Social and behavioural questions associated with Automated Vehicles A Literature Review

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I. Introduction & Methods

This literature review is part of a wider scoping study commissioned by the UK Department for Transport that aims "to identify the key social and behavioural questions associated with AVs". This literature review has informed the formulation of the research questions and recommendations which can be found in the main report. This review summarises the various themes and topics that have been addressed or discussed in the academic and in the grey literature relating to the behavioural, social and societal aspects of automated vehicles (AVs). The study also highlights the gaps in the literature linked to these topics.

In order to identify written material potentially relevant to the topic of the study, a range of academic and non-academic databases has been surveyed, yielding over 50 000 results. This initial search was then narrowed down to identify material directly relevant to the topic and a total of 432 documents were finally selected for examination. These documents included a range of academic and grey literature (e.g. consultancy or think tank reports). All 432 items were analysed and screened on title and abstract and coded based on thematic codes; in total, circa 100 thematic codes were created. Following this, an in-depth analysis of the most relevant and thorough documents, over 60, was undertaken. The results of the initial screening and the in-depth analysis were then cross-referenced to produce a literature review based on key themes. A detailed explanation of the methods used in the context of this investigation can be found in Annex A.

It is important to note that the abbreviation AV(s) is used in a comprehensive and inclusive way in this literature review. It covers the full range of automation (e.g. full or partial) and encompasses both vehicles that are "automated" (i.e. operate independently of other vehicles) and those that are "controlled" (i.e. follow instructions set outside the vehicle, be that by a second vehicle or central system). This general term has been deliberately chosen to reflect the lack of precision found in the literature. Detailed definitions of the terms used in this report can be found in the main report and in Annex B of this report. The term "connected and automated vehicle" (CAV) refers specifically to AVs that are connected to each other (Vehicle to Vehicle) or to their environment (Vehicle to Infrastructure).

First, this report summarises the results of the database search, identifying recurrent topics and gaps in the literature. Second, a summary of the in-depth literature review is presented. This summary is divided into 18 key thematic categories based on the following diagram (Figure 1 below), further explained in the main report. The summary of the literature review in Part III corresponds to the full literature review which can be found in Annex C.

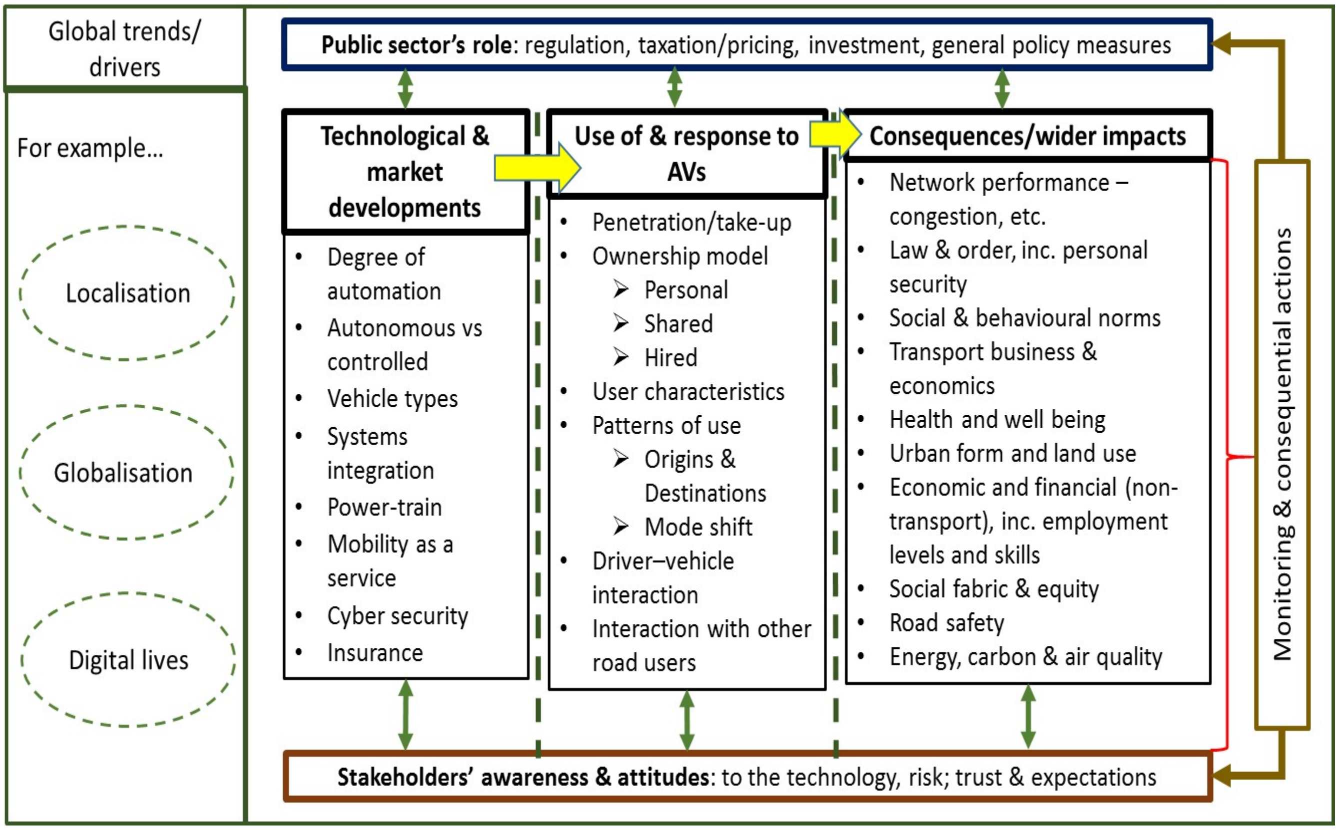

Figure 1 Conceptual Framework

II. Results of the databases search

The aim of the database search was to survey a range of databases - academic and non-academic - in order to find relevant written material related to behavioural, social and societal aspects of AVs. In total, five of the most relevant bibliographic databases were searched. In addition, relevant grey literature material was found in a range of non-academic databases and existing bibliographies. Selected keywords and their synonyms were used to undertake the search. The methods are described in detail in Annex A. Here the key findings of the database search are summarised.

Bibliographic Database: Initial Search Results

In total, the database searches using all keywords and synonyms related to AVs yielded 50,200 results. These search results were dominated by technical literature, as shown in Figure 2 below, the majority of the literature comprised engineering, computer science, and mathematics documents, as categorised by the databases. An aggregation of the material found on Scopus (one of the most comprehensive databases) indicates that social science references linked to AVs represent less than 6% of the total[1]. This clearly suggests that most AV related research, primarily academic, has focused on technical and technological aspects of AVs and not on the associated social, behavioural and societal issues. The pace at which AV technology is developing underscores the urgency of the need to better understand the social and behavioural implications of this tool.

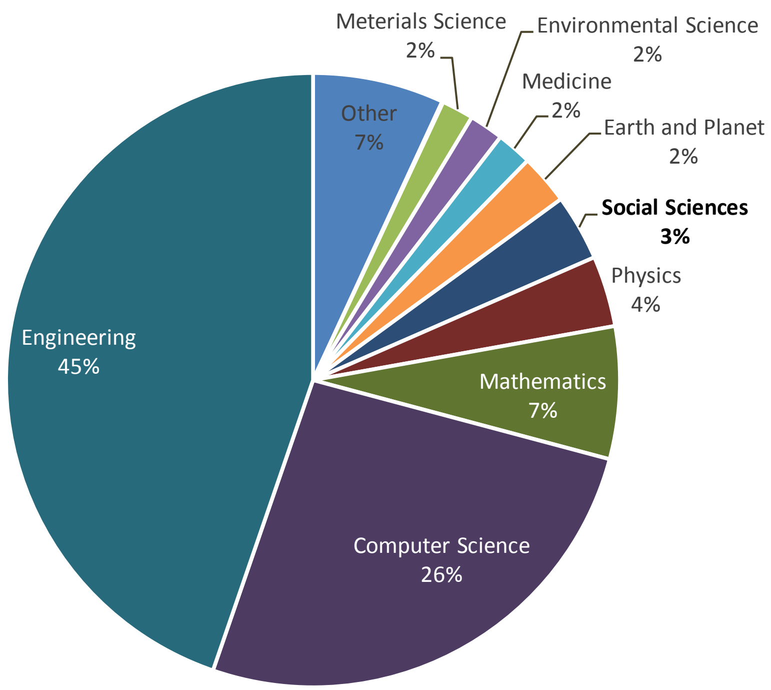

Figure 2 Scopus Database search results by field of study

As would be expected, given that AVs were first tested in the 1990s, the search results are dominated by documents from the last 10-15 years. Figure 3 below shows the years of publication for the search results, indicating an upward trend, continuing to present year. A large number of earlier documents, particularly those making up the bump in the mid- to late-90s referred to driverless trains, and were screened out in subsequent stages of the literature review.

[1] Note that this figure has over 100% results as each bibliographic reference can be categorised in more than one category (e.g. a reference addressing social science issues linked to AVs can also appear in engineering if it covers this topic)

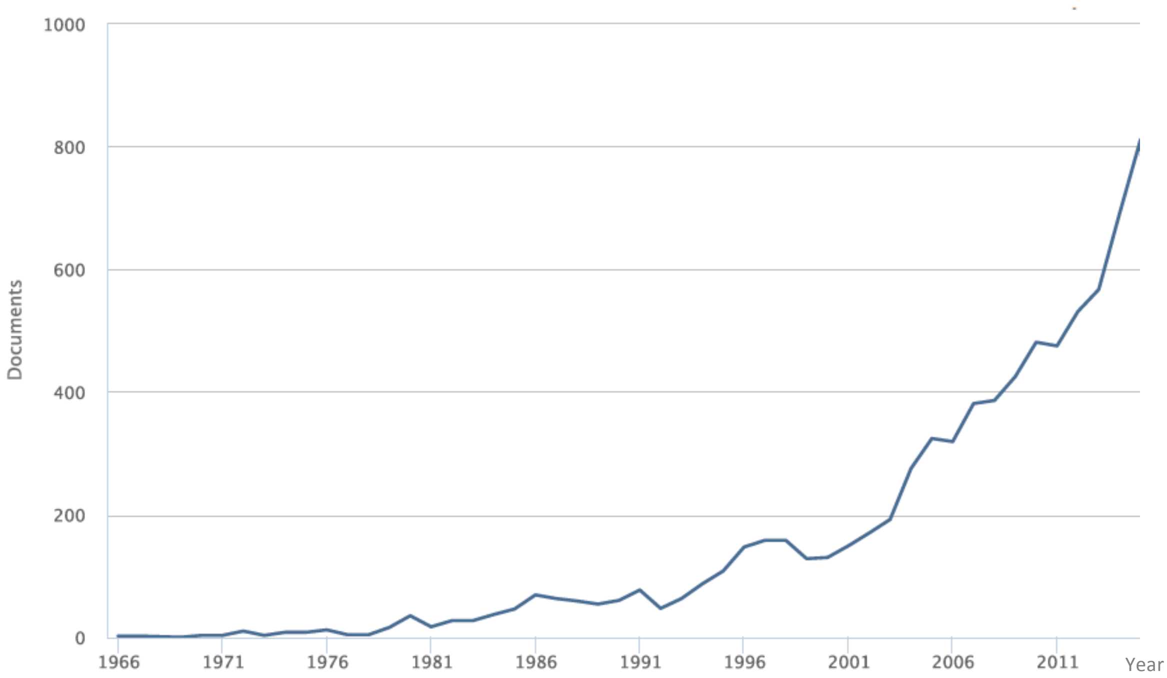

Figure 3 Scopus Database search results by year of publication

The two graphs below (figure 4 and 5) illustrate the country of origin of the documents in the search. The first shows unfiltered results, while the second shows only the search results for the social science discipline. While the USA dominates in both cases, in particular amongst the academic literature, the graphs show that the UK is one of the leaders in the production of social science knowledge relevant to AVs. However, as indicated in the second graph (figure 5), the number of references produced by UK authors in the field of social science, totals just above 40, which remains limited given the significance of the topic. Finally, these graphs need to be interpreted with caution as they may not represent a global sample, but rather focus on references written in English.

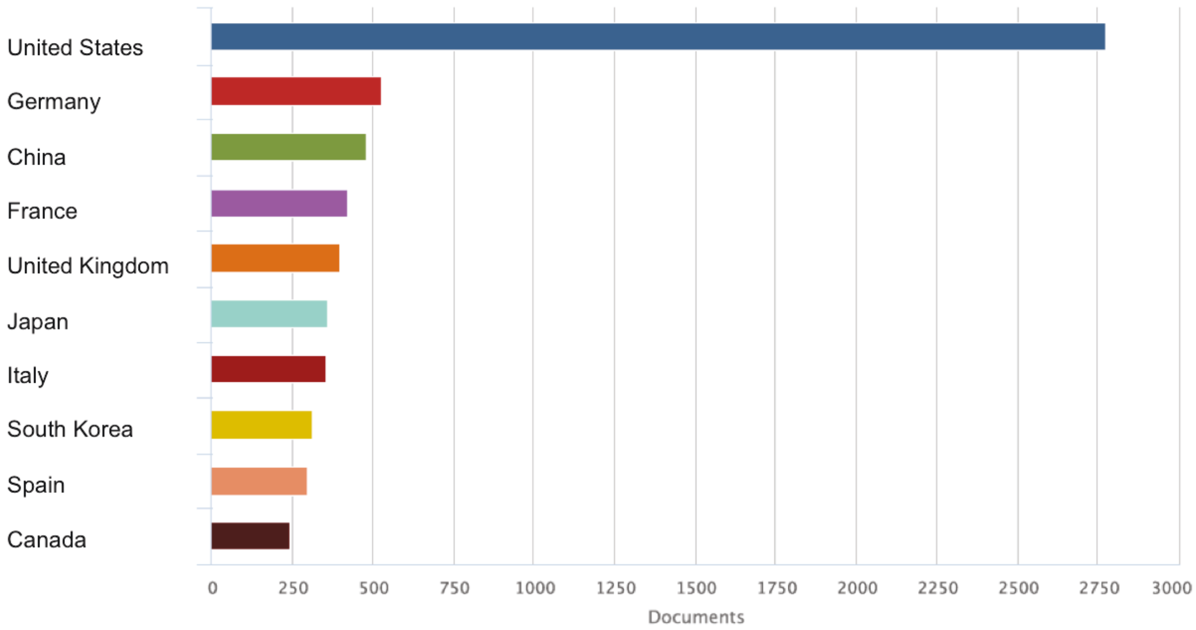

Figure 4 Scopus Database search results by country of publication

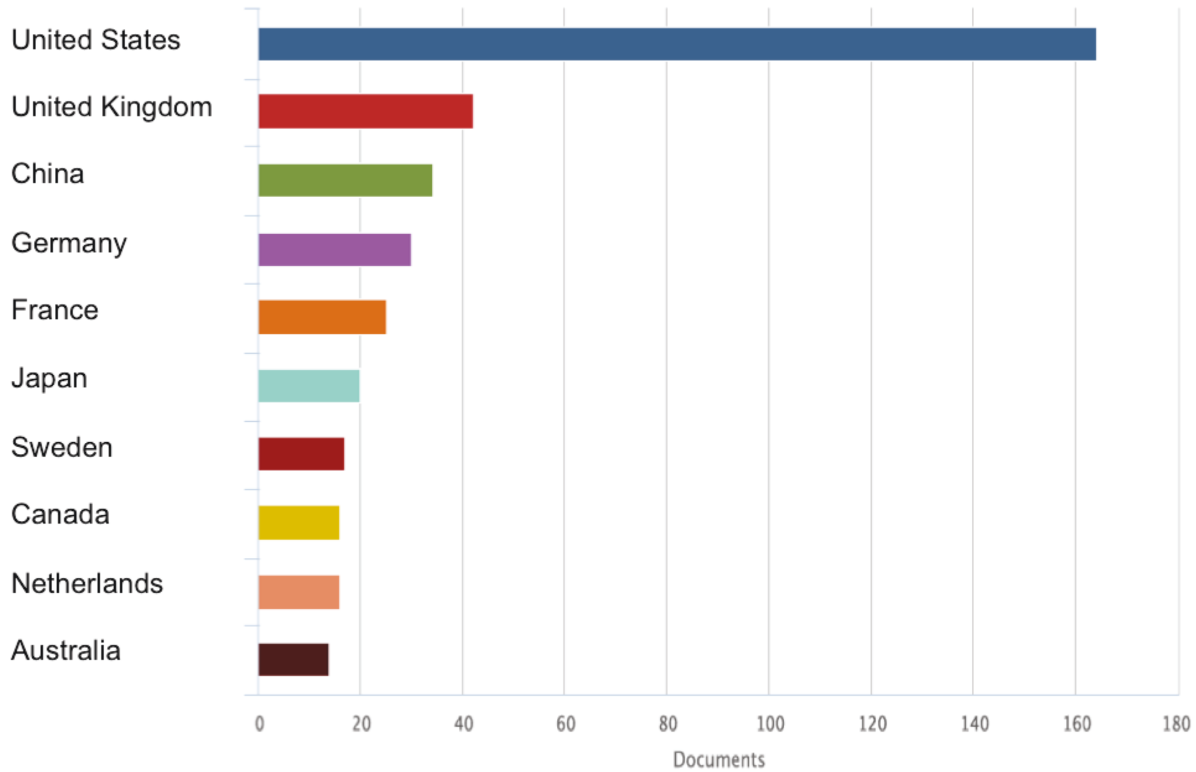

Figure 5 Scopus Database search results for social science, by country of publication

As described in the methods section (see Annex A), these results were narrowed down by excluding irrelevant subjects leaving 2296 results. These documents, combined with the items discovered informally, were screened for relevance and narrowed down to produce a body of literature of 432 documents. Table 1 below indicates the types of documents in the body of literature. Academic sources represent the majority of the documents examined. Given that the most relevant academic databases were thoroughly surveyed, the number of academic sources identified in the context of this study is likely to be representative of the total number of existing academic sources written in English.

Academic Sources Included:		**Grey Literature Sources Included**	
125	peer reviewed articles	20	Official Reports
7	academic books	40	Consultant/Industry Reports
116	Other (reports, presentations, conference papers)	42	Serious Broadsheet or Magazine
248	**All Academic Literature**	5	Light Tabloids or Magazine
		5	Marketing Material
		9	Visual Presentation
		63	Other
		181	**All Grey Literature**

Table 1 No. of academic and grey literature sources, by type

Topic Coding

As further described in the detailed methods section (Annex A), a list of 44 relevant thematic codes were defined (see Annex D for list of codes) in order to code the 432 references selected. Each reference was then screened on title and abstract, and over a hundred references were screened based on further reading, including over 60 references which were read in-depth. If one of the 44 thematic codes was discussed, either briefly or in-depth, by a reference, it was recorded and the relevant code was assigned. The histogram below (figure 6) shows the frequency of the relevant topic codes for both the grey and academic literature.

