. Innovation is considered to occur through three processes: first, learning about the new technology or practice; second, articulating a vision of how the new technology or practice may be adopted; and third, the building of social networks around the innovation. For innovations to gather momentum it is necessary for these three processes to align such that a dominant technology emerges (and competition between alternative forms of technology is removed), with a clear and shared vision of how the technology ought to be adopted, which is supported by social groups and actors that have the power to instigate change.

Landscapes: Socio-technical regimes and niches are situated in the framework beneath a socio-technical landscape (the highest level in the MLP). The landscape constitutes the *wider contexts* that are beyond the control of individual actors, including for example spatial structures (e.g. urban form), political ideologies, societal values, beliefs, concerns and economic systems and trends.

The MLP is illustrated in Figure 2.

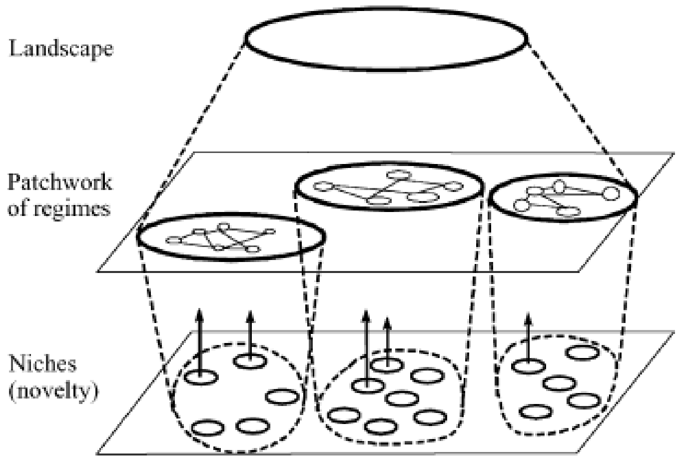


Figure 2: Multiple levels in a nested hierarchy (Geels 2002)

Transitions: Transitions from one regime to another are considered in the MLP to occur through a four stage process:

1. Innovations are first developed in small, protected spaces which are situated in the lower (niches) level of the MLP.
2. Niche adoption: The innovations then emerge as applied, small market niches, again operating outside of the dominant regime (in the lower 'niches' level).
3. Breakthrough: Wider adoption then occurs through 'niche accumulation' where an innovation is employed in multiple, discrete market spaces. Taken together, these begin to establish a more significant market share. As market share increases, the innovation is able to compete with the existing dominant regime. The process may be catalysed by a combination of i. favourable changes occurring at the

landscape level, ii. specific problems occurring within the existing regime and iii. promotion by powerful actors or social groups.

4. Replacement: In this last stage, the innovation replaces the previous system and a new socio-technical regime becomes established. This may be a gradual process.

To illustrate the framework's applicability to transportation, Geels (2005) draws on the MLP to explain the socio-technical transition from horse drawn carriages to automobiles in the USA (1860 – 1930). His account is summarised in Box 1.

Box 1: A case study of a socio-technical transition in transport

FROM HORSE DRAWN CARRIAGES TO AUTOMOBILES IN THE USA

Phase 1: Industrialisation and urbanisation (1860-1865)

Changing landscapes: Industrialisation (catalysed by the invention of steam power) triggers a process of urbanisation as people move from rural areas to cities to find work.

The transportation regime: Journeys consequently became too long to undertake on foot and horse drawn coaches are adopted as the dominant form of mass transit in cities.

Niche developments: However, as cities expand, large numbers of horses become increasingly expensive to 'maintain' for transportation. The horse tram companies begin to seek alternative power sources for their coaches. The first *electric* trams are demonstrated at exhibitions.

Phase 2: Suburbanisation and the adoption of electric trams (1885-1903)

Changing landscapes: Large-scale immigration to the USA increases the pace of urbanisation. Cities become and gain a reputation for being highly polluted. A preference for *suburban* living then emerges. Electricity becomes more widely available, stimulating a '*cultural fascination'* with electrical power.

Problems within the regime: Whilst the availability of horse drawn trams enabled the development of the first suburbs, this in turn increased demand for mobility, leading to congestion and worsening pollution from horse drawn transportation.

Niche breakthroughs: Thus electric trams, which were cheaper to run and less polluting, rapidly replaced horse drawn carriages. Electric tram systems attracted investment from real estate companies as new tramlines increase land values and the potential for development. The process of suburbanisation continues.

Changes within the regime: Streets were no longer viewed as spaces for social exchange, and were perceived instead as arteries for movement.

Niche innovations: The first automobiles (electric, steam and gasoline powered) were developed. These were used in particular market niches including as electric taxis, for promenading in parks, and for leisure racing and touring (for which gasoline powered vehicles are preferred).

Phase 3: Destabilisation of the electric tram regime (1903-1914)

Problems within the regime: Electric trams remain the dominant mode of urban transportation, but increasingly suffer from overcrowding. This contributes to their poor public image, which is reinforced by the perception of tram companies having profited from speculation in land markets. Tram fares are heavily regulated, reducing the ability of tram operators to generate income to invest in improvements, and public investment is also gradually withdrawn.

Niche accumulation: Automobiles remain firmly within the domain of the wealthy, but begin to be adopted by new groups for utilitarian, business purposes (e.g. by doctors or wealthy farmers in rural areas). Gasoline cars emerge as the dominant technology (relative to steam and electric vehicles), partly as their higher speeds and longer ranges are suited to popular leisure activities like racing and touring. Fuel is also readily available in general stores (e.g. for lighting) and there are established competencies in the maintenance of gasoline engines. Ford develop the Model T as an affordable basic car through innovative mass production processes.

Phase 4: Replacement of electric trams with automobiles (1914-1930s)

Establishing a new regime: As the drive towards suburbanisation continued, powerful social groups including policy makers and highway engineers see automobiles as a means to facilitate this. The expansion of cities necessitates greater mobility and cars (which were faster and more flexible than trams and now affordable to the masses) were seen as offering the perfect mobility solution. Road infrastructure was developed to accommodate cars (including the first highways), to the exclusion of pedestrians and children (who were displaced to purpose built playgrounds). Regulations were produced to manage traffic flow and to encourage the safe use of vehicles. Cars became a symbol of status and power and the present day car culture emerges (centred around leisure activities like touring and drive-in movies). By the middle of the 20th Century, the system of automobility has become firmly established.

3.2 The technology acceptance model

Now turning to individual level motivations for adopting innovations, Davis et al (1989) developed the original *technology acceptance model* (TAM) to examine user acceptance of computer technology. The TAM is an adaptation of the social-psychological 'theory of reasoned action' (proposed by Fishbein and Ajzen (1975)) and suggests a series of interrelated constructs to explain an *individual's* usage and intention to use a (new) technology. This is in contrast to the MLP, which considers societal rather than individual level transitions.

In the TAM, *actual use* of a technology is suggested to follow from an *intention* to use the technology. The *intention* arises from a *positive attitude* towards the technology. In turn, *attitude* is suggested to be related to the *perceived usefulness* of the technology and the *perceived ease of use*. In a development of the TAM (TAM version three), the perceived usefulness of the technology is further hypothesised to be related to subjective norms, image and experience. The model is depicted in Figure 3, with an adaptation added by the current authors to emphasise the perceived affective qualities of driving, which will be much altered in the AV experience.

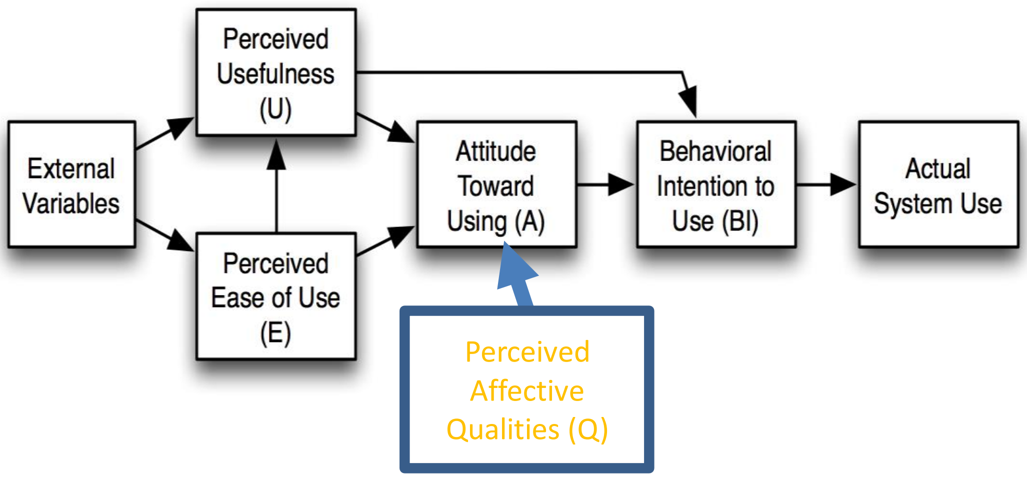


Figure 3: Modified technology acceptance model (Elaboration on Le Gris et al., 2003)

3.3 Summary

Together these different theoretical perspectives provide insights into some general concepts that merit attention in examining the prospects for the adoption of AVs. The MLP implies a need to consider prospective changes occurring at the landscape level. These might include ongoing migration to cities, the impact of mobile ICTs on lifestyles or strengthening agendas around climate change and the implications of this for energy-power systems and mobility. Second, it suggests attention be paid to the problems with the established automobility regime which might lead to its destabilisation (e.g. its inefficiency and high external costs, particularly in urban areas). It also provides an account about how AVs might initially emerge in applied market niches (such as airport parking, or on other protected corridors) which then accumulate, and the extent to which these niche markets and associated AV infrastructures might be promoted by powerful institutions including governments, highway authorities and motor manufacturers. With this in mind, the current perspectives of governments are reviewed next in Section 4, and the views of expert and professional groups are reviewed in Section 5.