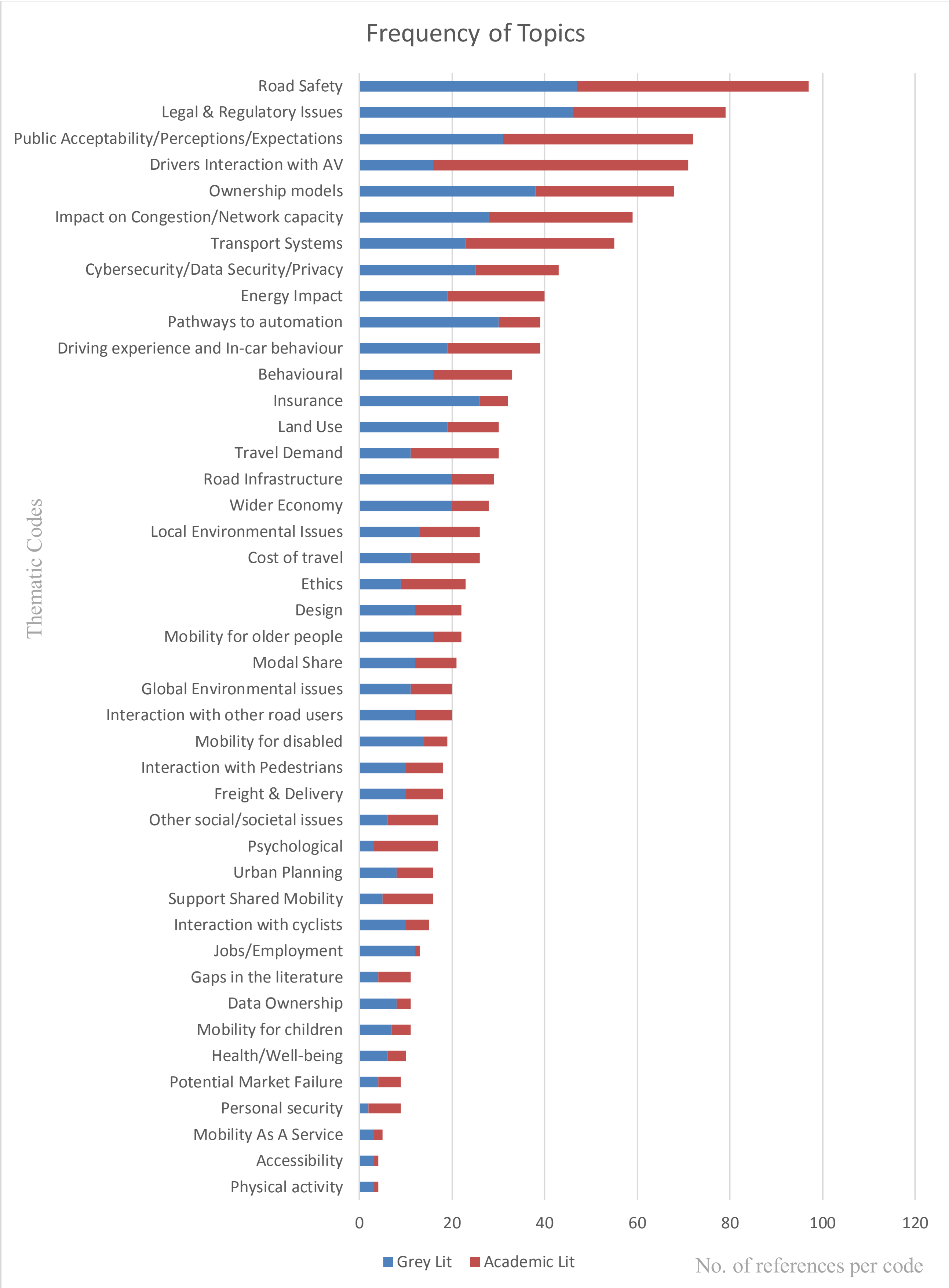

Figure 6 Frequency of topic codes in grey and academic literature

Findings indicate that **road safety, legal/regulatory issues, public perception, drivers' interaction with AVs and ownership models** were amongst the most commonly discussed topics (as illustrated in Table 2 and Figure 7 below). Road safety is one of the main selling-point/argument in favour of the introduction of AVs, hence the fact that most references address this point. Legal and regulatory issues are a frequent object of debate, especially over the last five years as it has a significant influence on the development and adoption of the technology. Public perception is addressed by both academic studies and the grey literature as it can also have a significant impact on the development and adoption of the technology. Drivers' interaction with AVs is a topic frequently examined by the literature and there is a relatively large body of academic work focusing on this topic (see Table 2 below), in particular drivers' reengagement with the vehicle in cases of emergency. Furthermore, the different ownership models that are likely to emerge in parallel with the development of AVs are frequently discussed, in particular in the grey literature. This is likely to influence the different roll-out scenarios linked to AVs use and adoption. Each of the topics in Figure 6 above are grouped and summarised in the literature review (in section 'Summary of findings from literature review' and in Annex C).

Topics More Frequently Discussed in Grey Literature	Topics More Frequently Discussed in Academic Literature
Road Safety	**Driver's Interaction with AV**
Legal & Regulatory Issues	**Road Safety**
Ownership Models	**Public Perception**
Public Perception	**Legal & Regulatory Issues**
Pathway to automation	**Network capacity**

Table 2 Topics most frequently discussed in the academic and the grey literature

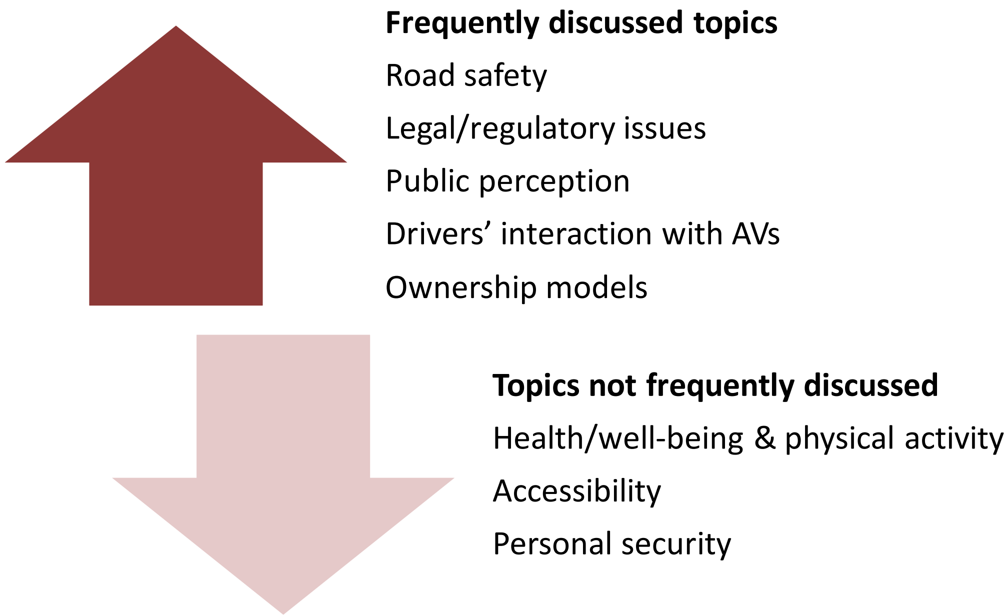

Figure 7 Most and least frequently mentioned topics linked to AVs (Combining both academic and grey literature)

However, a range of topics appear to be understudied in the literature. For instance, **health/well-being and physical activity linked to AVs was one of the least discussed topics, along with accessibility and personal security** (see Annex D for description of each code). The results of the coding clearly suggest that a range of social, behavioural and societal issues linked to AVs are under-researched.

Finally, it should be noted that while there were more academic documents in the body of literature, there were more total coding instances for grey literature, indicating that the grey literature documents tended to be more comprehensive and cover a wide range of topics. Conversely, many academic articles focused narrowly on one or a small number of topics.

III. Summary of findings from literature review

As mentioned in the previous section, findings of the screening, coding and in-depth review suggest that overall the social, behavioural and societal aspects of AVs are under-researched. This lack of research may be explained by the fact that AVs are still mostly in the conceptual development phase and pilot projects are limited. The grey literature has been more prolific in discussing AVs, but tends to lack evidence, rigour and in some cases impartiality.

In this section the in-depth review of a range of topics found in the grey and in the academic literature is summarised (further information regarding the methods can be found in Annex A). It follows five main thematic categories, as referred to in Figure 1 above, including:

1. Technological and market developments
2. Use of AVs
3. Consequences/Wider impacts
4. Stakeholders' awareness and attitudes
5. Public Sector's role

Each of these categories contains sub-themes. The extended version of the literature review can be found in Annex C. Each theme summarised in this section is connected via hyperlink to the detailed literature review for ease of reading.

a. Technological and market developments

1. Technological and infrastructure developments

Introduction

In this section we describe what has been written in the literature (grey and academic) regarding technological and market developments of AVs as it will affect the adoption and the roll-out of AVs and ultimately wider social, behavioural and societal issues. This section also addresses infrastructure development issues linked to AVs (Detailed literature review is available in Annex C).

Potential pathways to automation observed in the literature:

- The '**evolutionary**' pathway entails equipping cars with increasing levels of automated capability. This pathway is viewed as a four or five step process, with increasing automation and decreasing human involvement (Table 3 below)
- The '**revolutionary**' approach involves developing a fully automated vehicle immediately, without the intermediate steps

- A **‘hybrid’ model** of both pathways happening in parallel

SAE Level	Name
0	**No automation** the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems
1	**Driver assistance** the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
2	**Partial automation** the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task
3	**Conditional automation** the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene
4	**High automation** the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene
5	**Full automation** the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver

Table 3 SAE Standard - Adapted from OECD, 2015

AV infrastructure development

- The development of AVs will impact infrastructure: while it may reduce the need for certain types of infrastructure, it may also demand more technologically enhanced infrastructure to support Vehicle-to-Infrastructure (V2I) communication

Further research

Further research is needed to understand what infrastructure is required to support different type of AVs and roll-out scenarios (e.g. connected or non-connected AVs, urban or rural set up, type of vehicle, segregated lanes, etc.) Do AVs require large scale infrastructure to function safely and effectively and what are public attitudes/acceptability towards this?

Further investigation is also needed to understand the potential costs of road infrastructure, pricing and financing options (Who should pay for the new infrastructure? What type of infrastructure should be supported depending on the desired scenario...)?

2. Data and Security

Introduction

Security and data use linked to AVs are often mentioned as areas of concern by experts and by the public (see section on public perception). This literature review found limited written material covering these issues, however it focused on the behavioural and social aspects of AVs and not on the technical aspects. It is therefore possible that in databases dedicated to technological and engineering issues these topics are addressed more fully. In this section issues raised related to security and data in relation to AVs are summarised (Detailed literature review is available in Annex C).

Cybersecurity issues

- Potential cybersecurity issues linked to CAVs are a concern for the public and for experts
- However other sectors (e.g. aviation) have demonstrated that it is possible to safely manage cybersecurity threats, via measures like industry standards or specialised security systems
- Potential privacy issues linked to AV data use and ownership need to be addressed - through privacy standards and regulations for instance - as they could impact public perception and market uptake

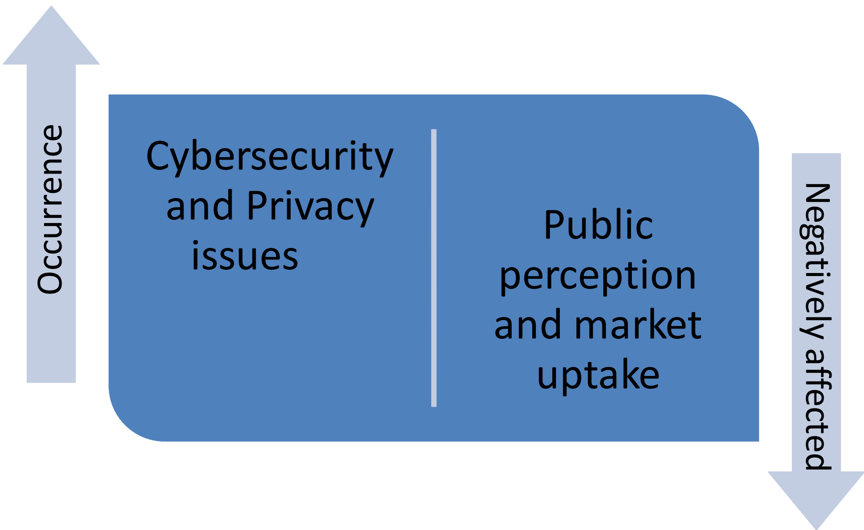

Figure 8 Cybersecurity and Privacy issues linked to CAVs

Data Use and Ownership

- The literature suggests that data collection and data sharing present opportunities to improve transport systems, in particular in the context of CAVs, and should be actively supported

Further research

Further research is needed regarding cybersecurity and data ownership if CAV systems are to be developed. Questions such as 'which safeguards (e.g. standards) should be established to prevent the misuse of data? who should own and control data generated by AVs? For what ends will the data be used? How will customer's data be protected? And how to ensure that data is shared by companies to enable connectivity? With whom should the data be shared?' seem to be under researched, yet they could have significant impact on the development of future CAV systems.

3. Cost of Travel

Introduction:

The cost of buying or using AVs is often mentioned in the literature, however the topic has not been comprehensively studied. This section summarises the discussions related to this topic in the literature (Detailed literature review is available in Annex C).

High initial cost

- Findings suggest that the initial cost of AVs is likely to be significant but could decrease once market penetration is high

Affordable shared AV travel

- Under shared mobility scenarios, the cost of using and operating AVs could become affordable

Public Opinion

- Even though the cost of owning or using an AV is likely to affect public opinion, it is unclear how much the public is prepared to pay to use AVs

The initial cost of AV is likely to be high

Shared mobility could make AV travel affordable

Further research:

Further research is needed to investigate the cost of travel linked to AVs under different 'use scenarios', in particular shared mobility scenarios.

4. Insurance

Introduction

The impact of AVs on the insurance industry has been widely mentioned in the literature. There is a wide consensus in the literature reviewed that AVs will disrupt the insurance market, as described in this section (Detailed literature review is available in Annex C).

AV disruption of the insurance market

- Most sources agree that auto insurance premiums will lower with the onset of AVs
- At the same time, liability will shift from users to manufacturers, as human error is replaced by technical failure as the leading cause of accidents
- However, this contraction of the insurance market will be disruptive for established players

Figure 9 AV expected disruption of the Insurance Market

Further research

Some insurance companies are currently investigating the issues associated with AVs' expected disruption. However, further investigation needs to be done to determine the effects of AVs on the insurance industry. Specifically, the literature review shows little research on the effect of shared mobility.

ii. Use of AVs

1. Ownership and Modal Share

Introduction:

The different ‘roll-out’ or ‘use’ scenarios of AVs and their potential impact has been widely discussed in the literature, and various authors highlight the importance of further understanding these possible scenarios. These different scenarios could influence public opinion and affect the short and long-term adoption of AVs. The potential social, societal and behavioural impact of AVs could vary greatly depending on the roll-out scenarios, and the impact on transport systems and societies could be profound.

Even though different authors have offered different visions regarding potential roll-out scenarios there is some broad consensus, as further described below in this section. Most authors agree that different ownership models are likely to result in different travel patterns and modal shares. The development of different scenarios will depend on different factors which could be greatly influenced by public authorities and other stakeholders (Detailed literature review is available in Annex C).

Automated Vehicles ‘roll out scenarios’ will have a different impact on modal share & ownership patterns

1. The **‘Business-as-usual’ scenario** where AVs would replace existing modes of transport could lead to an increase in car use and a decrease in public transport use. This is a **‘less desirable’** scenario
   - The mass uptake and popularity of AV cars might lead to the 'renaissance of the private car' and an increase in car use
     - partly caused by the fact that a large proportion of the population who cannot currently drive (e.g. elderly people, young persons, disabled) might want to start owning and using an AV
   - This change might end up hindering collective transport, such as rail

“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. 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 (Clark et al, 2016a).”

2. The **'Shared mobility' or 'Collective efficiency' scenario** where AVs complement public transport and where vehicles are shared. This is a 'more desirable' scenario.
    - AVs will be linked to new emerging mobility models
    - As a result, ownership models could shift and car ownership rates could decrease
    - Shared AVs integrated in the public transport system might provide a solution and AVs might optimise public transport
    - However, even in shared mobility scenarios car use could increase and public transport could become less popular

Different variables could influence these scenarios, in particular policy-making and customer preferences.

'Shared Mobility' Scenario

- On-demand mobility
- Decrease in car-ownership
- AVs complement public transport
- But... car use could increase and public transport use could decrease

'Business-as-usual' Scenario

- Increased car use
- Decrease in collective transport
- Decrease in passenger and freigh rail
- Decrease in active travel
- Increase in congestion

Figure 10 Different Scenarios linked to AV uptake

"Whether the AV locks us further in or out of the 'car based society' depends on the choices we make as a society, not solely on a specific technological development." Thomopoulos and Givoni (2015)

Further research:

The potential impact different uptake scenarios might have on modal share, in particular on the use of public transport and walking, needs to be further understood and researched. Furthermore, additional questions remain regarding the practicality of establishing shared AV systems, including forecasts of market penetration, system design, implementation and operation. Finally, it is important to further understand to what extent public authorities should invest/support automated mobility on demand systems.

2. Freight

Introduction

The impact of automation on road freight operations is reviewed in this section. It is a topic that does not appear to have been widely discussed in the literature (Detailed literature review is available in Annex C).

Connected AVs have the potential to optimise goods delivery and the wider freight network

- The greatest efficiency gains are expected to be made through highly connected vehicles
- Connected AVs, potentially in combination with other modes of transport, could improve the delivery of goods
- Integrated, connected AV operation throughout the value chain would create opportunities to optimize complex logistics systems, including in urban freight, long haul trucking, and seaport operations

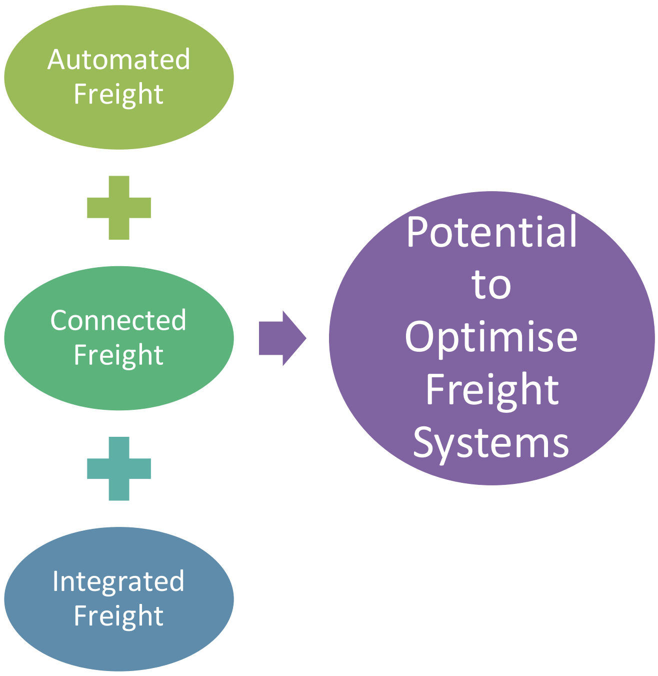

Figure 11 Potential to Optimise Road Freight Systems

Further research

Further research should be done in this field to understand the shape that a connected and integrated automated freight and delivery system could take. Automated factories, trucks, and aerial vehicles could all play a part in the supply chain of the future.

3. Driver's interaction with AVs

Introduction:

The literature discussing drivers' interaction with AVs, a topic often referred to as 'human-machine cooperation' or 'human factors', describes the interaction between human and semi-automated vehicles (usually level 3 or 4 automation). In this section we present a summary of the literature discussing various aspects of human-machine interface, in particular driver reengagement issues in partially or highly automated AVs and in-car driving skills and experience (Detailed literature review is available in Annex C).

Hand-over/Human driver reengagement issues

- Hand-over or human driver reengagement issues in partially or highly automated AVs have been relatively well studied in the academic literature.

- Hand-over issues could pose significant safety risks if the driver fails to regain control of the vehicle on time in cases of emergency. These risks might be judged as unacceptable by potential users.
- The general consensus is that the more a driver is engaged in non-driving tasks (e.g. reading a book), the less aware and ready to resume manual control of the vehicle the driver becomes. Yet being able to engage in non-driving tasks is likely to be one of the main selling points of AVs.
- There is a need to further understand and prevent safety risks linked to drivers' reengagement with the AV, for instance by designing solutions to maintain drivers' engagement and awareness and to inform AV drivers of their duty to resume control (through driver training for instance).

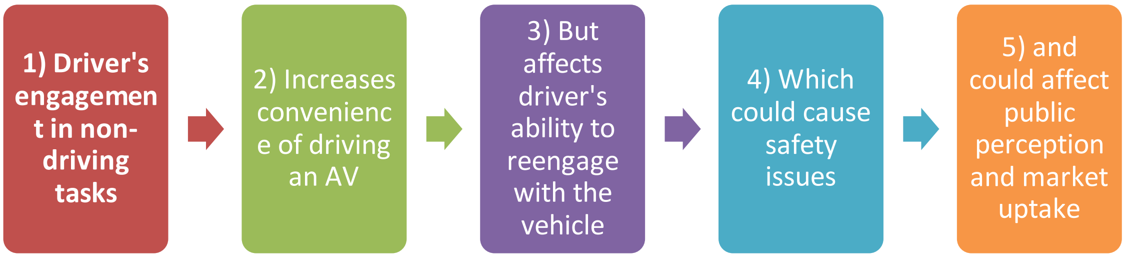

Figure 12 Potential safety risks in cases of partially or highly automated AVs

In-car driving skills and experience

- AVs are expected to improve the convenience and comfort of driving by allowing drivers to engage in non-driving tasks, such as working or being entertained, and by reducing the stress of driving.
- However certain studies and surveys suggest that drivers might not want to engage in non-driving tasks, in particular working, or might not be able to due to motion sickness issues. This puts into question the claims that AVs are likely to improve productivity levels.
- Even though AVs have the potential to reduce driving stress, certain studies indicate that platooning[2] might increase the driver's stress levels.

[2] In the context of this literature review platooning refers to AVs following one another closely on the road

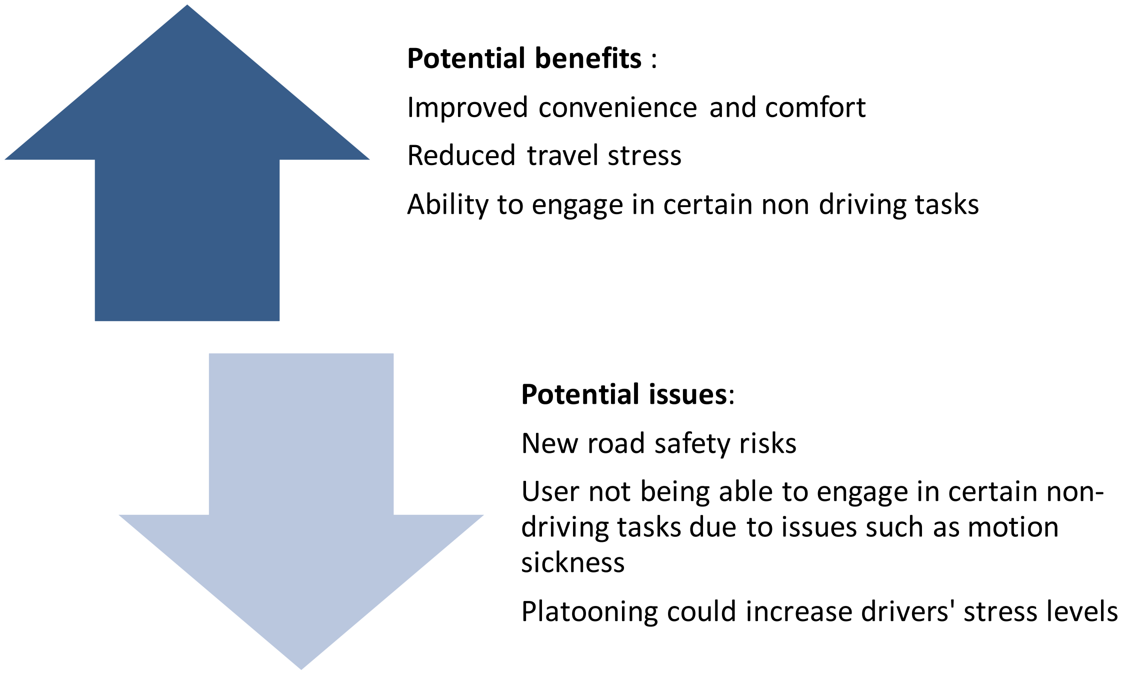

Figure 12.2 Potential benefits and issues linked to AV in-car experience

Further research

Some of the key research questions related to drivers' reengagement issues are: Under what conditions to allow AV users to engage in non-driving tasks in partially or highly automated vehicles? What solutions, such as training, should be implemented to keep the driver engaged and maintain/adapt driving skills?

Further research is needed to better understand drivers’ behaviour in different scenarios/contexts whilst in AVs. Questions such as to what extent will drivers be able to/want to work whilst in AVs? Could motion sickness issues prevent most drivers from engaging in non-driving tasks? To what extent will AVs reduce drivers’ stress? Finally, additional research is needed to understand whether drivers’ attachment to driving can affect AV adoption.

4. AVs’ interaction with other road users

Introduction:

This section summarises the literature on interactions between AVs and other road users. It starts by describing issues related to interactions between AVs and conventional car drivers in the context of mixed-traffic. It then discusses interactions between AVs and other road users in urban areas, in particular with cyclists and pedestrians (Detailed literature review is available in Annex C).

Interactions between AVs and other car drivers

Uncertainties remain about how AVs will interact with manually driven vehicles and vice-versa, in “mixed-traffic” situations.

- One of the safety issues most frequently mentioned is the fact that human drivers could be negatively influenced by AVs platooning and mirroring this practice (by decreasing the gap with the vehicle in front) could lead to road safety issues.

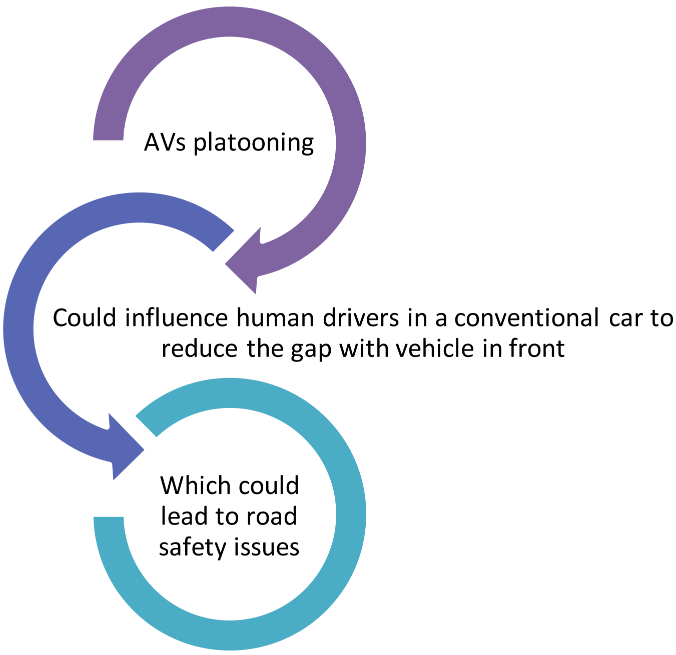

Figure 13 Potential behavioural impact caused by AV platooning

AVs’ interaction with cyclists and pedestrians

A range of potential behavioural and technical problems related to AVs’ interaction with pedestrians and cyclists have been identified and necessitate further investigation.

- AVs have the potential to boost pedestrians’ and cyclists’ confidence and to further encourage people to walk or cycle, providing AVs are adequately programmed.
- Traffic flow in urban areas could be negatively affected by pedestrians and cyclists’ behaviour change linked to the introduction of AVs (e.g. pedestrians deliberately jumping in front of an AV expecting it to stop); Consequently, AVs might need to be programmed to prevent these issues.

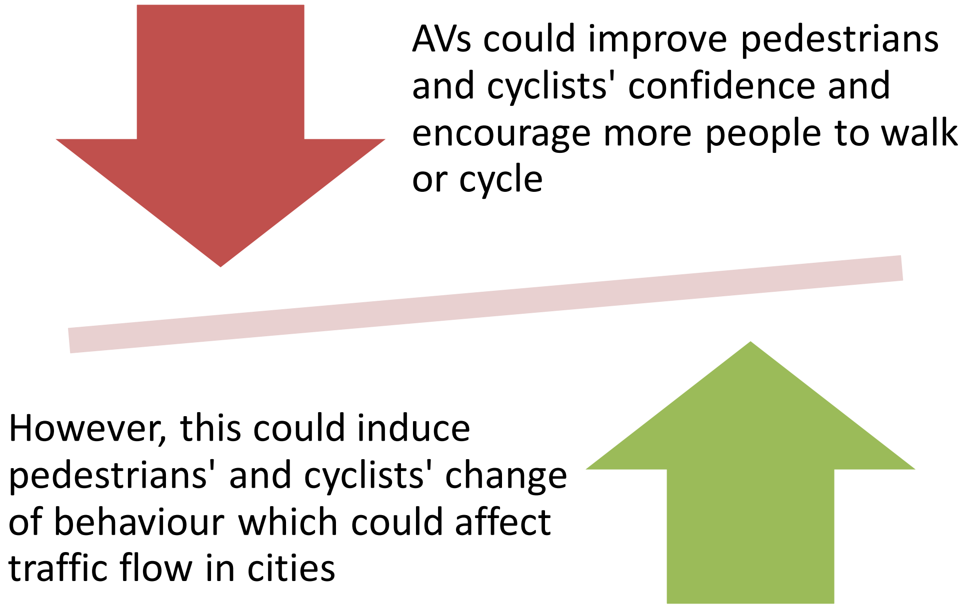

Figure 14 Potential behavioural changes linked to AVs' interactions with pedestrians and cyclists

Further research

Further research, in particular modelling work, is needed to examine how AVs will interact with other road users, in particular car drivers, pedestrians and cyclists, under different 'use scenarios', including in urban areas. Could these interactions lead to unsafe situations? Could it negatively affect traffic flow? A long list of detailed research questions has been developed by Parkin et al (2016) in the context of the UK project Venturer.

5. Market Uptake

Introduction:

Even though in the majority of the references reviewed authors were confident that AVs will be developed and adopted, a number of authors have warned that there are still barriers to AV market uptake. This section focuses on the opportunities and challenges related to market uptake & penetration in high-income[3] and in low-income countries (Detailed literature review is available in Annex C).

AVs market uptake & potential market failure in Western countries

[3] In this literature review high-income countries refer to the list of countries established by the World Bank. Reference available on this link http://data.worldbank.org/income-level/high-income

- The overwhelming majority of references reviewed have no doubt that the technology will be developed and introduced in Western countries
- However, several authors have highlighted that a number of obstacles could prevent AVs market uptake, in particular the high cost of the vehicle, liability issues, lack of business plan, and (lack of) consumer demand.
- Some assert that shared AVs and the support from public authorities and key stakeholders have the potential to generate wide market penetration of AVs

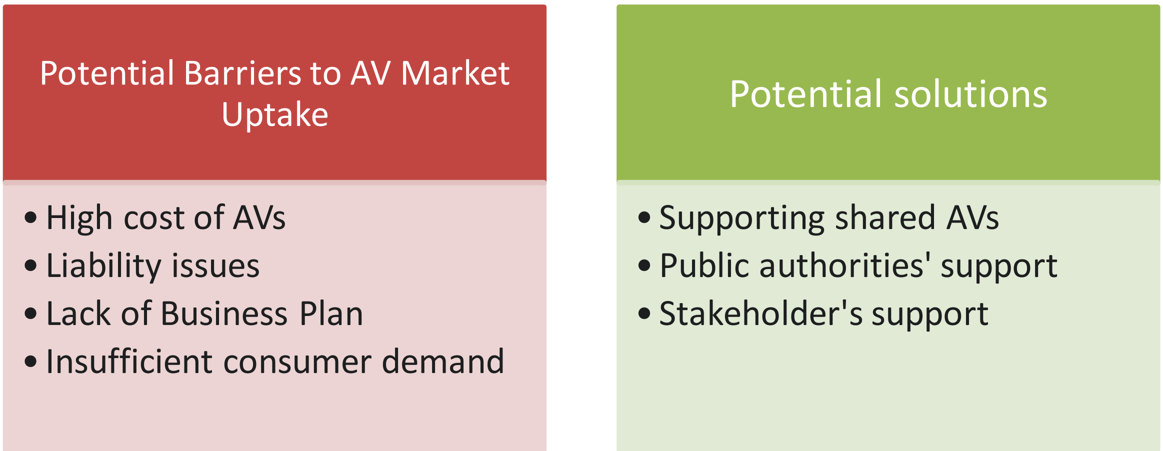

Figure 15 Potential barriers and solutions to AV market uptake

Mass market penetration and socioeconomic impact

- It is unclear whether mass AV market penetration will automatically lead to desirable socioeconomic impacts. Some state that mass AV market penetration, even though desirable for the industry, might lead to undesirable socioeconomic outcomes, such as unemployment, congestion or increased car use. Others argue that mass market uptake could generate positive outcomes such as reduced travel costs. The role of public authorities in achieving the right balance was mentioned.

Market uptake in non-Western countries

- The development of AVs in the Global South could present an opportunity for these countries to accelerate intelligent transport developments. However, doubts remain regarding the affordability and suitability of the technology in numerous contexts outside of Western countries.

Figure 16 This street in Kampala, Uganda's capital, might not be suitable for AV use. Source: Flickr, Creative Commons, link included here

Further research

Further research is necessary to examine whether mass AV market penetration will lead to desirable socioeconomic outcomes or not. Similarly, it is important to understand to what extent negative externalities linked to the use of AVs could lead to a market failure. Further understanding the opportunities and challenges of introducing AVs in non-Western countries is needed.

iii. Consequences/Wider impacts

1. Traffic Flow

Introduction

The potential impact AVs might have on congestion has been frequently discussed in the literature. A number of references, particularly consultancy reports, stress AVs' potential in reducing congestion as one of the main advantages of AVs' uptake. However, this assumption is partially refuted by a number of authors and institutions. The potential impact AVs might have on traffic flow is not straightforward and depends on a number of variables. Further understanding the potential impact AVs might have on congestion is key, as it is one of the main selling points for the uptake of AVs and could determine consumer and public acceptance (Detailed literature review is available in Annex C).

Potential increase in Travel Demand and in VKT

- Understanding the potential impact of automated vehicles on congestion is key as it is one of the main selling points for the uptake of AVs and could determine consumer and public acceptance.
- The potential impact of the introduction and use of AVs on traffic flow and congestion is uncertain and the literature diverges on this issue.
- The majority of academic references state that Vehicle Kilometre Travelled (VKT) are likely to increase as a result of AV uptake because of increased travel demand, and that this could lead to increased congestion.
    - Increased travel demand could be caused by 'non-drivers' wanting to use AVs for their travel and/or because AVs could become extremely popular and convenient

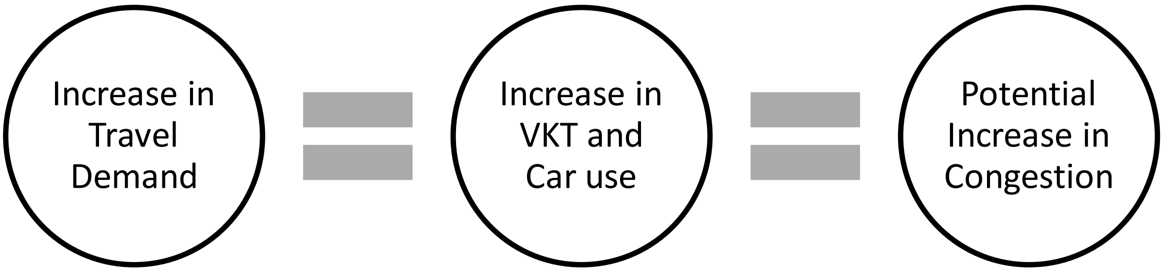

Figure 17 Potential AV deployment scenario

Potential to increase Highway Capacity

- However, under certain scenarios, AVs could potentially optimise highway capacity; primarily if AVs are used in the context of shared mobility, Vehicle to Vehicle communication (V2V) and Vehicle to roadside infrastructure communication (V2I), and if penetration rate is high.