Additionally, at the level of the individual, the TAM implies that an individual's attitude and intention to use an AV would follow first from their perceptions of the usefulness and ease of use of AVs. This is of relevance to understanding public perceptions of AVs, studies of which are reviewed later in Section 6.

4 Government perspectives on AVs

The report now considers current government policies on the development of AV technology, starting first with an examination of the UK government position. This is followed by a brief discussion of policies and programmes in continental Europe and in the USA.

4.1 Policy in the United Kingdom

The UK government set out a strategy to support the development of AV technology in a Department of Transport (DfT) document entitled "The Pathway to Driverless cars" (DfT 2015a). Their aim is "to ensure the UK is at the forefront of the testing and development of the technologies that will ultimately realise the goal of driverless vehicles".

The DfT distinguish between three levels of vehicle automation:

1. Driver assistance: where the driver maintains full engagement with the driving task at all times, but the vehicles is equipped with aids like adaptive cruise control, lane departure warning system, and autonomous emergency breaking;
2. High automation: where "a driver is required to be present and may need to take manual control for some parts of the journey"; and
3. Full automation where "a driver is not necessary".

It is acknowledged that "most commentators do not expect vehicles capable of fully autonomous operation on public roads in all circumstances to become available until at least the 2020s" (DfT 2015a, p.17). The potential benefits of full automation are identified as time savings, improved road safety, reduced emissions, reduced congestion, and increased access to personal transport for the mobility impaired. However, it is not possible for all such benefits to be realised until a significant share of the vehicle fleet is automated, and from a business perspective, KPMG (2015a) foresees only 20% market penetration of 'conditional' automation by 2020 and 40% penetration of 'high AVs' even by 2030. Hence, the UK Government discourse would appear to be emphasising, indeed exaggerating, the proximity of AVs to the mass market.

The DfT (2015a) strategy is underpinned by a comprehensive review of regulations and law (DfT 2015b) to identify whether changes to legislation are required to enable the operation of AVs on public roads. Under international law, the Vienna Convention on Road Traffic (agreed in 1968 and which later came into force in 1977 (Economic commission for Europe 1968)) states that 'every moving vehicle or combination of vehicles shall have a driver' and that 'every driver shall at all times, be able to control his vehicle'. This has been interpreted as a barrier to the trialling of AVs by some countries. However, while the UK are signatories to the treaty, it was never ratified, meaning that it is not legally binding in a UK jurisdiction[2]. It is concluded that trials of driverless cars can be performed on UK roads today, provided a test driver is present and that the vehicle is operated 'safely'. Safe operation is to be judged against a non-regulatory Code of Practice (published in July 2015 (DfT 2015c)), rather than against new legislation.

To stimulate the development of AV technology in the UK, the government launched several initiatives in 2015, including:

- funding £19m for the testing of driverless vehicles on public roads in Greenwich, Milton Keynes, Bristol and Coventry (DfT 2015a);
- a further £20m funding stream (to be matched by industry) for research and development of AV technology (DfT 2015d); and
- setting up the Centre for Connected and Autonomous Vehicles – A joint policy unit between the DfT and the Department for Business Innovation and Skills.

[2] In any case, given developments in AV technology, the wording of the Vienna Convention is being adapted to "allow a car to drive itself so long as the system can be overridden or switched off by the driver".

4.2 Policy across Europe

Individual European nations are developing their own strategies for enabling innovations in AV technology. Following on from the PROMETHEUS programme in the 1990s, the EU has continued to back innovation in AVs by funding various research streams in recent years, including (DfT 2015b):

- Safe Road Trains for the Environment (SARTRE) (2009-2012). This research programme developed technology to enable vehicle platooning on highways. The lead vehicle was manually operated, but 'following' vehicles were automated.
- Highly Automated Vehicles for Intelligent Transport (HAVE-it) (2008-2011). This project focussed on enhancing technology relating to driver handover and integration with AVs, and technology to improve reliability and safety. A number of demonstrator vehicles were developed. Volvo and VW were project partners amongst other industry bodies (HAVE-it 2015).
- CityMobil 1 and 2 (2012 – 2016). This project is funding three large-scale usable demonstrators (in Saint-Sulpice at a University campus, in La Rochelle, connecting the harbourside to the commercial area, and in Milan at the World Expo 2015 exhibition) and four small scale demonstrators (of three months in duration including demonstrations in Sardinia and Vantaa, Finland) (CityMobil2 2014).
- V-CHARGE (ended in 2015). This project investigated automated parking systems integrated with electric vehicle charging points (V-CHARGE 2015).
- Automated Driving APplications and Technologies for Intelligent Vehicles (ADAPTIVE) (2014-2017). This project (also involving VW) has an objective to "demonstrate automated driving in complex traffic environments", to improve sensor technologies, and to develop guidelines on how driver-automation systems should be integrated (Adaptive 2015).

4.3 Policy in the USA

Legislation for the trialling of AVs is dealt with at state level in the US and four states to date have passed laws to permit this: Nevada, Florida, California and Michigan. At Federal level, the National Highway Traffic Safety Administration (NHTSA) have published a 'preliminary statement of policy concerning automated vehicles' (NHTSA 2013) following requests from individual states to clarify how to conduct safe trials of AVs on public roads.

NHTSA note three related streams of technological development i. in-vehicle crash avoidance systems (either warning the driver or involving limited automated technology to control the vehicle) ii. vehicle to vehicle communications (developed for crash avoidance) and iii. self-driving vehicles. These are viewed on a continuum of automation which NHTSA define in terms of a four level hierarchy:

- Level 0: The driver completely controls the vehicle at all times.
- Level 1: Individual vehicle controls are automated, such as electronic stability control or automatic braking.
- Level 2: At least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping.
- Level 3: The driver can fully cede control of all safety-critical functions in certain conditions. The car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so.
- Level 4: The vehicle performs all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time. As this vehicle would control all functions from start to stop, including all parking functions, it could include unoccupied cars.

The SAE International (2014) J3016 hierarchy is similar, but divides Level 4, so that in the latter the driver is 'not ready to take over' but available, whilst a Level 5 in which human control is not foreseen. These hierarchies have been widely adopted in studies of expert and public perceptions reviewed in the next two chapters.

4.4 Summary

This brief review of European and American policy reveals that governments are already playing an active role in supporting the technological development of AVs (at this stage in niche 'protected spaces'). There are expectations of a range of potential societal benefits, but these are yet to be proven or even demanded by the market. A further important motivation in the UK context appears to be to ensure that the UK economy claims a significant share of the AV technology market as it emerges. There is some evidence that governments are boosting the benefits case for AVs, at least in terms of the speed with which they might be delivered.

5 Expert perspectives on AVs

The MLP highlighted the importance of support from professional groups for new technologies in underpinning the transition from one dominant transport regime to another. A growing body of grey literature on the prospects for AVs is developing from a range of different 'expert' sources. These include surveys of transport professionals, commissioned by transport system stakeholders (e.g. Begg (2014)) or by the insurance or automotive industry, reports by (research) consultancies who may be seeking to position themselves as experts on potential AV markets (e.g. KPMG (2012, 2015a&b); Atkins 2015), as well as opinion pieces written by informed academics (e.g. Mindell (2015)).