Further research

Further research is needed to ascertain the net impact AVs could have on traffic depending on different scenarios. Furthermore, limited research has been undertaken to assess the potential impact AVs could have in cities, where the roads will be shared with a range of other users. Could it improve traffic flow or could it slow it down?

2. Economy and Employment

Introduction

The use of automated vehicles has the potential to impact the economy and employment levels. In this section we review the written material which has discussed these topics and highlight the need for further research in this field (Detailed literature review is available in Annex C).

Impact of AVs on the economy and employment

- According to some authors, CAVs are likely to have a positive impact on the economy and under some scenarios could create new employment opportunities, but insufficient data and research are provided to support these hypotheses.

Potential Positive Economic Impact generated by AVs
Crash savings (e.g. savings in public resources needed to attend road accidents, such as emergency or health services)
Jobs in the automotive, technology, telecommunication and freight transport industry
Electronics manufacturers

- On the other hand, numerous authors caution that a range of economic sectors might be negatively impacted by the uptake of AVs, from private to public. The most concerning aspect of which is employment levels and consequently public perception.

Economic Sectors that may be negatively affected by AVs

Sectors specialised in road accident prevention and recovery

- Insurance sector relying on income from insurance premiums
- Legal sector specialising in road accidents
- Health professions specialising in road accident emergency and recovery

Sectors dependent on current auto-mobility system

- Automobile repair centers/garages
- Parking industry
- Retail industry

Public Sector

- Public parking revenues
- Traffic enforcement officers

Traditional Car manufacturers

- Established OEMs dominated by innovative technology firms

Figure 18 Economic sectors likely to be negatively affected by AVs

- Therefore, anticipating and adapting to potential changes in employment is critical to understand who will be the winners and losers and to plan accordingly.

Further research

Further research is necessary to assess the potential impact vehicle automation could have on the economy, and in particular on employment, since it could be a public concern. Questions such as “How many jobs directly and indirectly related to AVs, across sectors, could be at risk?

Comprehensive and thorough cost-benefit analysis, including all potential side-effects and impact, is also urgently needed.

3. Land Use

Introduction

Authors writing on AVs see two major shifts in land use patterns arising from AVs. First, most authors predict a drastic reduction in land used for parking, particularly under a scenario where the use of shared vehicles is high. This would come about as vehicles would serve many customers, and would not need to park for a large amount of the day. Second, most authors expect that AVs will result in an increase in urban sprawl. As road systems become more efficient, and travel time becomes more comfortable and less demanding, people might be encouraged to travel further distances on a regular basis (Detailed literature review is available in Annex C).

Impact AVs could have on land use

- Under shared mobility scenarios, cities could see a drastic reduction in land used for parking. However, some question to what extent the freed land would be used to create more liveable cities[4] rather than to accommodate more vehicles
- As AV travel becomes more efficient and more comfortable, willingness to travel longer distances could encourage urban sprawl, leading to a range of undesirable effects (such as increased car dependency)
- Public authorities have a responsibility to curtail the negative effects of AVs on land use patterns and maximise any positive benefits.

"Just as the rise of the automobile led to the emergence of suburbs and exurbs, so the introduction of AVs could lead to more dispersed and low-density patterns of land use surrounding metropolitan regions."
Automated vehicle technology: How to best realize its social benefits
(Anderson et al., 2014b)

[4] In the context of this literature review the term 'liveable city' refers to the liveability index developed by the Economist. Reference can be found following this link: http://www.eiu.com/public/thankyou_download.aspx?activity=download&campaignid=Liveability2016

Figure 19 Aerial picture illustrating urban sprawl is North America. Source: Flickr, Creative Commons, link included here

"My conclusion is that automated vehicles have great potential. But we must not allow them to shape our cities in the way the internal combustion engine was allowed to in the last century. In the 19th century, rail led to a concentration of population in city areas. In the 20th, the effect of the internal combustion engine was the opposite: high car ownership led to dispersal, seen at its most extreme in US cities. It will not be good for the economy or the environment if automated vehicles lead to lower density cities or higher car use." A 2050 vision for London: what are the implications of driverless transport? (Begg, 2014)

Further research

To what extent could shared mobility scenarios save parking spaces in cities? How will the freed space be used?
To what extent could AV use increase urban sprawl? How might one prevent this development?

4. Ethics

Introduction:

Results of this literature review suggest that ethical issues related to AVs have not been thoroughly addressed in the literature, yet AVs are being programmed to make ethical choices which could soon have real consequences. Ethical implications linked to AV use could have a significant impact on the way those vehicles are perceived by the public. This section summarises some of the key ethical debates mentioned in the literature (Detailed literature review is available in Annex C).

Ethical considerations with AV programming

- Most authors acknowledge that programming AVs to make ethical choices in case of unavoidable accidents is complex, yet inevitable.

"Defining the algorithms that will help AVs make these moral decisions is a formidable challenge." (Bonnefon et al, 2016).

Protecting the drivers at all costs?

- One of the most frequently discussed dilemma is to what extent should/could AVs prioritise the safety of their occupants at the cost of other individual's safety and should AV owners be permitted to choose?
- Research suggests that even though in theory the public support utilitarian AVs '(that sacrifice their passengers for the greater good)' potential buyers would prefer to buy a vehicle that protects them 'at all costs'

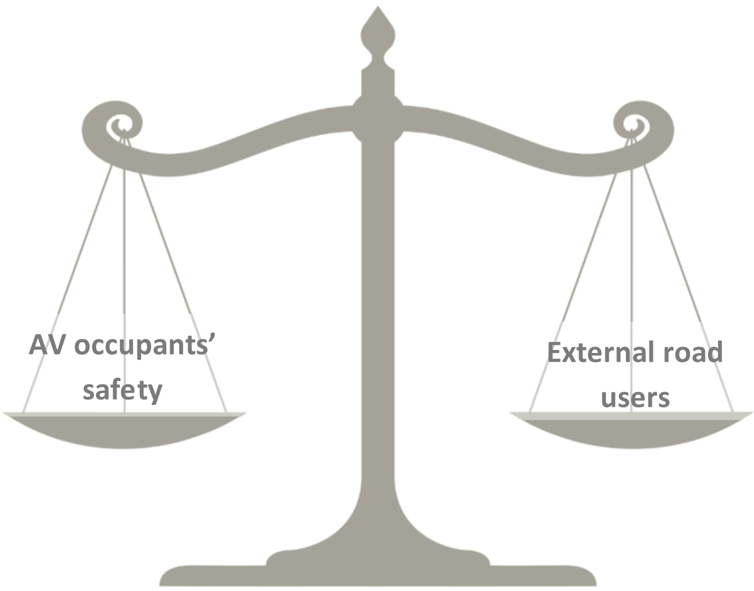

Figure 20 Ethical dilemma: should AVs be programmed to protect their occupants at all costs?

Call for an ethical debate

- The potential ethical implications of AVs programming could have an impact on public perception

- Several authors have called for an ethical debate to be held to discuss these complex ethical programming decisions before highly automated AVs are allowed on the roads.

Further research

Further research and debate is necessary to identify and discuss the various ethical dilemmas arising with AV programming and to establish moral codes or guidance to programme these vehicles.
Two of the most important research questions are summarised by Fagnant and colleagues: "to what degree should AVs prioritize minimizing injuries to their occupants, versus other crash-involved parties? And should owners be allowed to adjust such settings?" (Fagnant et al, 2015).

5. Energy and Environment

Introduction:

This section discusses the potential energy and environmental impact AVs could have under different scenarios. This topic has been relatively well addressed in the literature but, as described below, findings differ (Detailed literature review is available in Annex C).

Potential impact on energy consumption and pollution

- Several authors mentioned the potential AVs have to decrease road transport energy consumption and pollution, in particular if AVs are connected and AV penetration rates are high.

Potential energy and emission saving improvements through CAVs & high AV penetration rates		Potential outputs
Energy-saving driving practices (i.e. eco-driving)	→	Energy efficient driving
Changes in the design of vehicles, such as lighter vehicles	→	Energy efficient vehicles
Optimisation of the transportation system, in particular platooning, synchronised driving and optimised routing	→	Smoother traffic flow
Reduced need to search for parking space	→	Reduced energy consumption
Reduced need for street lighting at night	→	Energy efficient infrastructures

Table 4 CAVs potential energy and emission saving improvements

- However, several authors highlight that potential energy and environmental improvements are likely to depend on AV adoption and use ‘scenarios’.
    - Under the ‘**Business as usual scenario**’, potential increased travel demand, car use, VKT and reduced use of rail and mass transit might outweigh the potential environmental and energy benefits of AVs (For further details see section on ownership and modal share)
    - On the other hand, a number of authors noted that under ‘**shared mobility scenarios**’ – through car sharing or ride sharing – energy-efficient CAVs could generate energy and environmental benefits.
- But some authors warn that that even in the best scenario there is a risk that energy consumption and emissions could increase as a result of increased travel demand and VKT, possibly leading to a decrease in mass transit and rail use and call for an ‘environmentally beneficial transition toward vehicle automation’.
- Uncertainties in the literature remain regarding the source of energy AVs will use. Some argue that in the context of shared mobility the use of electric AVs is likely to occur. On the other hand, under business as usual scenarios, some argue that AV owners are likely to choose fuel types that are more reliable for long-distance driving. Thus, it isn’t clear whether AVs will automatically run on sustainable energy.

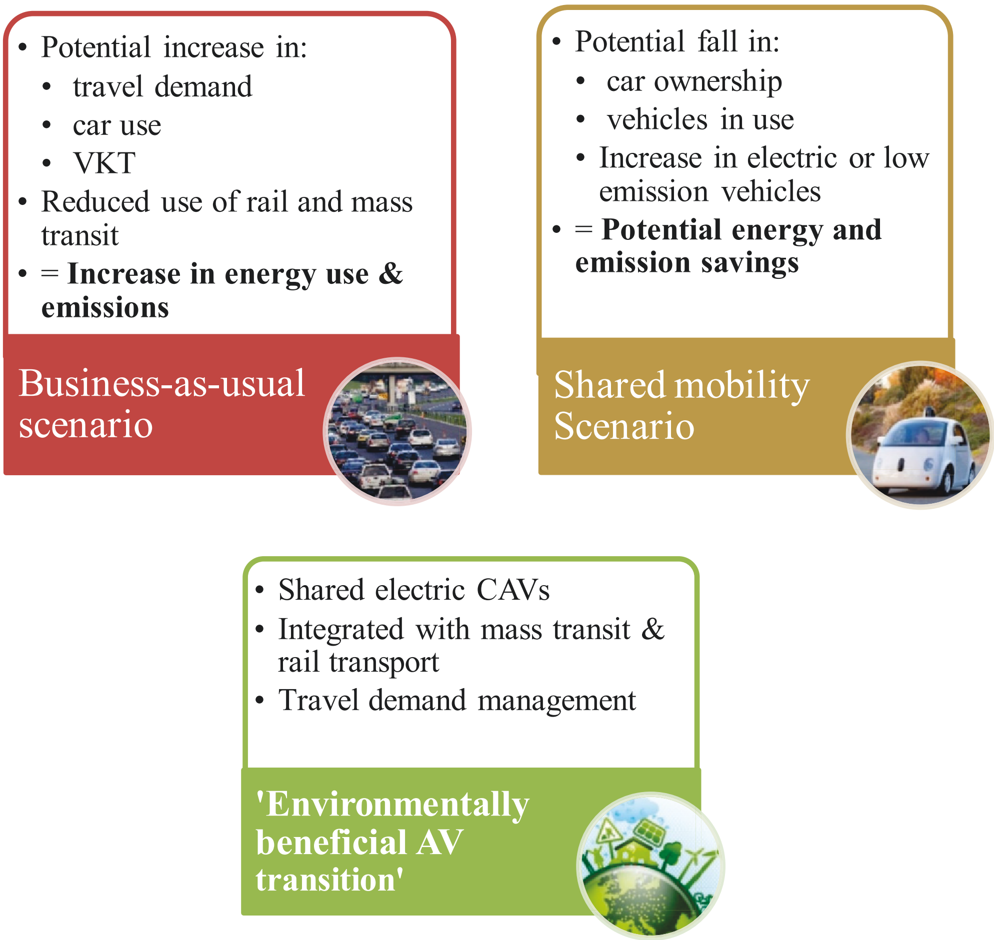

Figure 21 AV use scenarios: Energy and Environment

Further research

The impact AV use is likely to have on energy and emission consumption is unclear. Further research is needed to ascertain – and better quantify - the various assumptions and hypotheses mentioned in this section, in particular:

- To what extent could AVs contribute to energy and emission reduction - under which use scenario?
- Similarly, under which scenario could AV use lead to an increase in vehicle emission and energy consumption?
- To what extent AVs have the potential to be low emission vehicles?

6. Road safety

Introduction

Road safety was the topic most mentioned in the literature examined. The vast majority of the authors discussing road safety highlight AVs' potential to decrease greatly the number of accidents, and consider improved road safety to be among the chief benefits of AVs. The main controversy stems not from AVs' ability to improve road safety, but the extent of the improvement. While many studies predict a near-complete reduction of road accidents, other studies take a more moderate view. Understanding AVs' effect on road safety is a key issue; it is one of the major predicted benefits of automation, and is also an important factor in the public acceptability of AVs (Detailed literature review is available in Annex C).

Reducing human error

- Most references agree that AVs will have a positive and significant impact on road safety by reducing or eliminating human error.
- There is disagreement on the extent and the timing of these impacts
  - Many authors believe that AVs will have little impact until the widespread deployment of completely automated vehicles
  - Many authors point out that due to the nature of technological systems, some amount of failure is to be expected
- However, as described in various sections of this literature review, new road safety risks might emerge linked to AVs' interaction with other road users, in particular conventional car drivers, pedestrians and cyclists (see sections in Annex C on Driver's interaction with AVs and AVs' interaction with other road users).

Public acceptability and road safety

- Reducing the risk of crashes through automation is a key component to the public's acceptance of AVs; but the public's expectations that AVs will be entirely safe will have to be managed.

"Therefore we believe that a thorough assessment of safety implications of automated systems – including pilot tests and implementations – should be conducted in order to estimate their likely effects on traffic accidents' frequency and severity, and identify potential risks from improper human behaviour." (Frisoni et al., 2016)

Further research

In relation to safety, the most pressing need is to ensure that there is enough research undertaken in relation to the driver's reengagement with the vehicle and interaction with other road users, as this is likely to be the most problematic issue related to safety. To what extent are manufacturers addressing this issue? To what extent should the government further support research and development in this field?

7. Physical Activity

Introduction

The potential effect of AVs on physical activity, and, by extension public health, is not widely addressed in the literature, and not sufficiently understood (Detailed literature review is available in Annex C).

Potential impact of AVs on physical activity and health

- A number of authors warned of the potential impact AV use could have on the population's health.
- The popularity of AVs could lead to increased physical inactivity which could have detrimental health effects, such as an increase in obesity rates.

Further research

Changes in physical activity due to AVs is an under-researched area with wide-ranging public health impacts. Further research on this issue is related to AVs' effect on mode share: will the mass use of AVs shift travel patterns and reduce the share of walking, cycling, and public transportation use?

8. Accessibility and equity

Introduction

Accessibility and equity issues linked to AVs have not been widely addressed in the literature. Yet it is likely that the introduction of AVs could have an impact on both of these aspects. This section summarises the discussions found in the literature regarding these topics (Detailed literature review is available in Annex C).

Accessibility

- CAVs have the potential to improve accessibility for a range of people, in particular elder persons, the disabled, non-drivers and people who live in areas that are not well connected to collective transport networks.
    - The use of CAVs could increase flexibility and independence for a range of users
- However, these assumptions should be examined with caution as limited research has studied the level of social acceptance, desire and capability to use AVs amongst these potential users.
- Furthermore, these potential users might be the last to benefit from AVs as the safety standards required for fully automated vehicles will not be available in the short term.

Equity

- Some question the extent to which those with accessibility restrictions will be able to afford the use of AVs and whether the introduction of AVs could affect equity negatively.
- On the one hand some argue that the initial high price of AVs could limit the technology to the wealthy. Others argue that in the context of shared mobility a broad range of users could benefit from the technology.

Potential impact of AVs on Accessibility and Equity	
Opportunities	**Limitations**
Improved access for the elderly, disabled, children and those with limited access to collective transport	Concerns with social acceptance, capability or desire to use AVs
	Safety requirements may preclude the use of fully automated AVs in the short term
Affordability of shared mobility options	High cost of AVs could cause disparity of socio-economic access

Table 5 Potential impact of AVs on Accessibility and Equity

Further research

Further research is needed to investigate the likely interactions between certain groups of the population, such as older people, and AVs. Similarly, possible social acceptance issues amongst these potential users need to be further studied. Will elder persons, disabled and non-drivers, such as underage children, have the capacity to use these vehicles? Will they want to/feel comfortable in using a vehicle without a driver? To what extent do AVs have the potential to improve the life of non-drivers, in particular the elderly and the disabled? Begg (2014) asks: "If autonomous cars come to supplement bus services, should public transport authorities get into the business of operating them?"

Further research is also needed to better understand the potential social inequity issues the uptake of AVs might generate. Will the uptake of AVs widen inequity? Or, on the contrary, will it improve accessibility for all through shared mobility?

iv. Stakeholders' awareness & attitudes

Introduction

Public acceptability and public opinion has been widely discussed in the literature on AVs. It is clear that it has the potential to impact the technological development and the roll-out of AVs. Therefore, it is crucial to assess public perceptions regarding this new technological development. A number of institutions have undertaken surveys to assess public opinion. This section summarises the main findings and highlights gaps in the literature and limitations of the methods used (Detailed literature review is available in Annex C).

Cross-referenced results from a number of surveys indicate that:

- It is unclear to what extent the public is interested in using or buying AVs
- Men living in urban areas are more likely to be interested in AVs compared to women, in particular technology enthusiasts
- Older persons are less likely to be interested in AVs compared to younger persons
- Public perception of AVs varies from one geographical area to another (e.g. Californians are more likely to be interested in AVs compared to citizens who live in other US states).
- People who enjoy driving are less likely to be interested in AVs

Participants' interest in using/buying AVs	Participants more likely to be interested in AVs
Gender	Men
Age	Young people
Inhabitat	Urban dwellers
Geographical location	California
Attachment to driving	People who enjoy driving
Personality	Technology enthusiast

Table 5 Participants' interest in using/buying AVs; summary results across various surveys referred to in this literature review

Several key factors seem to have a strong impact on public opinion:

- Even though safety is one the main 'selling points' and benefits of using or buying an AV, it is also what concerns potential users most, in particular fear of software malfunction. Cybersecurity also ranks high on the list of concerns about AVs.
- Perceived usefulness and perceived benefits of AVs (e.g. travel time or congestion reduction) are likely to impact public opinion and acceptability of AVs
- The majority of the participants surveyed would be reluctant to pay more (than a conventional car) to buy or to use an AV.

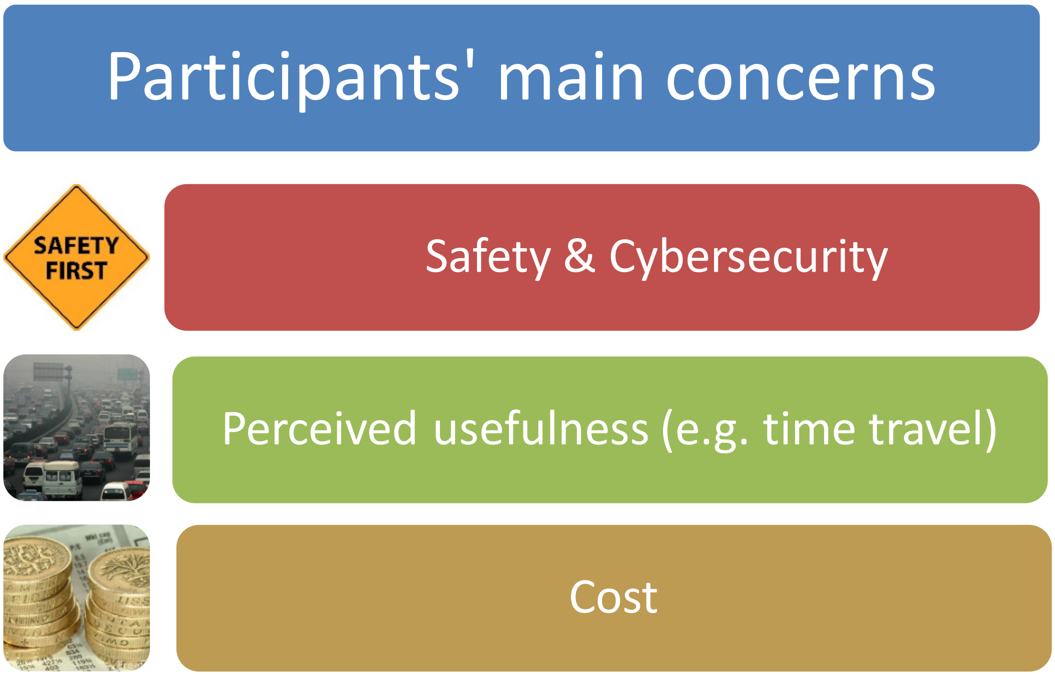

Table 6 Participants' main concerns related to AVs

The assessment of the methods used across surveys suggests that:

- The sample of the population surveyed is not fully representative
    - The majority of the surveys were undertaken in the USA
    - Many surveys have only interviewed drivers. Non-drivers have not been sufficiently targeted

Authors	Kyriakidis and colleagues	Schoettle and Sivak	Cyganski and colleagues	Ipsos Mori
Institution	Delft University of Technology	Michigan University	German Aerospace Center, Humboldt -University Berlin	Ipsos Mori
Date	2015	2014	2014	2014
Country	109 different countries	USA, UK and Australia	Germany	UK
Type	Crowd-sourcing online survey via Crowdflower	Crowd-sourcing online survey via Survey Monkey	Crowd-sourcing online survey	
Respondents	5000	1533	1000	1001

Table 7 Relevant surveys targeting large samples

- Most surveys rely on the public's imagination to assess their views on AVs. Only limited surveys have been undertaken in live scenarios
- Rigour and impartiality of the methods used in the context of a number of surveys is questionable. Only a handful have used robust methods.

Further research

Further research should be undertaken to determine under what conditions and scenarios the public would be most likely to use and accept AVs. Public opinion on AVs should be assessed specifying conditions of use (Clarck et al, 2016; Cyganski et al., 2014). In other words, specific scenarios should be presented when surveying participants' opinion. As stated by ScienceWise: "Further study on the specific situations in which the public would or wouldn't find vehicles acceptable and whether they would be willing to drive alongside automated or driverless cars would add to understanding of public attitudes" (ScienceWise, 2014).

As AV technology develops, public opinion needs to be regularly assessed and monitored. As stated by ScienceWise: ""it would be valuable to track public attitudes to the technology as it becomes more of a reality, to see how this affects positive or negative perceptions of the technology" (ScienceWise, 2014). Clark and colleagues from the University of the West of England stress the key role social science should play in examining the population's expectations and reaction to the development of AVs (Clark et al, 2016).

Finally, further research is needed to assess non-drivers' perception and expectations of AVs. Likewise, it is necessary to further understand older people's perception of AVs and their potential reluctance to use the technology. It is also important to further understand why a large percentage of females seem less interested in AVs compared to men.

v. Public Sector's Role

Introduction:

In this section we review the literature that has discussed the role, influence and responsibility of public authorities in relation to AVs. The first part discusses regulatory and legal issues related to AVs deployment and adoption, in particular at the national level. The second part raises issues regarding urban planning in relation to AVs (Detailed literature review is available in Annex C).

Regulatory and legal issues related to AVs

- Many authors have stressed the important role public authorities play in regulating and legislating for AVs and in shaping the adoption and use of AVs. Public authorities are expected to:
  - Legislate to support testing and adoption of the technology
  - Intervene to shape the 'adoption path' or 'use scenario' of the technology

- The need to further understand the potential impact AVs could have on transportation systems and the society before legislating was also highlighted
- Legal responsibility in case of an accident is a concern that needs to be further addressed by the relevant authorities

In relation to urban planning

- Few authors have discussed AVs in the context of urban planning, and there is a general lack of conversation and planning regarding AVs in urban areas
- Local authorities need to be involved in conversations and policy-making processes regarding AVs and should consider integrating AVs into their planning processes
- AVs have the potential to improve urban transport systems, but their development and use in urban areas need to be carefully managed by public authorities.

Public sector's role: At the national level

- Further understand the potential impact AVs could have on transportation systems and the society
- Legislate to support testing and adoption of the technology
- Intervene to shape the 'adoption path' of the technology

Public authorities should: At the local level

- Local authorities need to be involved in conversations and policy-making processes regarding AVs and should consider integrating AVs into their planning processes
- Carefully manage the development of AVs in urban areas

Legislators: Legal issues to be addressed

- Legal responsibility in case of a collision is a concern that needs to be further addressed

Figure 22 Public sector and legislators' role

Further research

Further research is needed to investigate the role of AVs in urban areas, from an urban planning perspective. Potential research questions include: What role should AVs play in cities? To what extent can AVs contribute to urban areas and improve urban mobility systems?

IV. Conclusion and Recommendations

To conclude, the findings of this study suggest that the social, behavioural and societal matters linked to AVs have not been sufficiently addressed, in particular by the academic literature. Out of the 44 different topics identified, only a handful have been thoroughly addressed. Others, such as health and well-being issues, in particular physical activity, are significantly under-researched. To date the focus has been primarily on the technological and technical aspects of AVs. This is probably because AVs are still at an experimental stage, however, with the technology rapidly developing, key social, behavioural and societal issues linked to AVs need to be given urgent consideration.

The majority of authors who have written on AVs have highlighted their potential benefits, in particular road safety, and have mentioned that it is likely to be a disruptive technology. A significant number of authors, in particular academics, have also highlighted their potential side-effects and have called for caution. One of the key messages is that depending on the adoption/use scenario implemented, or chosen, the social and behavioural impact of AVs uptake could be very different and could lead to completely different outcomes, some less desirable than others (see section on ownership and modal share). As summarised by Smith (2012): "Maximizing the net benefit of automated driving will require researching, modelling, planning, and regulating—cooperatively, not automatedly".

It is clear that in order to fully comprehend the potential, positive or less positive, changes this disruptive technology could generate, a range of multidisciplinary and comprehensive studies need to be undertaken. Understanding the potential impact of AVs should be looked at through the lens of a range of disciplines from sociology, medicine, psychology, economics to urban planning etc.

This report serves to provide an overview of the various discussions and studies that have been undertaken related to this topic. It has informed a series of research questions which can be found in the main report of this project.

Annex A – Methods

The literature review process began with two parallel strands: a search of academic and grey literature sources to develop a body of materials, and the development of a coding framework to analyse that literature. The objective was to identify prevalent themes in social and behavioural research and theory regarding AVs. The framework was applied to the literature discovered, with each piece of work coded for major themes.

The literature review process is outlined in the flowchart below, with each step described in the subsections below.

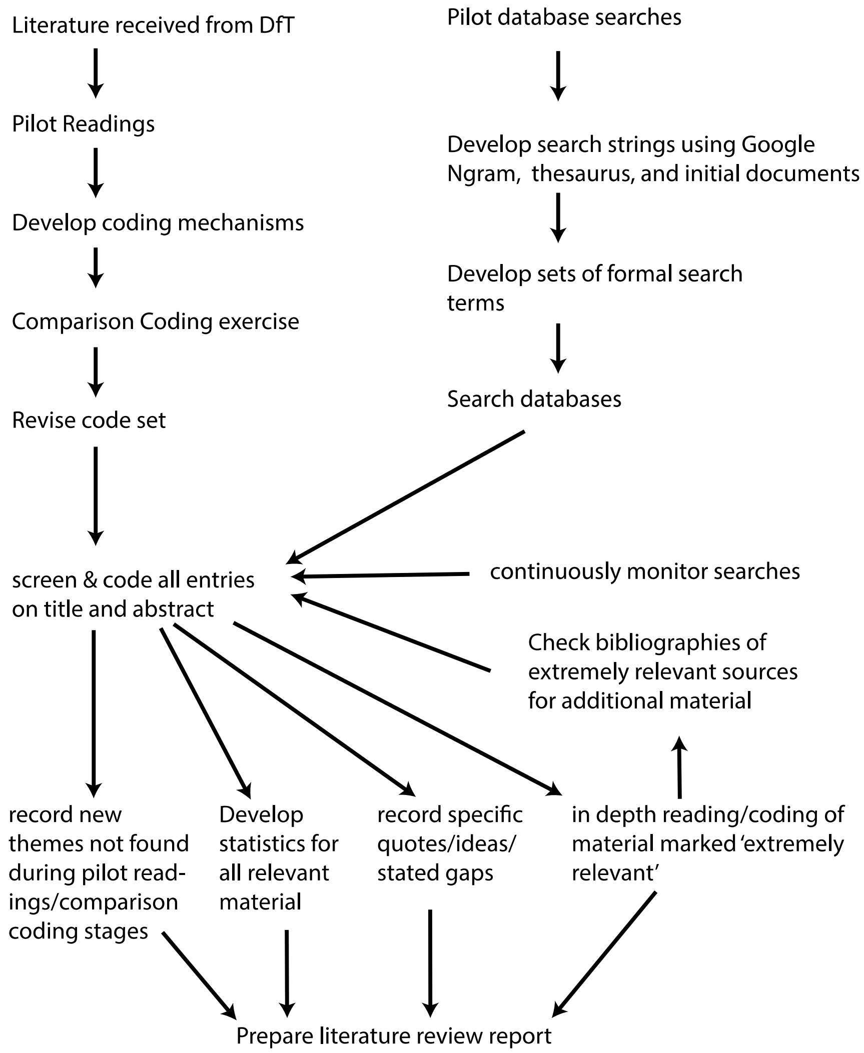

Figure 24 Literature Review Process

Literature Search

The objective of the literature search was to identify a body of information from the academic and grey literature that is indicative of the diversity of social and behavioural research on AVs.

First, formal search terms were developed using the results from the pilot searches, and terms used in the initial sample literature. A thesaurus and Google's Ngram Viewer was used to identify the most common words and phrases used to refer to AVs. Ngram viewer is a search product that identifies the prevalence of the searched word or phrase over time in Google's database of printed works. The synonyms found to be the most common were used for further searches. The relevant search terms are shown in the table below.

Keywords	Additional Synonyms
"Driverless car*" OR "Driverless vehicle*" OR "driverless"	"Advanced Driver Assistance System*"
"self-driv* car*" OR "self-driv* vehicle*" OR "self driv* car*" OR "self driv* vehicle*"	"Auto-pilot vehicle*"
"automated car*" OR "automated vehicle*" OR "automated car*" OR "automated vehicle*"	"Driverless automobile*"
	"self-driv* automobile*"
	"automated automobile*"
	"automated automobile*"
	robot* car*, robot* vehicle*
	self-piloted car*, self-piloted vehicle*
	Automated Road Transport
	"Automatic vehicle*" OR "Automatic car*"
	"Cybercar*"
	"auto* driving"
	"Google car"

Table 8 AV keywords and additional synonyms

These synonyms were used to search five bibliographic databases: Scopus, Transport Research International Documentation (TRID), International Bibliography of Social Sciences (IBSS), ProQuest Social Sciences and PsycINFO. These databases provide wide coverage of peer-reviewed literature in the fields of transport, social science, and psychology, as well as additional academic references (including conference papers and other reports) and some grey literature (such as official documents). Searches undertaken in the context of this investigation focused on material written in English. All years, all subject areas, and all document type were searched.

Databases	Content
SCOPUS	Largest abstract and citation interdisciplinary database of peer-reviewed literature
TRID	*Transport Research International Documentation* (*TRID*) is the largest online bibliographic *database* of transportation research, includes technical reports and conference proceedings
IBSS	*International Bibliography of the Social Sciences* (*IBSS*) is an essential online resource for social science and interdisciplinary research
ProQuest SOCIAL SCIENCE	*ProQuest's Social Sciences* collections provide comprehensive, global indexing coverage of the scholarly literature in the social sciences
PsycINFO	Bibliographic records centered on psychology and the behavioral and social sciences

Table 9 Bibliographic Databases used

The searches yielded over 50,000 results. In order to narrow the search down to a manageable number, and to weed out irrelevant works, the search results were separated into subject areas. 10 random entries within each subject area, for each search, were screened on title and abstract. If none of these entries were relevant to social and behavioural issues related to AVs, the subject area was excluded. These results were narrowed down by excluding irrelevant subjects leaving 2296 results. These documents, combined with the items discovered informally, were screened on title, and in some cases on abstract, for relevance and narrowed down to less than 300 references (see table below).

Screening	Hits
Across Databases and Categories	50200
Pre-selection based on Category	*2236*
Final selection from bibliographic databases	*248*
Final selection from Grey Literature	*181*

Table 10 Results from Bibliographic Databases search

While the database searches above yielded literature from academic and grey sources, the results were biased towards academic literature. In order to balance this bias, informal web searches (mainly using the Google search engine) were undertaken using key words previously identified. For instance, the terms ‘automated vehicles’ combined with ‘PDF’ produced a long list of consultancy and government reports. Furthermore, a search through 30 relevant bibliographies was undertaken to identify additional grey literature. Eventually a sample of close to 200 references were selected to represent the grey literature.

In total the combination of the selected academic sources and the sample of grey literature produced 432 documents. The table below indicates the types of documents found in the body of literature. Academic sources represent the majority of the documents examined. Given that the most relevant academic databases were thoroughly surveyed, the number of academic sources identified in the context of this study is likely to be representative of the total number of existing academic sources written in English.

Academic Sources Included:		**Grey Literature Sources Included**	
125	peer reviewed articles	20	Official Reports
7	academic books	40	Consultant/Industry Reports
116	Other (reports, presentations, conference papers)	42	Serious Broadsheet or Magazine
248	**All Academic Literature**	5	Light Tabloids or Magazine
		5	Marketing Material
		9	Visual Presentation
		63	Other
		181	**All Grey Literature**

Table 11 No of Academic and Grey Literature references found

Systematic review software

In order to analyse the 432 selected references, licences to use a systematic review software were purchased. A web-based software program, EPPI-Reviewer 4, was chosen to manage and analyse data in the literature review[5]. All 432 references, including dozens of PDFs, were uploaded to the software and all analytic work on the results of the database search was using this software. EPPI-Reviewer allows the references to be organised and coded methodically.

[5] Reference: http://eppi.ioe.ac.uk/cms/Default.aspx?tabid=2967

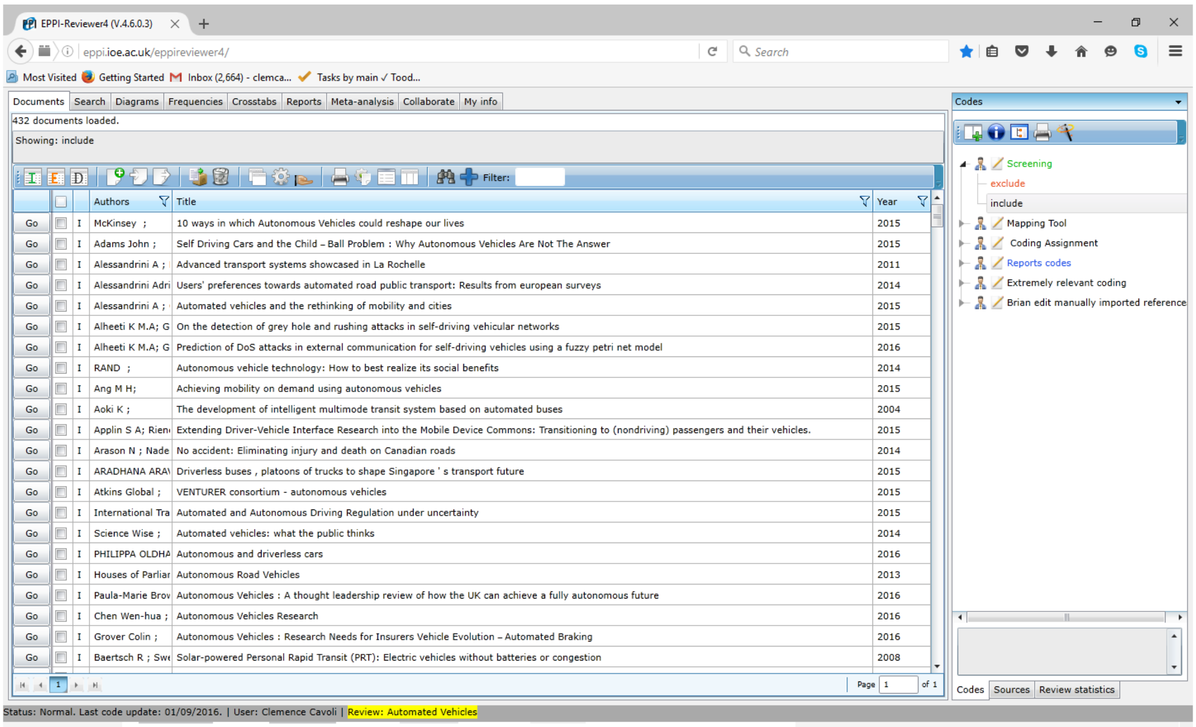

Figure 25 Screen shot EPPI-Reviewer 4

Development of Coding Mechanisms

A coding structure was developed to identify the characteristics of each reference, plus the key themes presented in it. This methodical approach was essential for identifying common areas of research and interest across a large number of documents, which would lead to an understanding of the state of the field and any gaps in the existing literature. A coding process was used whereby documents would be reviewed based on their title and abstract, their outline or their full text. As certain characteristics of the document were identified, or certain key themes expressed, the document was flagged, or coded, to reflect that. The result was a set of codes that described the relevant information for each document, which could be used to develop statistics for the body of literature, or identify documents for further investigation. For a list of these topics, see Annex D.