5.1 Likelihood of AV adoption

Begg (2014) conducted a survey of over 3,500 London transport professionals to discover their expectations on the use of AVs in London. Over 55% of survey respondents believe that Level two automation (at least two controls can be automated in unison) will be commonplace in the next 10 years; this perhaps is not surprising as many modern vehicles already have automated features. The expectations of when Level three automation (the driver can fully cede control of all safety-critical functions in certain conditions) will become commonplace shift further into the future with 54% of those surveyed choosing 2030 or 2040 as a likely date. A significant 20% of respondents believe this will *never* be commonplace. And this figure increases by almost 10% when respondents are asked about the prospects for removing the driver element altogether (i.e. Level four automation).

Litman's (2015) expectation is that while fully autonomous vehicles will be available in the 2020s they will have a large price premium and reliability issues. He expects significant market penetration to take place in the 2040s (up to 40% market share) with saturation (defined as the point at which everyone that wants an AV has one) occurring in the 2060s. Similarly, KPMG (2015a) foresees only 20% market penetration of 'conditional' automation by 2020 and 40% penetration of 'high AVs' even by 2030.

Lavasini et al (2016) develop a mathematical market penetration (Bass diffusion) model to predict likely diffusion curves for AV technology. The model is calibrated using historic data on the adoption of Hybrid Electric Vehicles and internet and cell-phone adoption in the USA. It is assumed that AVs will be available in 2025 and that market saturation will occur when 75 per cent of US households have purchased an AV. On this basis, the model predicts that 1.3 million AVs would be sold in the first five years, increasing to 36 million by year 10. Market saturation is predicted in 2059 (with 87 million AVs in circulation). Adoption rates are shown to be sensitive to the assumed market size – larger markets increase the adoption rate, but not to the AV cost premium relative to conventional vehicles.

The auto component website partcatalog.com (date unknown) asked 13 auto journalists (including only one woman) to express their opinions and predictions on the future of self-driving technology. Most expected fully autonomous vehicles to be available for purchase by 2024-26.

KPMG (2012), working with the Center for Automotive Research, conducted a market analysis of industry trends and interviewed over 25 leading technologists, automotive industry representatives, academics, regulators and government officials. The resulting report argues that technological change towards full automation is "inevitable" (p.5) given market dynamics and social, economic and environmental forces. It is considered that the marketplace (i.e. consumers) will be the "engine pulling the industry forward" (p.6). The transition to AVs is framed as a *radical revolution* (in the way we interact with vehicles and the future design of roads and cities, p.4) that will need several technological, regulatory and societal factors to successfully align to be achieved. From a technological point of view, the transition will need the convergence of sensor-based technologies and connected-vehicle communication solutions.

5.2 The process of AV adoption

By contrast, David Mindell, MIT professor and author of "Our Robots, Ourselves" (Mindell 2015), criticises the fundamental idea that progress in development of personal mobility means the *full automation* of private cars. Mindell thinks that "it's reasonable to hope" that technology will help cars "reduce the workload" of drivers in incremental ways in the future. But total automation, he thinks, is not the logical endpoint of vehicle development:

> *"The book is about a different idea of progress," Mindell says. "There's an idea that progress in robotics leads to full autonomy. That may be a valuable idea to guide research … but when automated and autonomous systems get into the real world, that's not the direction they head. We need to rethink the notion of progress, not as progress toward full autonomy, but as progress toward trusted, transparent, reliable, safe autonomy that is fully interactive: The car does what I want it to do, and only when I want it to do it." (Dizikes 2015).*

Begg's (2014) analysis of the London context, suggests that *rail-based automation*, used for both underground and overground services, will have the *biggest impact* on London over the next 30 years. The expectation is that, given the current operation of fully autonomous vehicles on segregated railways/paths (such as DLR, tube lines and UltraPRT), "the gradual transition to automated train operation is a virtual inevitability".

The report also states that if and when Level 4 (full) automation is achieved, lightly populated buses could be replaced by driverless taxis and cars, perhaps to be used as feeder services to heavily used corridors. Level 4 may indeed be sufficient for effective operation of clearly-defined route-based services such as buses. However, full Level 5 operation is necessary for taxi operation and it is not technically clear if and when 'go anywhere' might be achieved in complex urban areas. In relation to this, a report by the Boston Consulting Group (produced in collaboration with the World Economic Forum, based on intensive consultation with senior executives of automotive, technologies and insurance companies (Lang et al. 2015) claimed that *acceptance* by the public, policy makers and *affected third parties*, such as taxi drivers, is *crucial* for AV adoption and diffusion.

In their analysis, KPMG (2012) develop three possible scenarios for the way in which 'driverless cars' might diffuse into the system:

i. Conservative: where initial uptake of 'driverless cars' is gradual and 'driverless cars' never reach a 'critical mass' due in part to a lack of vehicle to external environment communication technology.

ii. Baseline: where the early applications of 'driverless cars' are viewed positively, increasing market demand for self-driving vehicles. AVs continue to be adopted by the general public at a linear rate but do not necessarily reach 100 percent market penetration.

iii. Aggressive: where initial uptake is rapid which catalyses technological development (including vehicle to external environment technology). This creates a virtuous circle whereby a critical mass is quickly reached.

The study by KPMG (2012) also identifies four possible new business models underpinning a transformed automotive industry which is dominated by self-driving cars:

i. the branded-integrated lifestyle model, where consumer-oriented tech companies come to dominate the new automotive ecosystem; Revenue is generated through the sale of 'integrated lifestyle experiences'.

ii. the open system model, where the operating system in the AV becomes the key component and revenue is generated primarily through data aggregation;

iii. the mobility on demand model, where shared vehicles dominate the scene; and finally

iv. the original equipment manufacturer (OEM) model, where existing automakers still retain a key role in the new marketplace.

KPMG (2012) further argue that four major requirements are needed for AVs to become widely adopted (i.e. beyond market niches such as rail). These are:

i. consumer acceptance, e.g. building trust, appealing to the right demographics, selling the value proposition and facilitating a learning curve among consumers;

ii. enabling the *network effect*, e.g. achieving critical mass, enabling the aftermarket (the market for spare parts and maintenance), targeting localised adoption, reducing the costs of ownership / use;

iii. developing a functioning legal and regulatory framework. This includes developing a legal framework to clarify liability issues, ensuring there is a uniform and cohesive approach across multiple geographical authorities, and offering incentives to automakers; and

iv. attracting the necessary investment, e.g. with clear political leadership to incentivise the development of AVs.

The journalists interviewed by Partcatalog.com (date unknown) felt that the biggest barrier to the adoption of AVs would be legislation. However, technology development, a proven AV safety record, business pushback and infrastructure availability would also play a key role.

In response to a survey by KPMG (2015b), a sample of senior insurance executives thought that *young adults* will be the earliest adopters of AVs, with no differences expected between genders. This expectation runs counter to the socio-demographic relationships indicated by public perception surveys reviewed in Section 6 - where males have been consistently shown to report more positive perceptions of AVs compared to females.

5.3 Potential benefits of AV adoption

Lawrence Burns (2013), former vice president of research and development at GM and professor of Engineering Practice at University of Michigan, sets out a utopian vision of a transport future, built around AVs. He suggests the present system of automobility (privately owned, gasoline powered vehicles) is outdated. Converging technological developments are now offering potential for a transition to a more efficient system oriented around connected, coordinated, shared, driverless, electric and tailored vehicles. His analysis estimates that such a system, in a city like Ann Arbor (Michigan) could be 70% cheaper, and reduce the city vehicle fleet to 20% of its current size. He argues that successful trials are essential to demonstrate proof of concept and to convince ‘the market’ of a need to transition towards an alternative, more efficient system.

Thomopoulos and Givoni (2015) develop a more nuanced argument. On the one hand, they see potential for AVs to contribute to a transition towards low carbon mobility, particularly if the car system is ‘de-privatised’ in favour of car sharing systems. On the other hand, they see AVs as a threat to the ‘Peak Car’ trend, by increasing the utility of car travel (enabling productive use of travel time and release of network capacity through vehicle-to-vehicle / vehicle-to-infrastructure communication) and hence encouraging increased car use to the detriment of other, more space and resource efficient modes.

Fagnant and Kockelman (2015) summarise estimates of a range of potential benefits of AV systems to the US, through a synthesis of academic and policy literature. Citing Hayes (2011), they note that fatality rates on the road system could be expected to reduce to as little as one per cent of current rates in the USA (standing at 32,000 fatalities per annum), given that the majority of crashes are attributable to human error. Based on a study by Atiyeh (2012), it is estimated that fuel economy could increase by 23% to 39%, and the speed of congested traffic could increase by 8% to 13%, given improvements in traffic flow efficiency. Shaldover (2012) is noted to have estimated lane capacity increases of up to 80% arising from co-operative adaptive cruise control, assuming a 90% AV market penetration.