The **characteristic codes** were developed to identify the document's characteristics, such as its source, its status as grey or academic literature, whether it was peer reviewed, and its use of evidence. These codes would help to identify the type of document, which could be related to the key themes expressed (List in Annex D).

The **key themes codes** were developed to identify the major themes and questions in AV literature. By coding for common themes across many sources, the researchers could identify the prevalence of these themes. These codes were developed based on the initial sample of literature, which consisted of literature collected and supplied by the Department for Transport, and literature collected from informal database and web searches. The literature was read, and the major topics of interest were identified (List in Annex D).

Once the key themes were identified, a comparison coding exercise was undertaken. Two researchers reviewed and coded the same sample of documents, and their results were compared. This process had two benefits: first, by comparing the coding decisions made by each researcher, differences in understanding could be made evident, and a more uniform coding process developed. Second, ambiguities and gaps in the coding structure were identified, leading to the creation of new codes to capture specific themes.

Screening and Coding of Documents

The coding framework was then applied to the body of literature, bringing the two strands of inquiry together. Each of the 2296 pre-selected documents was screened by its title and abstract. Irrelevant documents were screened out at this stage, while 432 relevant documents were coded based on mechanisms described in the previous subsection. For documents without an abstract, typically grey literature such as industry reports and news publications, the screening process was applied to the executive summary, introduction and conclusion, or a full reading of the document in the case of shorter news articles. This screening and coding exercise provides the basis for the statistical analysis of the body of literature presented later in this document.

During this screening and coding process, 62 particularly useful documents were tagged as 'extremely relevant' for a more complete reading. Extremely relevant documents aligned with the aims of this study and met one or more of the following criteria:

- being particularly comprehensive
- effectively using evidence to reach robust conclusions
- identifying gaps in the literature
- having a focus on public acceptability or expectations based on survey data

These documents were reviewed in their entirety to achieve a more in-depth understanding of the best and most relevant documents in the body of literature. Additionally, the bibliographies of some of these extremely relevant documents were reviewed to identify additional works to add to the main body of literature. Relevant new documents were screened and coded on title and abstract using the process described above. Many of the documents discovered in the bibliographies were already included in the identified body of literature; this provides confidence that our literature search, while not exhaustive, is indicative of the literature on AVs. Nonetheless, some new works were discovered, and added to the body of literature.

Throughout the screening, coding, and in-depth review processes, any new ideas, themes, or questions encountered were recorded. Specific passages that were particularly indicative of a major theme, or that were unique and insightful were also recorded. Particular attention was paid to passages stating the current gaps in the literature.

Finally, results of the initial screening, coding and in-depth analysis were combined into an electronic spreadsheet for further analysis. The 44 listed topics were joined into 18 different thematic categories listed in the core literature review (see Annex D). Content analysis and cross-referencing was applied to the data collected to produce a summary of the literature.

Limitations

Even though a range of themes/topics were identified and analysed in the context of this literature review, none of the topics was specifically targeted and this literature review remains broad. For instance, this literature review did not search ‘AVs’ combined with ‘land use’ in the databases; it is possible that additional references could have been found by further narrowing search terms. Thus targeted literature reviews should be undertaken for each of the themes identified.

Annex B – Definition of Terms

Because the technology is developing quickly and, with it, the terms used to describe it, this section is intended to reduce the scope for misinterpretation of what follows.

In this report, the term *automation* is used to describe the extent to which a vehicle is equipped to carry out the driving task, and *full automation* implies that the vehicle can carry out all aspects of the driving task (thus being equivalent to SAE's Level Five) (SAE International 2014).

Autonomy describes the extent to which a vehicle "makes decisions" on its own. A *fully automated* vehicle assesses its environment and selects a course of action in accordance with what it finds. In principle, an autonomous vehicle could carry out the driving task in its entirety without communicating with other vehicles or roadside infrastructure. Autonomy is here contrasted with *control:* a *fully controlled* vehicle in effect acts out instructions set outside it. One example of this is a following lorry in a convoy. The term *control* has been preferred to *connectedness* because of the use of the latter word also to describe the extent of communication between the vehicle and its environment (notably other vehicles and road-side infrastructure). A highly connected vehicle may actually have no automation: it may simply have extensive data-sharing arrangements such as those that enable a human driver to remain very well informed about traffic conditions ahead, for example.

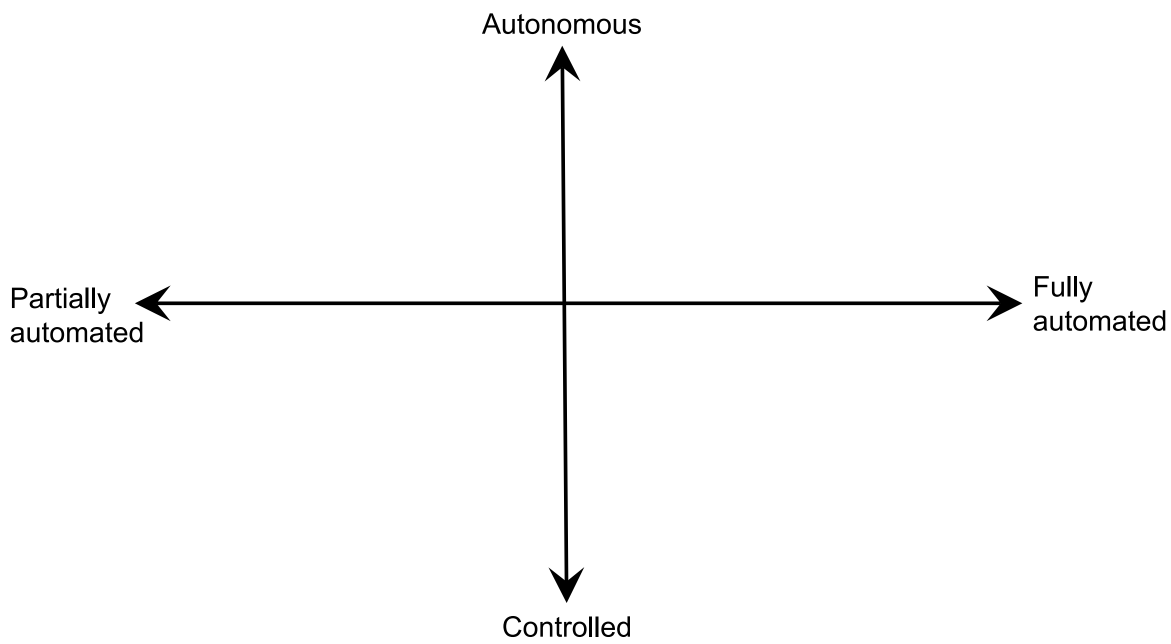

Figure 26 - Automation, autonomy, control

As Figure is intended to show, automation and autonomy/control are distinct axes and vehicles will occupy quite different points on the graph. For example, the following lorry in a convoy would probably lie in the bottom-right quadrant, whilst cars in the fleet today that offer "advanced driver assistance" will lie in the top-left.

A*utomated vehicle* is the general term used in this literature review, abbreviated to AV. Unless the level of automation is specified (e.g. full or partial), the range from partial to full is to be assumed. Equally, unless a point or range on the autonomy-control spectrum is specified, the full range is to be assumed.

Though these clarifications will hopefully be useful, it must be pointed out that they alone cannot capture adequately the *experience* of travelling in an AV. There is a very great difference, for example, between travelling in a fully automated “pod” which will not exceed 15mph, say, and in a partially automated conventional car at motorway speeds. Where appropriate, therefore, additional information about the nature of the travel experience will be specified. Where it is not, it should be assumed that the speed and comfort of an AV journey are at least *comparable* with those of journeys made currently using motorised transport.

Annex C – In-depth literature review

i. Technological and market developments

1. Technological and infrastructure developments

Introduction

In this section we describe what has been written in the literature regarding technological and market developments as it will affect the roll-out of automated vehicles (AVs) and ultimately wider social, behavioural and societal issues. This section also addresses infrastructure development issues linked to AVs

Different type of AVs

References reviewed in the context of this literature confirm that a variety of types of AVs is likely to emerge which will make regulation, standards and connectivity of AVs more challenging (Anderson et al., 2014a). A number of authors have highlighted the fact that car manufacturers have adopted an '**evolutionary approach**', essentially modelling AVs to current cars models, following a 'driver-centric' approach. In addition to traditional car makers, some companies are focusing on retrofitting existing vehicles with driving assistance options. As highlighted by Le Vine and Polak from Imperial College: "such systems require installation of dedicated hardware to retrofit existing vehicles with driving-assistance systems, whilst others do so by leveraging smartphone sensing and computing capabilities." (LeVine and Polak, 2014). On the other hand, technology companies, such as start-ups or larger companies such as Google, have embarked on a '**revolutionary' path**, changing mobility paradigms including vehicle shape and function (Frisoni et al., 2016). Many authors have mentioned the fact that driverless vehicles could lead to new vehicle design which would no longer focus on driving functions or 'crash survival' (KPMG & Center for Automotive Research, 2012).

Automation Pathways and Definitions

There is a general agreement in the literature that there will be **four or five stages** of automation starting with advance driver assistance systems and finishing fully automated vehicles or driverless vehicles. The table below illustrates the different stages of automation as described by the Society of Automotive Engineers (SAE)[6] . It is important to note that these stages of automation describe one AV development scenario or pathway, often called the 'evolutionary pathway', as described in the section on Ownership models, automation pathways will depend on the roll-out scenarios.

In this report, we frequently refer to automated vehicles (AVs) in a broad and comprehensive sense as described by the State of Nevada, USA: "Vehicle installed with automated technology

[6] "**SAE** International, initially established as the Society of Automotive Engineers, is a U.S.-based, globally active professional association and **standards** developing organization for engineering professionals in various industries." Wikipedia

which has the capability to drive the motor vehicle without the active control or monitoring of a human operator." (Definition based on the Statutes of Nevada, 2013). The UK Department for Transport (DfT) makes the difference between 'high automation' defined as: "This means a vehicle in which a driver is required to be present and may need to take manual control for some parts of the journey." And 'full automation': "This means a vehicle in which a driver is not necessary" (Department for Transport, 2015).

SAE Level	Name
0	**No automation** the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems
1	**Driver assistance** the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.
2	**Partial automation** the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task
3	**Conditional automation** the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene
4	**High automation** the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene
5	**Full automation** the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver

Table Annex 1 SAE Standard - Adapted from International Transport Forum, 2015

Software updates

The need for AVs' software to be regularly updated to maintain safety and security standards was highlighted by several authors (Anderson et al., 2014a). As stated by the Internal Transport Forum: "Designing vehicles for future system upgrades like the addition of sensors may also help reduce legacy risks" (International Transport Forum, 2015). Le Vine and Polak from

Imperial College hint that regular 'software maintenance' might become mandatory just like a regular maintenance schedule (Le Vine & Polak, 2014).

Connectivity and infrastructure

The majority of the references support **connectivity** between vehicles and between vehicles and infrastructure. Vehicle to Vehicle communication (V2V) and Vehicle to Infrastructure (V2I) have the potential to optimise the road network, thus improving traffic, reduce fuel consumption and improve road safety (Guériau et al, 2016).

Most authors highlight the fact **that significant infrastructure investments** are likely to be needed to accommodate AVs, in particular V2I infrastructure (International Transport Forum, 2015; Anderson et al., 2014a; KPMG & Center for Automotive Research, 2012). The need for specialised AV infrastructure (e.g. recharging stations, special communication networks) was stressed by a number of authors; some even state that AVs might need segregated highway lanes until manually driven vehicles are phased out of the market (Bierstedt et al, 2014). A team from Carnegie Mellon University go as far as saying that: "The conversion to a fully automated road infrastructure will be one of the most momentous challenges that humanity will face in the 21st century." (DiClemente et al., 2014). In their research, Wagner and colleagues, from the university of Texas, highlight the fact that one of the barriers preventing the implementation of V2I infrastructure is likely to be public budget restrictions (Wagner et al, 2014). However, the uncertainty surrounding the adoption of AVs, and potential uptake scenarios, means that it is unclear what specific infrastructures are needed (Ibid).

On the other hand, the wide scale adoption of CAVs could **make existing road infrastructure redundant and could lead to new traffic management laws**. A number of authors mentioned that road infrastructure signs might no longer be needed, and that as a result the design of highways might change significantly (Le Vine and Polak, 2014). Professor Begg for instance, argues that traffic controls such as speed humps or speed cameras might become a "thing of the past" (Begg, 2014) as AVs will be programmed to follow specific rules. In one of its reports, consultancy company KPMG state that new traffic management laws will have to be implemented to accommodate CAVs and "This could very well revolutionize traffic management" (KPMG & Center for Automotive Research, 2012).

Further research

Further research is needed to understand what infrastructure is required to support different type of AVs and roll-out scenarios (e.g. connected or non-connected AVs, urban or rural set up, type of vehicle, segregated lanes, etc.) Do AVs require large scale infrastructure to function safely and effectively? Further investigation is also needed to further understand the potential costs of road infrastructure and pricing and financing options (Who should pay for the new infrastructure? What type of infrastructure should be supported depending on the desired scenario...)?

2. Data and Security

Introduction

Security and data use linked to AVs are often mentioned as areas of concern by experts and by the public (see section on public perception). This literature review found limited written material covering these issues, however it focused on the behavioural and social aspects of AVs and not on the technical aspects. It is therefore possible that in databases dedicated to technological and engineering issues these topics are addressed more fully. In this section issues raised related to security and data in relation to AVs are summarised.

Cybersecurity

Security issues linked to AVs, in particular **software hacking and misuse**, are often listed as one of the main public **concerns** (Kyriakidis et al, 2015) which could hinder AV market uptake if not addressed (Fagnant et al, 2015). The importance of **cybersecurity**[7] issues linked to AVs was mentioned by several authors (Colwell, 2015; KPMG & Center for Automotive Research, 2012; KPMG, 2015; Felix et al., 2015; Feng et al., 2014). DiClemente and colleagues, from Carnegie Mellon University, acknowledge that “the automated system is considered to create much larger security and privacy related issues than the on-board computers currently used in cars" (DiClemente et al., 2014). The biggest cybersecurity risk is the "potential risk of a malicious attacker taking control of the car while in operation and provoking intentional accidents” (Ibid), including potential terrorist threats (KPMG & Center for Automotive Research, 2012). Connected AVs through ‘wireless networks’ may be ‘particularly vulnerable’ to attacks (Feng et al., 2014). Thus, cybersecurity is a potentially extremely serious and concerning issue which needs to be addressed.

Suggestions to **address cybersecurity concerns** were made by several authors. Fagnant and colleagues, from University of Texas, mentioned the aviation sector as an example of how to safely manage large scale cybersecurity issues linked to AVs (Fagnant et al., 2015). DiClemente and colleagues stress the importance of research and development in this field and the need for AV manufacturers to “invest a large portion of their R&D in researching methods for protecting the information and blocking any unauthorized access"(DiClemente et al., 2014). The International Transport Forum calls for the establishment of "encrypted security standards" (International Transport Forum, 2015). Similarly, Wagner and colleagues, from University of Texas, stress the need for public authorities to “play a leading role in the development and management of a security certificate system that ensured all messages sent and received were genuine and secure." (Wagner et al., 2014). Therefore, a range of solutions, in particular security standards or security certificates, could be implemented to prevent potential cybersecurity issues linked to AVs.

Data Use and Ownership

[7] Cybersecurity is defined as: “measures taken to protect a computer or computer system (as on the Internet) against unauthorized access or attack”, Merriam Webster dictionary

The large amount of informatics data which could be generated by AVs also raises potential **privacy issues linked to data use and ownership** (KPMG, 2015; KPMG & Center for Automotive Research, 2012; Brown, 2016). Questions such as 'who owns the data', 'how is the data stored' and 'who has access to the data' are frequently raised (Bierstedt et al, 2014;McCarthy et al., 2015). These questions will be particularly important as data generated by AVs are likely to be privately owned in many countries and this could present a growing concern for users (Ticoll, 2015). Think tank RAND stress the importance of clarifying 'who should own the data obtained through AVs' and highlight the potential risks linked to the lack of data protection, including negative impact on AV market uptake (Anderson et al., 2014a). Similarly, Fagnant and colleagues highlight the risks of data misuse if proper safeguards are not established and call for new **privacy standards** to protect AV users' privacy (Fagnant et al, 2015). A report commissioned by DG Internal Policies calls for further protection of AV's users' data and states that "ethics will play a key role in the definition of the **legislative framework regulating the use and management of such data**" (Frisoni et al., 2016). Therefore, addressing the potential impact AVs might have on information privacy, whilst the technology is under development, is needed.

However, several authors also highlight that the quantity of **data** AVs could generate **could also present opportunities to improve transport systems**. Atkins, a consultancy company, highlights the potential in gathering data from CAVs which could be used by city authorities for "optimising transport networks, enhancing the operation of transport systems and improving the planning process" (McCarthy et al., 2015). Fagnant and colleagues, also mention the potential benefits in using AV data to manage congestion charging for instance, and to improve the efficiency of the transport system (Fagnant et al, 2015). KPMG & Center for Automotive Research (2012) highlights the same possibilities where AV data collection can help better analyse road use patterns to improve the network.

Furthermore, a number of authors stress the importance of **data sharing in the context of connected automated vehicle systems**, in particular V2V and V2I (DiClemente et al., 2014; International Transport Forum, 2015). The International Transport Forum mention the fact that for AV systems to be connected "available data transmission frequencies, low-latency, trusted, secure and fail-safe data transmission protocols and harmonised data syntax that ensures safe interoperability" are needed (International Transport Forum, 2015). Several authors stress that competition between AV developers and manufacturers might hinder data sharing. Thus, sharing AV data is a requisite for V2V and V2I communication and the establishment of a connected AV system, it should be supported by all AV stakeholders.

Further Research:

Further research is needed regarding cybersecurity and data ownership if CAV systems are to be developed. Questions such as 'which safeguards (i.e. standards) should be established to prevent the misuse of data? who should own and control data generated by AVs? For what ends will the data be used? How will customer's data be protected? And how to ensure that data is shared by companies to enable connectivity? With whom should the data be shared?' seem to be under researched, yet they could have significant impact on the development of future CAV systems.

3. Cost of Travel

Introduction:

The cost of buying or using AVs is often mentioned in the literature, however the topic has not been comprehensively studied. This section summarises the discussions related to this topic in the literature.

High initial cost

References often refer to the cost of future AV vehicles, in particular privately owned vehicles. They highlight that the price is likely to be initially high and will go down following a market penetration. There were a variety of price differentials predicted between AVs and manually-driven vehicles. KPMG (2015) had the lowest predicted price difference, expecting a fully automated car to eventually cost US$1000 more than a comparable manual vehicle. While automation is expected to come at a higher purchase price, the additional cost of automation technology is expected to be offset by operating cost savings, though many authors are vague as to the source of these savings (DiClemente et al., 2014; Alessandrini et al., 2015). A report by consultancy company Fehr and Peers estimates that it may take up to 20 years for AVs to become affordable (Bierstedt et al, 2014). Therefore, findings suggest that the initial cost of AVs is likely to be significant but could decrease once market penetration is high.

Affordable shared AV travel

Several authors discussed the cost of using and operating AVs in the context of shared mobility. Many authors, such as Clark and colleagues (2016b) noted that the cost of traveling with an AV might be reduced in shared mobility scenarios. By breaking up the cost of car use into a pay-per-usage model, a shared AV scenario would make car travel accessible to people who cannot afford the fixed costs of vehicle ownership. Indeed, the International Transport Forum observes that “Residents who cannot afford to buy and maintain a private car or who are unable to drive may be some of the earliest adopters of these shared systems." (International Transport Forum, 2015). Fagnant and colleagues provide a more in-depth analysis of the potential cost of operating AVs from the point of view of an automated taxi service. Their simulation suggests that “a private fleet operator paying [US]$70,000 per new SAV could earn a 19% annual (long-term) return on investment while offering SAV services at $1.00 per mile of a non-shared trip (which is less than a third of Austin’s average taxi cab fares)" (Fagnant et al., 2015). The savings in this estimate is based on reduction in costs to insurance, fuel savings, and parking. The timeline for realizing this type of savings is uncertain, however. Furthermore, think tank

RAND (2014a) noted that users of paratransit[8], or community transport, would be likely to see cost savings by taking advantage of new automated services. Thus, under shared mobility scenarios, the cost of using and operating AVs could become affordable.

Public Opinion

In a series of interviews that took place in the USA, consultancy company KPMG (2013) found that cost was a major concern to potential consumers, making the potential for cost savings over manually driven vehicles a major factor affecting market uptake of AVs. Regarding the cost of AV purchase, the evidence is more mixed. Kyriakidis and colleagues (2015) undertook an online survey that was sent to 5000 respondents across 109 countries. Asking respondents how much extra they would pay for a vehicle with automated systems, they found that: "22% of the respondents did not want to pay more than $0 [extra] for a fully automated driving system, whereas 5% indicated they would be willing to pay more than $30,000" (Kyriakidis et al, 2015). Thus, even though the cost of owning or using an AV is likely to affect public opinion, it is unclear how much the public is prepared to pay to use AVs.

Further research:

Further research is needed to investigate the cost of travel linked to AVs under different use scenarios, in particular shared mobility scenarios.

4. Insurance

Introduction

The impact the introduction of AVs is likely to have on the Insurance industry have been widely mentioned in the literature. There is a wide consensus across references that AVs will disrupt the insurance market, as described in this section.

AV disruption of the insurance market

Most authors agree that auto insurance **premiums will decrease as AVs proliferate**. Based on the assumption of reduced crash rates, the literature reviewed predicts a **decrease in drivers' liability**. Ticoll (2015), a research fellow, supports this prediction of lowered costs for drivers. Consultancy company McKinsey (Bertoncello and Wee, 2015) predicts that as human involvement in driving diminishes, the amount of accidents attributable to human error will decrease, with the remaining accidents being considered "technical failure". This is predicted

[8] Term often used in the USA to describe "a specialized, door-to-door transport service for people with disabilities who are not able to ride fixed-route public transportation" Reference: http://www.amputee-coalition.org/fact_sheets/paratransit.html

to cause a **shift in liability from drivers to manufacturers** (Anderson et al., 2014a). KPMG (2015) highlighted that this development represents a "historic" change in the auto insurance industry. It calls on insurers to adapt a flexible approach to change, diversify their activities, and form strategic partnerships within the industry to survive the simultaneous contraction and reconfiguration of the industry.

Further research

Insurance companies are currently investigating the issues associated with AVs' expected disruption of the insurance market. Further investigation needs to be done to determine the effects of AVs on the insurance industry. Specifically, the literature review shows little research on the effect of shared mobility.

ii. Use of AVs

1. Ownership and Modal Share

Introduction:

The different roll-out scenarios of AVs and their potential impact has been widely discussed in the literature, and various authors highlight the importance of further understanding these possible scenarios. These different scenarios could influence public opinion and affect the short and long-term adoption of AVs, and further eventually they may have a profound impact on our transport systems and on our society. The potential social, societal and behavioural impact of AVs could vary greatly depending on the roll-out scenarios.

Even though different authors might offer different visions regarding potential roll-out scenarios there is some broad consensus, as further described below in this section. Most authors agree that different ownership models are likely to result in different travel patterns and modal shares. The development of different scenarios will depend on different factors which could be greatly influenced by public authorities and other stakeholders.

Roll-out scenarios

The **first scenario**, referred by some authors as the '**business as usual**' scenario or the 'evolution' scenario primarily describes the continuation of current ownership patterns where AVs would replace manually driven vehicles. This scenario is largely supported by conventional Original Equipment Manufacturers (OEMs). Several authors highlight that in this scenario car use could increase. Consequently other modes of transport, such as collective or active transport, would decrease. This scenario would also lead to unwanted consequences, such as an increase in congestion, environmental pollution or obesity levels. Clark and his colleagues from the University of the West of England, describe this first scenario 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. 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” (Clark et al., 2016a).

Similarly, Fraedrich and colleagues, from Humboldt University of Berlin, stress that this ‘evolution’ scenario would be led by traditional car makers. They would be in direct competition with players such as Google, who would introduce full automation embedded into an 'all digital' era, where the automobile becomes a moving computer and the focus is less on the hardware but more on the software (Fraedrich et al, 2015). Likewise, in a report written for the city of Toronto, Research Fellow Ticoll[9], describes this first scenario as primarily ‘Ownership Leads’ adding: “while various shared and public AV mobility services gain market share, privately owned AVs retains a large presence.” (Ticoll, 2015).

As highlighted by a number of authors, this first scenario is undesirable because it could lead to an **increase in car use**. In their paper, Thomopoulos and Givoni (2015), from LSE and Tel Aviv University, highlight the threat posed by what the authors call the 'renaissance of the private car' linked to AVs, which could lead to a new rise of car ownership and car use with and could threaten public transport and alternative modes of transport. As stressed by Fagnant and colleagues from Texas University most scenarios linked to AV use are heading towards: "more vehicle-miles traveled (VMT) and automobile-oriented development" (Fagnant et al., 2015). A report commissioned by DG Internal Policies also highlights the risk in private vehicle increase leading to "unfavourable scenarios [...] where the diffusion of automated vehicles would end in spurring private transport demand and the negative externalities related thereto" (Frisoni et al., 2016). As described by some authors, this change might reflect the resilience of the automobile sector and the fact that the attraction and attachment to owning a car, in particular in Western societies, might be enhanced by this technological change (Wells et al., 2015; Fraedrich et al., 2015). As described by Schwanen (2016), from Oxford University:

"The continuing dominance of the privately owned internal combustion engine, the neutralising absorption of car sharing by the car industry and the current enthusiasm over automated cars are reinterpreted as manifestations of automobility's capacity to endure through adaptation and influence over its environment. The socio-spatial inequalities and injustices associated with automobility are likely to persist through change as well."

[9] from the University of Toronto

As described by many authors, the rise in car use **could lead to a modal shift away from collective transport** (Wadud et al., 2016; Clark et al., 2016a; Wolmar, 2016; Ticoll, 2015). In his study, Guerra, from the University of Pennsylvania, reports on modelling work undertaken by various local authorities in the USA and concludes that as a result of AV uptake, the modal share for public transport is likely to decrease (Guerra, 2015). The risk that an increase in private transport demand would hinder public transport is highlighted in a report commissioned by DG Internal Policies (Frisoni et al., 2016) and by the think tank RAND (Anderson et al, 2014). As stated in Frisoni et al. (2016) "Another potential negative impact is that driverless vehicle technology can distract from investment and capacity building of public transport" (Frisoni et al., 2016). As AVs become increasingly convenient and popular and their cost decreases, an increasing amount of public transport users might switch to AV use and use AVs as an alternative to public transport. As stated by LeVine and Polak from Imperial College: “there is a risk that it [public transport] finds it increasingly difficult to compete with private car use.” (LeVine & Polak, 2014). Similarly, a number of authors highlight the fact that active travel, such as walking or cycling, might be negatively impacted by the uptake of AVs.

The **potential negative impact AV uptake** might have on **rail** in particular is highlighted by a number of authors (Enoch, 2015; Brown, 2016; Ticoll, 2015; Wolmar, 2016). As mentioned by LeVine and Polak: “Some experts argue, for instance, that the case for high-speed rail will be substantially weakened by future improvements in automated-car technologies” (LeVine & Polak, 2014). Consultancy company KPMG argue that the potential for decreased congestion linked to AV " could also bring the end to battles over the need for (and cost of) high-speed trains." (KPMG & Center for Automotive Research, 2012). In a study investigating public opinions of AVs, ScicenceWise concludes that members of the public worry that the uptake of AVs will have a detrimental effect on public transport (such as HS2) and will lead to a waste of public resources (ScienceWise, 2014).

The ‘Shared mobility’ or ‘Collective efficiency’ Scenario

On the other hand, a number of authors mention that AVs could be deployed following a different scenario, based on **'shared mobility'** and emerging mobility models, which would lead to ‘collective efficiency’, a decline in car ownership and optimisation of public transport. But some warn that this model might still lead to an increase in car use.

This scenario, called by Clark et al. (2016a) ‘collective efficiency’, ‘On-Demand Leads’ by Ticoll (2015) and ‘transformation scenario’ by Fraedrich et al (2015), would lead to a new mobility paradigm. This scenario would focus on the 'last mile' problem and would integrate AVs with existing collective mobility systems, including mass transit, to offer ‘automated mobility on-demand’ and 'door-to-door' service. These shared “automated universal taxi system or dial-a-pod" (Enoch, 2015), called by some automated personal rapid transit (one client per vehicle), could also be used in the context of ride-sharing (several clients sharing the vehicle at the same time). This development is likely to be driven by start-ups such as UBER, who would operate as ‘automated taxis’ or potentially by public authorities to complement public transport systems. The design and the shape of the AVs would vary depending on the needs and context, it could be small pods for instance or larger collective vehicles.

The majority of references state that **new mobility and ownership models are emerging** and that AVs should be thought about and designed to accommodate these models. The models discussed are primarily car-sharing, car-pooling or 'E-Hailing' (Uber model) that are emerging to provide alternatives to car ownership. Several authors argue that trends indicate that shared mobility is on the rise (Enoch, 2015; Fagnant et al, 2015; De Almeida Correia & Van Arem, 2016), and that the uptake of fully automated and connected vehicles could lead to new mobility systems in areas that are sufficiently dense for these systems to be economically viable. In its report on AVs, the International Transport Forum highlights that AVs have the potential to 'reshape individual travel' (International Transport Forum, 2015). In the context of the project CityMobil2, a team of academics from the Sapienza University of Rome, highlight that the benefits derived from AVs will be generated through shared mobility. As stated by the team "The aim [of CityMobil] is to develop a revolutionary vision based on automated collective public transport, automated vehicles for urban freight distribution, and a shift of paradigm, consisting in the decline of car ownership and the rise of purchase of mobility services." (Alessandrini et al., 2015).

According to a number of authors, **automated Personal Rapid Transit** (PRT) could become very popular, in particular for the 'last mile' of the journey (Choromanski et al., 2013; Chebbi et al., 2014; Lowson, 2011; Cepolina et al., 2011). Automated PRT described as providing "on-demand, private transit directly from origin to destination" (De Graaf, 2011) is often called an "automated taxi network (ATN)" (Brownell et al., 2014) and presented as a good alternative to privately owned cars in cities. Yap and colleagues, investigated the potential of automated personal rapid transit and concluded that passengers who usually travel first class would be likely to use personal rapid transit for the last mile of their journey (Yap et al., 2015).

Many references highlight the fact that mobility on demand combined with AVs is likely to **change ownership models and lead to a decrease in privately owned cars** (Frisoni et al., 2016; Ticoll, 2015; LeVine & Polak, 2014). In one of its reports, Atkins mentions that "Many people are re-thinking their relationship with vehicles, with a move towards access over ownership - particularly among young urbanites." (McCarthy et al., 2015). Fox, from Georgetown University mentions that shared AVs could "help to break the tie between identity and personal automobile ownership" (Fox, 2016). This vision is also shared by the Transport System Catapult which states that: "When travellers can rely on shared automated transport to provide their end-to-end mobility needs, there will be a declining demand for private vehicle ownership" (Wockatz & Schartau; 2015). Professor Begg also mentions that "The great promise of automated cars is not that we could each own one[...] but that no one would need to own one at all" (Begg, 2014). Consultancy company KPMG estimates that car ownership in the USA could be halved with the rise of shared mobility (KPMG, 2013). Fagnant and colleagues, from the University of Texas, undertook a sophisticated modelling of the use of shared automated vehicles (SAV) under various conditions and scenarios (Fagnant et al., 2014 & 2015). The results of their study indicate that shared automated vehicles: "may save 10 times the number of cars needed for self-owned personal-vehicle travel.", and that each SAV could potentially replace 9 manually driven vehicles (Fagnant et al., 2014). Similarly, a team based at MIT investigated shared mobility in Singapore and their modelling work suggest that: "a shared-vehicle mobility solution can meet the personal mobility needs of the entire population with a fleet whose size is approximately 1/3 of the total number of passenger vehicles currently in operation." (Spieser et al., 2014). Schoettle and Sivak from the University of Michigan come up to similar results (Schoettle & Sivak, 2015). Finally professor Begg, stresses that "if mobility and accessibility are to be maintained" it is essential to maintain the 'modal shift away from car' (Begg, 2014).

The potential shared automated vehicles have in **optimising transport networks** is highlighted by several authors (Enoch, 2015; Pendleton et al., 2014; Fatnassi et al., 2014). In the context of the CityMobil2 project, Alessandrini and colleagues modelled the use of SAV and suggest that shared AV systems have the potential to optimise the transport system, in particular if it is run by public authorities to ensure integration with public transport (Alessandrini et al., 2014 & 2015). The positive impact AVs could have on the network performance was also highlighted by Lam and colleagues from Hong Kong University: "Our results show that ride sharing can effectively lower the operational cost and an increase of the vehicular capacity can further enhance the system performance" (Lam et al., 2014). In their modelling study Zhang and colleagues from Stanford University estimate that the demand for taxis in Manhattan, New York "can be met with about 8,000 robotic vehicles (roughly 70% of the size of the current taxi fleet), while the case study of Singapore suggests that an AMoD [Automated Mobility on Demand] system can meet the personal mobility need of the entire population of Singapore with a number of robotic vehicles that is less than 40% of the current number of passenger vehicles." (Zhang et al., 2016).

By decreasing car ownership and optimising the transport system shared AVs could bring about a range of **positive outcomes** (Anderson et al, 2014a; Alessandrini et al., 2015; De Almeida Correia & Van Arem, 2016). This could lead to reduced congestion and, providing AVs are electric or low emissions vehicles, this scenario could also lead to a decrease in emissions. Clark and colleagues also highlight that under this scenario: "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" Clark et al (2016a). The American Institute of Architects, highlights the potential SAV have in improving walkability (McDonald, 2011). Therefore, an SAV system as described by Fagnant et al. (2014; 2015) could have beneficial environmental impacts if it reduces the number of vehicles in use. Howard and Dai from Berkeley University state: "Shared driverless cars or self-driving taxis have the greatest potential environmental benefits and their adoption should be particularly targeted" (Howard and Dai, 2013).

According to a number of authors, this second scenario is **more desirable than the first scenario**, in particular at the local level, and will lead to less unwanted consequences, such as urban sprawl (Bansal et al, 2016). Ticoll (2015) strongly recommends the city of Toronto to actively plan for this scenario. As stated by Thomopoulos and Givoni: "A change where public and sharing will be seen as superior to private and individual transport, could make the automated car a blessing" and provide an opportunity to 'de-privatise car use' (Thomopoulos and Givoni, 2015). Discussing the outcomes of the European project CityMobil2, Alessandrini et al. (2015) conclude that: "The expected positive impacts derive from the development of car sharing" (Alessandrini et al., 2015). Therefore, many authors recommend supporting the development of shared mobility as it is expected to generate positive outcomes and could discourage the use of privately owned vehicles.

The **potential of automation used for public transport** and the potential shared AVs have in complementing public transport, was mentioned by a number of authors (Benmimou et al., 2009; Aoki, 2004; Clerget et al., 2001; Alessandrini et al., 2015). In his 2014 report on London, Professor Begg highlights the potential full automation and connectivity have in improving the bus network by optimising it and how it could ultimately make the bus systems cheaper to operate and to use (Begg, 2014). A number of authors highlight the potential automated shared mobility have in complementing existing public/collective transport systems, in particular for the last mile of the journey. For instance, SAVs could provide efficient and flexible services in between rush hours (where large buses might not be needed/as efficient for instance) (Alessandrini et al, 2014). Professor Begg also highlights the potential on-demand pods have to fill the gaps left by certain public transport systems (such as lack of frequency or reliability) (Begg, 2014). In their 2015 paper Owczarzak et al (2015), from Poznan University, discuss the possible uses of AVs for public transport, potentially in the context of public transport on demand. Based on their modelling exercise for the city of Poznan in Poland (1 million inhabitants), they conclude that a combination of traditional public transport (such as buses) and public AVs could be extremely efficient in particular regarding travel time and cost of travel (Owczarzak et al., 2015). Lam et al. (2014) also argue that if automated ride sharing is used as a mode of public transport it could ‘enhance the system performance’. AVs could also present an opportunity to improve paratransit systems, used to provide mobility service to persons who are less able to drive such as disabled or elderly (Anderson et al., 2014a). Therefore, a number of authors have mentioned that shared AV systems could complement public transport, in particular in urban areas.