However, the net benefits of AVs are expected to be eroded overall by anticipated increases in Vehicle Miles Travelled (VMT) resulting from increased access to car-oriented travel (for the young, elderly or mobility impaired for example). This, they suggest, has the potential to lead to automobile oriented development, but with a requirement for fewer vehicles and less parking. Given reductions in crashes, congestion benefits, parking savings and after accounting for increases in VMT, Fagnant and Kockelman (2015) estimate annual benefits to the US economy of the magnitude of $196bn (assuming a 90% AV market share). Barriers to the uptake of AVs are identified as vehicle costs, the fragmented (non-federal level) approach to licencing AVs, and concerns surrounding litigation, security (system hacking) and privacy.

5.4 AV market simulation studies

A number of academic groups have been developing simulation models to identify the potential impact of different forms of AV systems on travel demand, vehicle ownership and use. At this stage in their development, the simulation models have relied in the main on assumptions about travel choices, which are not necessarily grounded in evidence from stated preference experiments. Hence, the result must be treated with some caution. Two examples are reported here.

Brownell and Kornhauser (2014) identify five criteria that a public transport system must satisfy in order to compete with private vehicle ownership. These are: a) congestion reduction and competitive commuting times, b) safety improvements over private car use, c) better environmental credentials, d) economic viability and e) equivalent levels of comfort and convenience. It is argued that these conditions are potentially met by an autonomous taxi network. A modelling exercise is then performed to estimate and compare the efficiency (in terms of travel times, fleet size and costs) of personal rapid transit (PRT, where passengers are picked up and dropped off at taxi ranks) and smart para transit (SPT, a demand responsive system) autonomous taxi systems. The model assumes that these systems are able to serve the total travel demand simulated for the state of New Jersey. SPT is shown to be more efficient than PRT in terms of fleet size and cost, but will have higher vehicle occupancies (more ride sharing). It is suggested that SPT could be competitive with private car ownership against the first four test criteria, given that the fleet size is reduced and is able to use road space more efficiently (hence reducing congestion) than current systems. However, it is acknowledged that the analysis does not consider whether an SPT system could compete with private vehicle ownership in terms of comfort and convenience - especially given the observation that SPT requires ride sharing which may not be desirable. This is noted as a major potential barrier to the uptake of autonomous transport systems.

Fagnant et al. (2015) develop a simulation model of potential uptake of automated taxis in Austin, Texas. It is assumed that all travellers living within a 12mi by 24mi area of Austin choose to travel by automated taxi. This somewhat limits the validity of claims made on the basis of the simulation. Nevertheless, it is estimated that every automated taxi could be expected to replace the private ownership of around nine conventional vehicles. Hence, land that is currently used for the storage of private vehicles could be turned over to amenity. On the other hand, automated taxis were shown to generate an additional eight per cent of ‘empty-vehicle’ travel that would not exist under a private ownership model.

5.5 Implications for the insurance industry

A further report by KPMG (2015b) specifically explored the new insurance landscape engendered by the transition to AVs. They found that over the long term, with the car stock replaced by more and more AVs, the risk profile of vehicles on the road would substantially decrease, leading to much lower total losses for carriers. Collision frequency per vehicle could drop by 80% by 2040 (equivalent to about 0.009 incidents per vehicle). However, the reduction in incidents per vehicle could be offset by the increased severity incurred in each incident as AVs, and their component technologies, will be more expensive. KPMG estimates that current accident expense could increase from $14k to $35k by 2040. This conservative view perhaps overestimates the expense as a substantial share of AVs could be in the form of transportation pods, which may not be so expensive.

The KPMG (2015b) report also presents the results of a survey of senior insurance executives, whose companies account for over $85 billion in private and commercial auto premium. The survey found a mixed level of knowledge of AVs among respondents, with 29% reporting to be very knowledgeable and 23% claiming to have little or no knowledge at all. Respondents were also sceptical about the potential transformation. Few providers have taken action, especially in the near future (next 12-18 months). Not due to doubts about possible ramifications but because they believe that the change will happen far into the future, if at all. Many insurers had held discussions about impacts of AVs on their operations but 74% of companies felt unprepared for the change.

When the transformation starts to take hold, most survey respondents agreed there will be major changes across all the core functions, from underwriting to claims. Respondents anticipated a shift in the insurance landscape, including new insurance products to become available to cover AVs but also more competition due to new entrants in the insurance market. Auto manufacturers and tech companies were expected to play significantly bigger roles in the future in the insurance industry.

5.6 Summary

Overall, although identifying technical barriers and some objections to AV adoption, most of the publishing activity emphasises and promotes the desirability of overcoming these barriers. Whilst most of the expert opinions are realistic with respect to the likely timeline of adoption, they are not particularly consensual in the specifics, and the technologists do not question, in print at least, whether Level 5 AVs will eventually be achieved and mass-adopted. There is an expectation that automation will first be widely applied to (closed) urban rail systems rather than to personal transport. The insurance industry, whilst taking part in studies of AVs, remains sceptical of the prospects of a significant transition to AVs and is not yet actively preparing for this eventuality.

6 Public perspectives on AVs

The report now considers the perspectives of different groupings within the ‘general public’. A number of international studies on public perceptions of AVs were identified through a literature search (summarised in Appendix A). They include:

- Surveys of members of motoring organisations (conducted by, for example, insurance companies, roadside recovery companies);
- Population representative opinion polls, conducted by recognised polling companies, and reported online or in the general media; and
- In-depth academic studies of specific dimensions of perceptions of AVs (conducted on small samples, which are not necessarily representative of well-defined population groups).

The surveys cover a broad range of issues relating to ‘public opinion’ including: level of awareness of AV technology, *general* attitudes[3] towards AV technology (whether it is viewed as a positive or negative development), perceptions of *specific* aspects of AV technology (e.g. safety, law and liability) and whether these are causes for concern, preferred modes of AV operation, anticipated use of in-vehicle time, willingness to pay for AV technology, and stated preference mode choice experiments. Correlations between different aspects of AV perceptions and socio-demographic / psychological characteristics have also been examined. All of the surveys employ a *quantitative design*, in which perceptions have been investigated using responses to *closed questions* either through simple yes/no answers, Likert scales or ranking exercises (i.e. testing pre-conceived hypotheses). The implications of this are discussed in the section summary.

6.1 Awareness of and general attitudes toward AVs

Schoettle and Sivak (2014) surveyed perceptions of self-driving vehicles across a sample of 1,533 adults living in the UK, USA and Australia (the sample frame is not reported). Awareness of AVs was shown to be high, with 71% of US respondents, 66% of UK respondents and 61% of Australian respondents reporting that they had previously heard of AVs. Overall, a prevailing *negative perception* of AVs amongst respondents was observed across most (though not all) of the surveys reviewed. This was evidenced through, for example, an AA (2013) survey of 23,450 members (all motorists) in which 65% of respondents reported enjoying driving too much to ever want a driverless car. Likewise, 61% of a sample of 1,099 UK adults (weighted to be population representative) said they would probably or definitely *not* consider buying a driverless car (Adams

[3] where attitude is defined by Payre et al. (2014) as “a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavour”.

2015). (A similar result was reported by Insurance.com (2014) in a survey of 2,000 American drivers). In another population-representative survey of UK and US residents, Accenture Research (2011) found that just over half (51%) of respondents would *not* be comfortable using a driverless vehicle. This was also supported by TE connectivity's (2013) survey of 1,000 US adults in which nearly 70% of respondents reported that they would *not* be comfortable in an AV.

A smaller number of surveys revealed more positive attitudes, however. Schoettle and Sivak (2014) found that over half of their sample held positive *general opinions* of AVs, and had positive expectations about their potential benefits e.g. expecting fewer crashes, reduced crash severity, and lower emissions. Cisco (2013) surveyed 1514 adults across 10 countries. They found that 57% of respondents would ride a driverless car, with higher proportions being reported in emerging markets (e.g. 95% in Brazil, and 86% in India compared to 45% in the UK). Payre et al.'s (2014) survey of 421 French drivers revealed that the majority of respondents (68%) rated Fully Automated Driving (FAD) as being *more useful* than manual driving. By contrast, Kyriakidis et al. (2015) found *manual driving* to be rated as the *most enjoyable* mode of driving and FAD as the *least enjoyable* mode of driving (amongst a sample of 4,886 international respondents to an online questionnaire).

This somewhat mixed picture of overall public perceptions of AVs might, to some extent, be explained by differences in question framing and sample composition. For example, Payre et al. (2014) asked whether FAD is expected to be *useful,* while Kyriakidis et al. (2015) ask whether FAD is expected to be *enjoyable*, a quite different proposition. With respect to sample composition, Payre et al. (2014) draw on a smaller sample of *drivers only*, which is likely to introduce certain response biases, compared to the larger, *general* sample interrogated by Kyriakidis et al. (2015).

6.2 Perceptions of specific aspects of AV technology and operation

While evidence on *general perceptions of* AVs appears inconclusive to date (albeit with an indicative orientation towards negative views), all of the studies reviewed confirmed *concerns* about specific aspects of AV technology and operation. Respondents to the Schoettle and Sivak (2014) survey (who were positive overall about potential benefits) expressed high levels of concern regarding loss of access to driver controls (also confirmed by Accenture Research (2011)), AV operation being less safe than manual driving, security issues (pertaining to software and data hacking), and self-driven vehicles moving while unoccupied. Kyriakidis et al. (2015) found that respondents were most concerned about hacking of the automated systems, issues relating to the legal framework for AV operation and liability, followed by safety. Respondents to Casley's (2013) survey ranked safety as their most important concern (of three closed options specified) followed by well-developed laws to enable AV operation and lastly cost.

A study by Howard and Dai (2014) revealed that respondents could simultaneously acknowledge potential benefits of AVs, whilst also expressing concern about these same characteristics. Their survey of 107 potential early adopters (Science Museum visitors in Berkeley California) showed that increased safety and ability to multi-task were rated as 'attractive features' of driverless cars, but respondents were at the same time concerned about their anticipated loss of control over AVs.

6.3 Socio-demographic / psychological characteristics and perceptions of AVs

Several studies examine whether socio-demographic characteristics are associated with positive or negative perceptions of AVs. Males have been consistently shown to report more positive perceptions of AVs compared to females (Casley 2013, Power 2012, Kyriakidis et al. 2015, Payre et al. 2014, Schoettle and Sivak 2014), but were also more likely to express concern about liability issues than females (Howard and Dai 2014). Missel (2014) found that younger people, those living in urban areas (corroborated by Power 2012) and those that are 'just not interested in cars' were more likely to view AVs positively compared to other groups, as were respondents from emerging economies (Cisco 2013) as noted previously. Casley (2013) found that higher education levels were correlated with higher levels of concern about safety. Kyriakidis et al. (2013) reported that those with higher income, driving more and prior experience of adaptive cruise control were willing to pay more for AV technology than other groups.

In terms of psychological characteristics, Kyriakidis et al. (2013) sought to identify whether the 'big five' personality traits (openness, conscientiousness, extraversion, agreeableness and neuroticism) explained perceptions of user acceptance of, concerns about, and willingness to buy AV technology. The personality traits were not found to be strongly correlated with perceptions of AVs, apart from an observed consistent relationship between neuroticism and expressing concerns about data security.

Payre et al. (2014) investigated the relationship between attitudes towards AVs and intention to use FAD. They found that viewing FAD as pleasant, safe and useful (used as a measure of attitude) predicted intention to use FAD. They also confirmed that intention to use FAD was predicted by 'high sensation seeking'. High sensation seeking is defined in this context as "a trait describing the tendency to seek novel, varied, complex and intense sensations and experiences and the willingness to take risks for the sake of such experience" and this has previously been shown to be correlated with 'risk taking behaviour'. This indirectly indicates that FAD is currently perceived to be a high-risk activity relative to manual driving. Whether a person feels that they are able to control events that affect him/her (i.e. their 'locus of control') was not found to predict intention to use FAD.

6.4 Preferred modes of AV operation

Seventy percent of UK respondents (from a representative sample) reported opposition to the notion of banning manually driven cars to make room for driverless cars (Adams 2015). Howard and Dai (2014) also confirmed a preference for the integration of AVs with general traffic over the provision of dedicated, segregated lanes.

Payre et al. (2014) found that FAD was viewed most positively when related to the context of driving in monotonous (highways) (corroborated in Power (2012)) or stressful conditions (in congestion). At the same time however, there was lower intention to use FAD in built-up areas, which could similarly be viewed as stressful and congested. The authors explain that this may be due to higher anticipated hazard rates in built up areas and respondents perceiving themselves as more capable drivers than automated systems in complex, unpredictable situations. A review of 25,000 online 'soundbites' reported by Power (2012) also showed a positive attitude towards AV sharing initiatives, given the anticipated high costs associated with the private ownership of AVs.

6.5 Perceived benefits of AVs and use of in-vehicle time

Few studies have examined how people anticipate using in-vehicle time when free from the driving task. Howard and Dai (2014) found that people viewed the prospect of being able to multi-task and not having to find parking spaces as amongst the most positive aspects of AVs. By contrast, 41% of respondents to Schoettle and Sivak's (2014) survey expected to carry on 'watching the road' and this was the most frequently selected in-vehicle activity (followed by 'I would not ride in a self-driving vehicle' – 22.4% and reading – 8.3%). Casley's (2013) study also suggested that the prospect of being able to use travel time productively was not seen as an important motivation for acquiring an AV. Improved fuel efficiency, shorter journey times and environmental credentials of AV systems were rated as greater benefits.

Cyganski et al. (2014) note that the potential to use travel time productively is *assumed* to be a valuable prospective benefit (e.g. by governments), but that there has been little systematic research in relation to people's preference for this. An online survey of 1,000 German participants (a 'nearly' representative sample) was conducted. The survey measures current travel time uses as well as expected travel time uses for four AV 'use cases': 1. Highway pilot, 2. Valet parking, 3. Full automated vehicle, and 4. Vehicle on demand. The survey revealed that 77% and 69% of public transport users *never* worked on short and long-distance journeys respectively. Hence, travel time is only used 'productively' by a minority of travellers. Consistent with this is the finding that only 13% of respondents viewed the ability to use travel time for work as an advantage of AVs. A probit regression model confirmed that a positive attitude towards productive use of in-vehicle time was associated with: being male, not having a rail card, not having a high annual car mileage, using cars and trains frequently, having a positive perception of public transport and currently using travel time productively. It was also seen to be more beneficial in scenarios in which AVs were used in urban contexts.

Malokin et al. (2015) attempted to measure the 'utility' associated with the ability to use travel time productively on public transport and investigated the extent to which this attribute of AVs may trigger a change in commute mode choices (towards AVs). They conducted a revealed preference survey of commuters in the Sacramento – San Francisco Bay Area transportation corridor (n=2,120). Logit models indicated that the ability to work on the move in AVs could potentially contribute to a further 0.7 percent of commuters choosing lift sharing and a further 0.3 per cent of commuters choosing 'driving' alone (with people switching mainly from bus, but also from biking and commuter rail). It is noted that this model shift would translate to a significant increase in the number of cars on the road, though it is acknowledged that AV systems may also incorporate alternative models of car access.

6.6 Willingness to pay for full automation

Attempts to measure people's willingness to pay for full automation have so far revealed a wide range of valuations (summarised in Table 2) and there is no real consensus currently emerging in the literature. Schoettle and Sivak (2014) found that over half of respondents (57%) stated that they were *not* willing to pay extra for full automation although a quarter of their respondents were willing to pay at least $1,880 (the 75th percentile). Similarly, Kyriakidis et al (2015) found that about a fifth (22%) of respondents would not pay for full automation, but a small minority (5%) would pay in excess of $30,000. Payre et al. (2014) found that willingness to pay ranged between €0 and €10,000, with a mean of €1,624 (or $1,835) amongst the 78% of respondents (French drivers) that envisaged buying a fully automated vehicle. Adams' (2015) representative sample of UK residents generated a mean willingness to pay of £2,117 (or $3,239) to 'add driverless technology to their car'. Howard and Dai (2014) observed that 'over two-thirds of respondents of all nine demographic groups cite costs as a concern' and suggest that further econometric analysis is required to establish more robust measures of 'willingness to pay' for full automation.

Table 2: Willingness to pay for driverless technology

Source	Measure	Currency	Willingness to pay	USD exchange rate	USD equivalent
Schoettle and Sivak (2014)	75th percentile	USD	1,880.00	1.00	1,880.00
Schoettle and Sivak (2014)	90th percentile	USD	8,550.00	1.00	8,550.00
Kyriakidis et al. (2014)	95th percentile	USD	30,000.00	1.00	30,000.00
Payre et al. (2014)	Mean	Euro	1,624.00	1.13	1,835.12
Adams (2015)	Mean	Sterling	2,117.00	1.53	3,239.01

Notes: Exchange rates extracted from Google Finance on 24th Sept 2015

6.7 Stated preference mode choice experiments

Krueger et al. (2016) conducted a stated preference experiment to examine people's mode choices, when faced with the availability of a shared autonomous vehicle system with or without dynamic ride sharing. The stated preference survey was conducted online and completed by 435 urban residents in Australia. Prezi software was used to introduce the concept of SAVs, drawing on Burn's (2013) vision of future AV systems. A multinomial logit model is estimated, on the choice between SAV without ride sharing, SAV with ride sharing or not using SAV for a familiar trip. The likelihood of selecting an SAV option is found to increase if the respondent is younger, currently a multi-modal (and not a uni-modal car oriented) traveller, or if the journey is to work (indicating potential for AV commuter systems). The model predicts that up to 36% of trips could shift to SAVs which, consistent with Malokin et al.'s (2015) findings, is noted as significant and an indicator of the 'disruptive potential' of SAVs.

6.8 Summary

In summarising then, surveys of public opinion show awareness of AVs, and positive expectations about the potential benefits of AVs. However, manually driven private cars are viewed positively, and there is concern amongst the public over many aspects of AV operation (e.g. the loss of control and whether AVs will actually be safer than manual cars). The limited number of studies to date on use of in-vehicle time, have shown little indication of a perceived need to 'free up' time from the driving task, which is still enjoyed by many. There may however, be an emerging demand for automation technology in monotonous driving conditions (such as inter-urban highways) rather than in more challenging urban environments, where automation is not currently proven nor trusted.

It also appears that a limited range of methodologies have been applied to the study of public perceptions to date. It was noted in the chapter introduction that the studies reviewed have all employed quantitative survey instruments. Any quantitative measure of 'public' perception is heavily influenced by the composition of the sample and whether this is representative of particular population groups. This is not always adequately discussed in reporting of survey results. Quantitative research also limits respondents to the rating or ranking of closed options. The framing (i.e. provision of use case contexts), and definition of such closed response questions will always introduce certain response biases e.g. Asking "are you concerned about safety?", is likely to prompt someone unfamiliar with a technology to respond positively. An enhancement is to introduce AV operating scenarios to respondents before asking for their perception of different aspects of AVs (as was the case in Howard and Dai (2014) who showed footage from a television documentary before asking people for their perceptions of 'self-driving'). Carefully designed stated preference surveys (e.g. Krueger et al. (2016)) have the potential to provide insight into travellers' potential mode choices when faced with the option of using an AV. Lastly, given that most respondents are unlikely to have any real experience of AV technology to date, exploratory qualitative research would seem appropriate to gain in-depth understanding of people's levels of awareness of, and to explain their current views on, AVs. This would help to justify the definition of closed response options used in questionnaire surveys (as applied in Payre et al. (2014) in which a small number of (five) interviews were conducted to inform survey design).

7 Market analysis and adoption scenarios

In this final chapter, the report draws on these insights from the reviews of theory and of government, expert and public perspectives, to consider the prospects for the emergence of AVs as a dominant form of transportation.

7.1 AV market 'niche accumulation'

It is clear that there remains a great deal of uncertainty over the possible role of AVs in a future transport system. It has been shown, through applications of the MLP (in Section 3.1), that previous transitions in transport have been driven by (landscape level) structural changes (e.g. migration to cities and suburbanisation) and associated transport problems (in an existing regime) which have demanded new mobility solutions (e.g. private cars) that provide clear benefits to the public at large (e.g. affordable, flexible, personal transport).

As city populations continue to grow, the problems associated with private car oriented systems (congestion, air quality, lack of parking supply) will inevitably be exacerbated. This, coupled with a potentially growing demand for lifestyles built around mobile ICTs and sharing economies, has already provided the conditions for the emergence of a number of niche transportation markets – for example car clubs and ride / taxi sharing schemes for which demand is highest in space constrained urban centres. Given understanding of the current socio-technical context, the availability of current automation technology and existing market niches in transport, the following are suggested as potential stages in a process of 'niche accumulation' in relation to the possible adoption of AVs:

1. Wealthier groups are already purchasing vehicles with automation technology to alleviate themselves of aspects of the driving task, with perhaps the greatest potential for use on inter-urban journeys (e.g. adaptive cruise control). It is likely that further automotive technologies will be incrementally included in commercially marketed vehicles in response to market demand and safety regulations.

2. AV systems have already been implemented in controlled settings such as airports (e.g. personal rapid transit at Heathrow Terminal Five) and even in 'closed' rapid transit systems (e.g. the Docklands Light Rail in London, UK). Such systems are likely to become widespread and it is possible that all new light rail systems, which operate on a dedicated right of way, will be automated as a matter of course.

3. Demonstrator, 'flexible route' AV systems (e.g. shuttle buses) will be increasingly trialled in less controlled urban environments (but within dedicated spaces), raising their profile as a novelty technology / feature of the city. This has the potential to increase public confidence in the viability of live AV systems.
4. Demonstrator systems may later evolve into city-wide networks operating along dedicated lanes. Given that mass transport will be increasingly required to meet demand in space constrained urban areas, public transport and taxi operators may turn to automation technology to reduce labour costs (as is anticipated by Uber for example (Hern 2015)).
5. Flexible, AV sharing schemes (which may be booked in real time using smart phones) may emerge to replace existing car clubs, lift sharing and taxi schemes (first as demonstrator projects, but then as commercial operations).

7.2 AV adoption scenarios

However, for AV systems to move out of niche markets and into the mainstream (replacing private, manually driven cars) will require enormous changes in the way infrastructure is designed, operated, regulated and used. Supposing the transition does occur, then depending on how the environment of level four operation evolves, or indeed is managed, will potentially unlock wider benefits, or indeed create significant disbenefits. These are illustrated through the following two key rival visions:

- 'Business-as-usual' with road transport remaining an essentially private 'owner-user' set of practices, with more cars and traffic resulting from removed constraints on who can use vehicles and when. Few vehicles are electric as purchasers must still choose a single vehicle for all likely household journey needs, including occasional long-range trips. In this context congestion, energy consumption and emissions are likely to rise due to demand growth outstripping supply efficiency. Greater physical inactivity would be a potentially growing problem for public health.

This scenario contrasts with:

- 'Collective efficiency', with AVs variously owned publicly and used in return for fares like taxibuses, or collectively, like car club vehicles, or offered by private companies for hire like taxis. Ride-sharing is also encouraged. The total number of vehicles falls, but they are used more intensively and efficiently, meaning viable market opportunities for private sector operators. As a result, congestion is reduced due to fewer vehicles which also use the roads in a way optimised by the network management system. They are mainly electrically powered, as the integrated charging and use management system works effectively under collective ownership. Therefore local pollution and noise emissions fall and global emissions also fall. Significant areas of city centres and residential areas are freed from parking land uses and pedestrianisation spreads to reduce the operating complexity of AV systems and encourage physical activity and to balance the reduction of pedestrian freedom in some other streets used by AVs.

7.3 Concluding summary

To conclude then, it is clear that governments, highway authorities and the automotive industry have an important role to play in shaping how AVs ultimately emerge, in avoiding some of the potentially unintended consequences illustrated by the 'business-as-usual' scenario. At this stage however, there appears to be a mismatch between the expected societal benefits set out in government policies and the (absence of) demand for alternatives to manually-driven cars amongst the general public. Government also demonstrates itself to be reluctant to engage in policymaking in relation to the role of AVs, instead emphasising the wider economic benefits of 'high value manufacturing', seen as best maximised without 'political interference' in the transition process. Nonetheless, as the technology develops, social research will be essential for examining the nature of the transport and lifestyle related opportunities and problems as perceived by different groups in the population (and how these might alter in the medium term) and the potential for AVs to provide desirable solutions.

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APPENDIX A - SUMMARY OF STUDIES OF PUBLIC PERCEPTIONS OF AVS

Source	Survey, sample and population	Analysis	Findings
AA (2013)	A (likely online) survey of AA members' views of driverless cars (n=23,450). The survey was conducted by Populus in June 2013.	Descriptive	Revealed generally negative perceptions of driverless cars amongst AA members e.g.: Only 38% of respondents felt driverless cars would be as safe as human drivers, 57% felt driverless cars would have to be segregated from other traffic, 56% would not trust manufacturers / government assurances on safety, 65% said they enjoyed driving too much to ever want a driverless car.
Accenture Research (2011)	An online, population representative survey of UK and USA residents' views on whether they would use driverless cars (n=2006). Conducted in Nov and Dec 2010.	Descriptive	Revealed feelings of concern about driverless cars across approximately half the survey sample e.g. 51% of respondents reported that they would not be comfortable using a driverless car. The most important factors to encourage use of driverless cars amongst this group included 'ability to take back control', '100% reliability', and the prospect of 'reductions in accidents'.
Adams, T (2015)	An interview survey of 1,099 UK adults (18+) conducted in August 2015 by Opinium Research. Weightings applied so that results are representative of UK population.	Descriptive	The survey reveals general wariness about AV technology e.g.: 61% of respondents said they would probably or definitely not consider buying a driverless car. 75% of respondents felt that they would be a better driver than a computer. 70% of respondents were opposed to the idea of banning driven cars to make room for driverless cars. By contrast, 82% of respondents were in favour of monitoring software that would reward safe drivers through reduced insurance premiums. 65% of respondents were also in favour of road pricing (in place of VED and fuel duty) On the other hand 69% of respondents noted that the passing on of vehicle logging data to vehicle manufacturers would decrease the appeal of AVs.

Source	Survey, sample and population	Analysis	Findings
			Respondents were most concerned about AV sensors not detecting hazards, followed by computers crashing and hackers gaining control.
Casley (2013)	An online and postal survey of students of Worcester Polytechnic Institute (USA) and students at a nearby high school (n=450). The sample is not representative of a well-defined population (but implicitly focusses on younger groups). The survey examines factors associated with propensity to buy a driverless car and level of concern about using a driverless car. The survey was conducted in Feb and Mar 2013.	Mainly descriptive. Some factor analysis and use of 'estimated marginal means' to compare responses across groups (age, education, gender, income)	The survey examines which of safety, cost and acceptability of legal structure are most important to AV adoption amongst survey respondents. Safety is ranked as the most important consideration, followed by legal structure and cost. Fuel and time efficiency and environmental credentials were ranked as important positive attributes of AVs, but potential of increased productivity (whilst in transit) was not. Males were shown to be more likely to be early adopters of AVs than females. Those with higher education levels reported greater concern about safety. Those with higher incomes reported lower concern regarding legal frameworks for AVs and lower concern about costs of AVs.
CISCO systems (2013)	A (likely online) survey of 1514 respondents in three age groups (18-29,30-49 and 50+) across 10 countries. The sample population (and whether the sample is representative) is not defined. The date of the survey is not defined (likely 2013)	Descriptive	This survey indicated a slightly more positive attitude towards driverless vehicles, though the question wording is rather simplistic: 57% of respondents reported that they would ride driverless cars, with higher proportions reported in emerging markets (e.g. 95% in Brazil, 86% in India vs 45% in UK, 28% in Japan).
Cyganski et al (2014)	An online survey of 1,000 participants in Germany. The sample was nearly representative of the German population. The survey examined responses to four use cases: 1. Highway pilot, 2. Valet parking, 3. Full automated vehicle, 4. Vehicle on demand. The focus of the analysis was on whether ability to use travel time productively was	Descriptive analysis of attitudes towards different use cases and likely travel time use. Probit model to identify factors associated with preference for working in AVs	Attitudes towards AVs: 57% of respondents declared an interest in automated driving. 62% said "they would not want to hand over the complete vehicle operation" Insights into travel time use: Current travel time use: Public transport: Enjoying the landscape and talking to companions were noted as the most frequent current uses of travel time on buses and trains. Working is only undertaken by a

Source	Survey, sample and population	Analysis	Findings
	viewed as a valuable attribute of AVs in different scenarios		minority - 77% and 69% of respondents never work on short and long distance journeys respectively. In car travel time: “Focussing on the ride and the route” is the main activity. 80% of drivers listen to music. 7% of drivers reported working. Potential travel time use in AVs was found to vary according to the use case presented: In line with current travel time use, enjoying the landscape and travelling companions were seen as the most positive use of travel time. Only 13% of respondents felt that being able to work on the move was an advantage. A positive attitude to the potential to work in AVs was associated with: Being male, not having a rail card, not having a high annual car mileage, using cars and trains frequently, having a positive perception of PT, currently using travel time productively. It was also seen to be more beneficial in use cases 3 and 4 i.e. scenarios in which AVs are being used in urban contexts.
Howard and Dai (2014)	An exploratory self-completion paper survey of 107 likely early adopters (Science Museum visitors) in Berkeley California. The sample is not intended to be representative. The survey was conducted in Spring 2013.	Mainly descriptive. Logit models used to identify factors associated with opinions of different aspects of AVs	Respondents rated: “increased safety, amenities like multitasking, and convenience of not having to find parking to be the most attractive features of self-driving cars.” (of the closed options specified) Respondents were most concerned about liability, cost and lack of ability to control the vehicle (of the closed options specified) The most popular mode of operation was rated as ‘AV integrated with general traffic’ (chosen by 46% of the sample, against closed options of separate lanes – 38% and no opinion – 11%) The logit models revealed a number of demographic associations with perceptions of different aspects of AVs: “Men are more likely to be concerned with liability, and less likely to be concerned with control than women. Individuals with higher income are most concerned with liability, and those with lower

Source	Survey, sample and population	Analysis	Findings
			income appear to be more concerned with safety and control. Single-occupancy vehicle commuters and cyclists were most concerned with giving up control. All groups were concerned with costs.”
Insurance.com (2014)	An online survey of 2,000 American drivers (50% male) conducted in June 2014. It is not known whether the sample is representative of a particular population.	Descriptive	This survey indicated a general resistance to the prospects of buying and using driverless cars amongst current American drivers. E.g. 22.4% stated they would be very likely to buy a self-driving car. This increased to 37.6% of respondents given hypothetical 80% reductions in insurance costs. 24.5% stated they would never buy a self-driving car. 76.2% stated the would not trust a self-driving car to take their child to school.
Krueger, Rashidi and Rose (2016)	Online stated preference survey of 435 urban residents in Australia. The stated preference test examined potential for users to switch to a shared autonomous vehicle (SAVs) for a familiar trip. Prezi software was used to introduce the concept of SAVs	Multinomial logit model of choice between SAV without ride sharing, SAV with ride sharing or not using SAV.	The likelihood of selecting an SAV option for a familiar trip reduces with waiting time. Young travellers are relatively more likely to choose one of the SAV options. The likelihood of selecting an SAV option increases if the journey is a work trip. SAV with ridesharing is less attractive if the journey is a leisure trip. People with multi-modal travel patterns are more likely to select SAV. It is suggested that uni-modal, car oriented travellers are likely to be hesitant to adopt SAVs The stated preference survey indicated that up to 36% of trips could shift to SAVs. The authors note that this indicates the ‘disruptive potential’ of SAVs.
Kyriakidis, Happee and Winter (2015)	A 63-question online survey (n=4886) of respondents from 109 countries conducted in July 2014. No information is given on how the sample was recruited.	Descriptive and bivariate correlations. The paper has a focus on the relationship between the ‘Big Five’ personality traits	Manual driving was reported as the most enjoyable and full automation the least enjoyable mode of driving Respondents were not in favour of vehicles with no steering wheel (M=2.94 on a scale of 1 to 5 with 5 being agreement) Respondents were in agreement with sharing data with surrounding vehicles, vehicle developers and roadway

Source	Survey, sample and population	Analysis	Findings
		(openness, conscientiousness, extraversion, agreeableness and neuroticism) and perception of AVs.	organisations, but were less positive about sharing data with insurance companies and tax authorities. Respondents reported most concern about misuse and hacking, followed by legal issues and safety. Data privacy was their smallest concern. Respondents were willing to pay more for full automation than for partial automation. The higher the level of automation, the more secondary tasks respondents would be willing to engage in especially rest, watch movies, or read. Most people expect AVs to be on the road by 2030. 51% of respondents expected automated driving to be so advanced in 30 years' time that manual driving would no longer be allowed. There were few correlations with demographic characteristics: Men were found to be more willing to pay for automation than women. People with higher income / those that drive more / those that currently use adaptive cruise control were willing to pay more for automation. Personality factors were not strongly correlated with public opinion – Neurotic people were more concerned about data transmission from AVs. People in higher income countries were more concerned about data transmission from AVs.
Malokin et al (2015)	Survey of commuters in the Sacramento – San Francisco Bay Area transportation corridor (n=2120).	Multi-nomial mode choice model is estimated. Propensity to use travel time productively is included as a predictor variable.	Ability to use time productively is shown to add to the utility of train travel and detract from the utility of bus (lack of space) and car (lack of ability to use time) commuting. The logit model is then used to predict mode shares for scenarios in which AVs become available, and hence open up the potential for using in car time productively. The models indicate that lift sharing would attract 0.7 percentage points more commuters and driving alone 0.3 percentage points more commuters (with people

Source	Survey, sample and population	Analysis	Findings
			switching mainly from bus, but also biking and commuter rail). The switch is triggered given that driving now has the added utility of productive time use, which is no longer unique to rail / PT. It is noted that the model shift would translate to a significant increase in the number of cars on the road, though it is acknowledged that alternative models of car access may also be required in the transition to AVs.
Missel (2014)	Ipsos conducted 1,001 interviews with a nationally representative sample of the British public aged between 16 and 75 years old. The fieldwork was conducted between 26th June and 3rd July 2014	Descriptive	The survey revealed a general wariness towards AV technology amongst the British public and demonstrated a number of demographic differences: Only 18% of respondents felt it important "for car manufacturers to focus on driverless technology". There was greater interest in AVs amongst men, those living in urban areas / London, younger people, those reporting that they are 'just not interested in cars'. The safety benefits of vehicle development were shown to be far more important than new technology per se. 50% of those surveyed reported "that new technologies such as forward-collision avoidance systems and lane departure warning systems to make cars safer are the most important for manufacturers to focus on."
Payre, Cestac and Delhomme (2014)	An online survey of 421 French drivers is conducted to identify predictors of intention to use a fully automated car. The sample is not representative of any defined population and the sampling frame is not adequately discussed. Respondents are recruited through email distribution lists relating to ergonomics, psychology, engineering (this is not really explained).	Descriptive statistics Bivariate correlations. Linear regression estimated on 'intention to use a fully automated car' (7-point Likert scale)	The questionnaire tested six hypotheses: 1. Fully automated driving (FAD) would be considered more useful than manual driving. This was confirmed – 68.1% of respondents scored above 4 on a 7 point scale. 2. Positive attitudes towards FAD (whether it is pleasant, safe, useful) predicts intention to us a FAD. This was confirmed (but seems a rather obvious correlation given the hypothetical nature of the scenario). 3. High sensation seekers intend to use FAD more than low sensation seekers; This was confirmed. Drivers with 'external locus of control' intend to use FADs more than drivers with 'internal locus of control'. This was rejected: 'Locus of control'

Source	Survey, sample and population	Analysis	Findings
			("a personality trait that echoes the extent to which a person believes he or she can control events that affect him/her") was not found to be correlated with intention to use FAD. 4. Drivers expected to be more interested in FAD on highways, in traffic congestion and when driving is monotonous, than in built-up areas. This was confirmed. 5. Drivers would be interested in FAD when impaired (after drinking). This was confirmed. 71% of participants reported interest in using FAD while impaired. 6. Men would be more interested in FAD than women. This was confirmed at a bivariate level. Statistical significance was lost when contextual acceptability (relating to the extent to which people felt that driving is boring, FAD is safer, preference for manual control, use of FAD when driving with passengers) and interest in driving when impaired were included in the regression model i.e. there are underlying preferences grouped within genders.
Schoettle and Sivak (2014)	An online survey of public perceptions of autonomous and self-driving vehicles in the US, UK and Australia (n=1533 adults across the three countries. There is no discussion of whether the sample is population representative). The survey was performed in July 2014.	Descriptive statistics ANOVA to identify bivariate associations between perceptions of different aspects of AVs and demographic attributes.	This survey reveals a number of conflicting perceptions: The majority of respondents had heard of AVs (70.9% USA, 66% UK, 61% Australia), held a general positive opinion of AVs (56% US, 52% UK, 62% Australia), and held positive expectations about the potential benefits of AVs (e.g. fewer crashes, reduced crash severity, lower emissions) By contrast, at the same time respondents also reported high levels of concern regarding not having driver controls, riding in AVs, security issues, AV operation being less safe than manual operation, self-driving vehicles moving when unoccupied, and self-driven commercial vehicles (including buses and taxis) - Concern was higher amongst females compared to males. Notwithstanding these concerns, a majority expressed interest in owning self-driving technology (68% Australia, 66% USA, 63% UK).

Source	Survey, sample and population	Analysis	Findings
			With respect to use of travel time use, the most frequently cited response was "Watch the road even though I would not be driving" (41%).
TE Connectivity (2013)	A telephone (landline and mobile phone) survey of US adults. 1000 calls were completed in May 2013. No information is given on the nature of the sample or sample frame.	Descriptive statistics	This survey reveals a generally negative view of AVs: Nearly 70% of respondents reported that they would not be comfortable in an AV (males reported lower levels of concern compared to females). 55% of respondents ranked safety as the most important aspect of AVs that would need to be improved before AV technology became acceptable. 60% of respondents noted that they would be reluctant to give up driving control. Younger groups were more likely to report being comfortable in a car with driverless technology than older groups (18-34: 38%, 55-64: 20%, 65+: 18%).
J.D. Power (2012)	Summarises results from the 2012 US Automotive Emerging Technology study. 17,400 vehicle owners were surveyed. The survey included a broad range of topics, including perceptions of AV technology.	Descriptive (detail on method is lacking)	20% of respondents specified that they would definitely or probably purchase autonomous vehicle technology. Compared to the sample average, higher interest in AV technology was shown amongst males (25%), those aged 18-37 (30%), those living in urban areas (30%) and those with an interest in automatic parallel parking features (41%). The study also reviewed 25,000 online soundbites from social media. The authors note that 'online sentiment is generally positive'. E.g. Vehicle owners recognise safety benefits and the ability to make use of free 'in-vehicle' time. Car enthusiasts are unenthusiastic about loss of status / losing the pleasure of driving. Automated driving is seen as most beneficial in 'boring' driving contexts, but would people wish to retain the ability to drive in pleasurable environments.

Source	Survey, sample and population	Analysis	Findings
			Vehicle sharing programmes are seen as positive initiatives given the expected costs associated with private ownership of AVs.
Van der Waerden et al (2015)	Stated preference survey of 673 respondents in the Netherlands.	Respondents are asked to select compare different driving scenarios and select their preferred option	16 choice alternatives are presented (combined randomly in 8 choice tasks, consisting of 2 driving situations and 1 'none of these' option). The driving situations are defined in terms of: level of driving automation, road type, length of trip, traffic density, familiarity with the road, ability to perform secondary task. This is an early paper, and the results are somewhat under-developed. However, the modelling shows that drivers prefer systems with partial rather than full automation.

APPENDIX B - SUMMARY OF SIMULATION MODELS OF AV SYSTEMS

Source	Method	Findings
Brownell et al (2014)	A comparison of the potential efficiency of personal rapid transit (PRT)oriented autonomous taxis (individuals are picked up and dropped off at taxi ranks) vs a smart paratransit (SPT)autonomous taxi system (a demand responsive system). Fleet sizes, costs, and vehicle occupancies are estimated for simulated trips in New Jersey, USA.	Five criteria a transit system must satisfy to challenge private vehicle ownership: "(a) the system must reduce congestion and decrease commuting times, (b) it must be safer than the conventional automobile, (c) it must have fewer negative environmental impacts than the conventional automobile, (d) it must be economically feasible, and (e) it must offer its passengers comfort and convenience to rival the automobile." Potentially met by an autonomous taxi network. Paper compares the personal rapid transit (PRT) model (individuals are picked up and dropped off at taxi ranks) and the smart paratransit (SPT) model (a demand responsive system. Trips are booked and vehicles allocated to collect and drop off people). A modelling exercise is performed to estimate and compare the efficiency (in terms of travel times, fleet size and costs) of PRT and SPT autonomous taxi systems as replacements for private cars. SPT is shown to be more efficient in terms of fleet size and cost, but will have higher vehicle occupancies (more ride sharing). It is suggested that SPT could be competitive with private car ownership, given that the fleet size is reduced and is able to use road space more efficiently (hence reducing congestion). However, it is acknowledged that the analysis has not considered transit criteria 5 (comfort and convenience) which will be a major barrier to the replacement of privately owned cars with shared autonomous taxis (especially given the observation that SPT requires ride sharing which may not be preferred).
Fagnant et al (2015)	A simulation model of potential uptake of automated taxis in Austin, Texas. Mode choices based on assumptions rather than a stated preference survey.	It is noted that automated vehicles will 'merge the paradigms of short term car rentals (car clubs) and taxi services'. The simulation model assumes that all travellers living within a 12mi by 24mi area of Austin choose to travel by automated taxi. This somewhat limits the validity of claims made on the basis of the simulation as the modal transfer to automated taxi is not based on evidence from stated preference surveys. On the basis of this assumption, it is estimated that every automated taxis could be expected to replace the private ownership of around 9.34 conventional vehicles. Hence under this scenario, land that is currently used for the storage of private vehicles could be turned over to amenity. On the other hand, automated taxis were shown to generate an

Source	Method	Findings
		additional 8% of 'empty-vehicle' travel that would not exist if travellers drove their own vehicles.