Even though the ‘Shared mobility’ scenario is more desirable than the first scenario described, a number of authors warn that **even in the best case scenario it is possible that shared AVs might become more popular than conventional public transport or rail and could lead to a decline of those services**. In his paper, Enoch describes a possible scenario where shared automated taxis, 'dial a pod' and other AVs start to replace 'traditional modes' such as buses, cars and conventional taxis, as these new modes are "better able to meet user needs" (Enoch, 2015). Fagnant and colleagues (2015) mention the possibility that the rail freight sector might be impacted by the rise in road freight linked to AV (Fagnant et al, 2015). As highlighted in a report commissioned by DG Internal Policies (Frisoni et al., 2016): "Users that would typically take transit may switch to shared automated vehicles if they are significantly more convenient at a comparable price. This may cause transit to be starved of ridership, resulting in lower cost recovery of transit infrastructure, and eventually reduction of services or increases in fares, both of which will perpetuate loss of users to AVs" (Frisoni et al., 2016). Finally, a number of authors highlight that it is of course possible that these **different scenarios could complement each other or exist in parallel**, but the impact each scenario is likely to differ radically (Fraedrich et al., 2015; Ticoll, 2015).

The realisation of the **different scenarios described above depend on many factors**. The most important variables are the regulatory and policy environment and market uptake based on customer preferences (Wadud et al., 2016; Clark et al., 2016a). Howard and Dai, from Berkeley University, conclude that AV's will enter the market and: "How we choose to implement this technology will make the difference, and that largely depends on the views of political and market actors"(Howard and Dai, 2013). As further discussed in this literature review the impact AVs are likely to have on our societies largely depends on which scenarios are being implemented and supported (Wadud et al., 2016). Public policies and regulation implemented at different levels will have a significant impact on the development of future scenarios (Wadud et al., 2016; Fox, 2016)

"Whether the AV locks us further in or out of the 'car based society' depends on the choices we make as a society, not solely on a specific technological development." Thomopoulos and Givoni (2015)

Further research:

The potential impact different uptake scenarios might have on modal share, in particular on the use of public transport and walking, needs to be further understood and researched, in particular through modelling work. Furthermore, additional questions remain regarding the practicality of establishing shared AV systems, including forecasts of market penetration, system design, implementation and operation. Finally, it is important to further understand to what extent public authorities should invest/support automated mobility on demand systems.

2. Freight

Introduction

The impact of automation on road freight operations is reviewed in this section. It is a topic that does not appear to have been widely discussed in the literature.

Delivery Optimisation

Several authors state that **CAVs have the potential to optimise goods delivery**. As described by Le Vine and Polak, from Imperial College, "Groceries ordered online, for instance, could be picked up by a 'personal service vehicle' and delivered to one's home when most convenient for the customer, rather than when a delivery van and driver happen to be available" (Le Vine and Polak, 2014). Cho and colleagues envision a more advanced shift, consisting of "an unmanned delivery service using a cooperative heterogeneous unmanned system consisting of a self-driving car and an unmanned aerial vehicle (UAV)" (Cho et al., 2014). Thus, connected AVs, potentially in combination with other modes of transport, could improve the delivery of goods.

Freight Optimisation

Many authors agreed that **AVs have the potential to revolutionize the freight and logistics industries**. The European-funded CityMobil project investigated the use of CAVs for **urban freight** and highlighted its potential to optimize that system (Alessandrini et al., 2015). Automated **trucks** were the focus of a Carnegie Mellon University study, finding that the "logistics industry will be positively impacted, as by then, automated trucks could work 24/7 and achieve maximized efficiency." (DiClemente et al., 2014). Hospodka et al (2015) also highlighted the potential economic benefits derived from using road AVs for freight. Chatti (2011) specifically names **seaport operations** as being fertile ground for optimization, with automated trucks allowing for greater efficiencies in distribution. This **integrated, connected operation throughout the value chain would create opportunities to optimize complex logistics systems**.

Further research:

Further research should be done in this field to understand the shape that an integrated automated freight and delivery system could take. Automated factories, trucks, and aerial vehicles could all play a part in the supply chain of the future.

3. Driver's interaction with AVs

Introduction

The literature discussing drivers' interaction with AVs, a topic often referred to as 'human-machine cooperation' or 'human factors', describes the interaction between human and semi-automated vehicles (usually level 3 or 4 automation). In this section we present a summary of the literature discussing various aspects of human-machine interface, in particular driver reengagement issues in partially automated AVs and in-car driving skills and experience.

Hand-over/Human Driver reengagement issues

Hand-over or human driver reengagement issues are frequently mentioned in the literature on AVs and have been relatively well studied. Even though AVs have the potential to improve drivers' performance (Funke et al, 2008) **hand-over issues might pose serious safety risks**. Hand-over or driver reengagement situations occur when highly automated vehicles suddenly require the driver to resume driving. These situations are most likely to happen in level 3 or 4 automation where the driver would still be required behind the wheel in cases of emergency but would not have to attend to the roadway. Several authors have investigated driver's levels of awareness and capacity to regain control of the vehicle and perform driving tasks in case of semi-automated vehicles. **The general consensus is that the more a driver is engaged in non-driving tasks (e.g. reading a book), the less aware and ready to resume manual control of the vehicle the driver becomes** (Merat et al., 2012a & 2012b; De Winter et al., 2014; Anderson et al., 2014a; Harbluk et al., 2014; Shen et al., 2014; Begg, 2014; Wolmar, 2016). The challenge this may pose is summarised by think tank RAND: "To experience the greatest benefits of the technology, human drivers will need to be able to engage in other tasks while the vehicle is driving automatedly. For safety, however, they will need to quickly reengage (in a matter of seconds or less) at the vehicle's request. Cognitive science research on distracted driving suggests this may be a significant safety challenge. Similarly, developing the appropriate mental models for human-machine collaboration may be a challenge for a technology widely available to the public." (Anderson et al., 2014a). Merat and colleagues, from University of Leeds, have undertaken extensive work on this issue and conclude that the risks arise when the driver's attention is "diverted to the distracting secondary task", such as watching a movie (Merat et al., 2012a & 2012b). This may pose substantial safety risks if automation fails and the driver needs to suddenly regain control of the vehicle. Some indicate that this risk is **judged as unacceptable by potential users** (Harbluk et al., 2014). Therefore, even though engaging in non-driving tasks is one of AV's main selling points, substantial safety risks remain unresolved linked to a driver's reengagement.

The need to further understand and prevent safety risks linked to drivers' reengagement with their AVs was highlighted by several authors (Wagner et al, 2014; Merat et al., 2012a & 2012b). As summarised by Merat and colleagues: "Designers, policy makers, and researchers must give careful consideration to what role the person should have in highly automated vehicles and how to support the driver if the driver is to be responsible for vehicle control" (Merat et al., 2012a). The importance of **designing solutions to maintain driver's engagement and awareness**, a**nd to inform AV drivers of their duty to resume control** was highlighted by several authors (Neubauer et al., 2012; Merat et al., 2012a & 2012b; Merat et al., 2014a & 2014b). A report produced by think tank RAND, stresses common OEM executives' concerns: "about how to alert a driver that he or she needs to take control back of an AV, perhaps in a matter of seconds. " (Anderson et al., 2014a). Example of solutions to prevent these issues are briefly mentioned, in particular driver training, such as 'intelligent tutoring systems', and the need for public agencies to adapt driving tests (Brown, 2016; Beggiato et al., 2015). However, solutions to address driver reengagement issues remain under-researched and should be further addressed in order to prevent safety risks.

- **In-car driving skills and experience**

A number of authors have highlighted that **improved convenience and comfort are expected for AV users and drivers**, in particular in cases of fully automated vehicles (LeVine and Polak, 2014; Bierstedt, 2014; Wagner et al, 2014). Frequently mentioned benefits of using or driving AVs, range from the ability to engage in non-driving tasks, such as working or being entertained, to reduced stress whilst driving. However, these assumptions have been questioned by several authors who argue that these claims need to be taken with caution.

A claim frequently mentioned in support of AVs is the fact that they are likely to **improve productivity** as AV users would be able to work whilst travelling. However, several studies have **questioned this assumption**. In their paper, Clark and colleagues (2016b), from the University of the West of England, report contrasting findings related to in car behaviour 'expectations'. On the one hand, they refer to the Howard and Dai (2014) study that surveyed potential users and found that multi-tasking is one of the most attractive aspect of AVs, on the other, they report that in their survey, Schoettle and Sivak (2014) found that over 40% of people surveyed expected to continue staring at the road. Schoettle and Sivak's findings are shared by Cyganski and colleagues, who surveyed[10] 1000 participants to examine their views on time-use whilst travelling in AVs. Based on the results of their survey, the authors conclude that "Perceived benefits with respect to time use were mainly **window gazing and relaxing**" and "the underlying assumption of people wanting to spend their time 'productively' while traveling, if only they could, has to be regarded with caution." (Cyganski et al., 2014). Therefore, survey results contradict assumptions that AV users will automatically desire to multi-task, including working, whilst using AVs and this might not lead to an increase in productivity.

One element that might prevent AV users from engaging with certain activities whilst driving, is **potential motion sickness**. Diels and colleagues, from Coventry University, are amongst the few authors who have undertaken rigorous research regarding this issue. They conclude that "all envisaged scenarios are predicted to increase the risk of motion sickness" linked to AV use (Diels, 2014). As stressed by the authors, motion sickness issues could negatively affect public perception and consequently market uptake (Diels at al., 2015). They stress the need for AV design to address and prevent potential motion sickness issues and conclude that "basic perceptual mechanisms need to be considered in the design process whereby self-driving cars cannot simply be thought of as living rooms, offices, or entertainment venues on wheels" (Diels et al., 2016). Motion sickness issues related to AVs seem to be under-researched, yet their implication on AV use could be significant.

The potential for **reduced travel stress** is often mentioned as one of the main elements for improved convenience and comfort of using AVs (DiClemente et al., 2014; Cottrell & Barton, 2013) however, no evidence is provided to back up those claims. Cottrell and Barton, from University of Idaho, state that "Evidence indicates that automation is likely to decrease mental workload and stress, therefore producing a more positive set of emotional responses." (Cottrell & Barton, 2013). However, another piece of research suggests that **platooning could increase drivers' stress** levels. Zheng and colleagues, from University of Tokyo, assessed driver's stress levels in the context of platooning and reported that mental stress increased as the distance between the driver's vehicle and the vehicle in front decreased. In the context of their studies, the authors found that platooning "corresponded to significantly higher ride discomfort according to subjective reports." (Zheng et al., 2015). Thus, even though AVs have the potential to decrease stress associated with driving, platooning might increase stress levels.

Another topic frequently discussed linked to the driver's interaction with AVs, is the **driver's attachment to manual driving** and the risk this could pose to AV adoption. Based on the results of their online survey[11], Kyriakidis and colleagues, conclude that "respondents, on average, found **manual driving the most enjoyable mode of driving**" (Kyriakidis et al, 2015). Several studies and authors highlighted that members of the public who enjoy driving could be reluctant to using an AV (ScienceWise, 2015; Brown, 2016; Morris et al., 2015). In their study

[10] Participants were interviewed through an online survey
[11] The online survey was sent to 5000 persons from 109 countries

on public perception, Howard and Dai (2013) report that car owners who enjoy driving are more likely to want to retain control over their vehicle. This finding is also highlighted by Begg who states that one of the key challenges posed by AVs is the "Resistance of individuals to forfeit control of their cars" (Begg, 2014). This reluctance could also be caused by a 'perceived loss of freedom' associated with the use of AVs (Enoch, 2015). Therefore, drivers' attachment to manual driving and potential reluctance to drive an AV could affect market uptake of those vehicles.

The **vehicle design** has also been discussed linked to the driver's interaction with AVs. Most authors highlight the fact that the vehicle design is likely to change to reflect the vehicle's new functions and role, set to be increasingly removed from the experience of driving a car (KPMG, 2013). In one of its articles, the Economist emphasises the potential change in customers' behaviour and expectation, highlighting the fact that future AV consumers "might be more interested in the software services the car has to offer than the hardware aspect of the car" and that this is likely to alter the design of vehicles (The economist, 2016). An interesting body of research has looked at the potential anthropomorphism features have in improving the driver's trust in AV. For instance, giving the AV human characteristics, such as a human voice, or enabling AVs to 'express emotions', following human models, could increase trust levels in those vehicles (Riaz et al., 2015; Fraedrich et al, 2015). Thus, new vehicle design, including anthropomorphism features, is likely to emerge to reflect the new purpose of the vehicle.

Further Research:

Some of the key research questions related to drivers' reengagement issues are: Under what conditions to allow AV users to engage in non-driving tasks in cases of semi-automation? What solutions, such as training, should be implemented to keep the driver engaged and maintain/adapt driving skills?

Further research is needed to better understand drivers' behaviour whilst in AVs. Questions such as to what extent will drivers be able to/want to work whilst in AVs? Could motion sickness issues prevent most drivers from engaging in non-driving tasks? To what extent will AVs reduce drivers' stress? Finally, additional research is needed to understand whether driver's attachment to driving can affect AV adoption.

4. AVs' interaction with other road users

Introduction:

This section summarises the literature on interactions between AVs and other road users. It starts by describing issues related to interactions between AVs and conventional car drivers in the context of mixed-traffic. It then discusses interactions between AVs and other road users in urban areas, in particular with cyclists and pedestrians.

Interactions between AVs and car drivers

Several authors have pointed out the fact that a range of **uncertainties remain about how AVs will interact with manually driven vehicles and vice-versa, in "mixed-traffic" situations** (Brown, 2016; Fagnant et al, 2015; Fraedrich et al, 2015)**.** Le Vine and Polak, from Imperial College, describe the "Challenges of a dual-operation road network (some vehicles in automated operation, some under control of human drivers)" as a potential safety problem linked to the introduction of AVs (Le Vine and Polak, 2014). The potential difficulty in managing mixed driving scenarios where AVs and non AVs share the road was highlighted by several authors.

One of the safety issues most frequently mentioned is the fact that human drivers could be influenced by AVs platooning and this might induce an unsafe change of behaviours. Gouy and colleagues investigated the impact AV platooning could have on non AV drivers. Their study indicates that non AV drivers might be negatively influenced by platooning. Their findings indicate that non AV drivers may be more likely to reduce the safety distance between their vehicle and the vehicle in front and conclude that "The results of this study point out the importance of examining possibly negative behavioural effects of mixed traffic on […] car drivers" (Gouy et al., 2014). Similar concerns were raised by expert participants during a workshop held by the Institution of Engineering and Technology in 2016 (Brown, 2016). Thus the introduction of AVs in mixed traffic situations could negatively influence the driving behaviour of human drivers, leading to potential road safety issues.

AVs' interaction with cyclists and pedestrians

Similarly, technical and behavioural **questions regarding the interactions between AVs and other road users in urban areas, in particular pedestrian and cyclists, were discussed by several authors (**Parkin et al., 2016; Le Vine & Polak, 2014)**.** In a literature review written in the context of the UK project Venturer, Parkin and colleagues list **key technical issues** related to AV's interactions with pedestrians and cyclists, including: "the ability to detect and avoid cyclists taking paths through a junction which conflict with the automated vehicle's path, and the ability of automated vehicles to sense and respond to human gestures" (Parkin et al, 2016). The authors also mention that issues related to interactions with other road users will depend on the type of 'use scenario' in place, for instance whether AVs operate in a fully segregated network or whether they are used in a shared space. Writing for London Essays, John Adams, Emeritus Professor of Geography at UCL, highlights the fact that **road users' behaviour** is likely to change once AVs become widespread and wonders to what extent will AVs be able to share the road with other users such as pedestrians or cyclists (Adams, 2015). Parkin and colleagues also mention that the literature related to this topic remains limited (Parkin et al, 2016). Yet, should AVs share the road with other users, in particular in urban areas, it will be key to further understand the potential changes this will generate.

Several authors have mentioned that improved road safety linked to the introduction of AVs could **boost pedestrians' and cyclists' confidence and could encourage people to walk or cycle**. In the context of the CityMobil 2 project, Alessandrini and colleagues argue that thanks to the use of AVs "pedestrians and cyclists would be more confident that the cars were being driven correctly" (Alessandrini et al., 2015). Likewise, in a report focusing on London, Prof Begg emphasises the potential AVs have to make cycling and walking safer and to further encourage these modes of transport (Begg, 2014). However, Parkin and colleagues state that pedestrians and cyclists' perception of increased safety around AVs will depend on how AV are programmed vis-a-vis the gap between a vehicle and a cyclist (i.e. if the gap programmed is too close, pedestrians or cyclists might not feel safe). **Thus, AVs have the potential to improve pedestrians' and cyclists' experience on the road providing they are adequately programmed.**

However, **pedestrians and cyclists' behaviour change linked to the introduction of AVs could end up negatively affecting traffic flow in urban areas**. UCL's Emeritus Professor John Adams posits that at best pedestrians and cyclists are likely to reclaim the roads or at worst take advantage of the new system, expecting that AVs will automatically stop or slow down in the interest of safety (Adams, 2015). Adams stresses that the shift of power dynamics between cyclists, pedestrians, and automated vehicles (compared to conventional vehicles) could slow or potentially disturb traffic flow. As stated by Adams: "Pedestrians would no longer cower at the roadside trying to judge whether gaps in the traffic could see them safely to the other side. They would be liberated to stride confidently into the road, knowing that traffic would stop for them" (Adams, 2015). Addressing this potential issue, Le Vine and Polak, from Imperial College, mention that "Driving in cities would be unacceptably slow if automatedly-operating cars were required to assume that every pedestrian might jump into traffic as fast as humanly possible", implying that AVs will have to be programmed to anticipate these issues and make some compromises on safety (Le Vine and Polak, 2014). Therefore, some potentially complex behavioural changes might be generated by the introduction of AVs, and require to be addressed to anticipate potential safety and/or traffic flow issues.

Further Research:

Further research, in particular modelling work, is needed to examine how AVs will interact with other road users, in particular car drivers, pedestrians and cyclists, under different 'use scenarios', including in urban areas. Could these interactions lead to unsafe situations? Could it negatively affect traffic? A long list of detailed research questions has been developed by Parkin et al (2016) in the context of the UK project Venturer.

5. Market Uptake

Introduction:

Even though in the majority of the references reviewed authors were confident that AVs will be developed and adopted, a number of authors have warned that there are barriers to AV market uptake. This section focuses on the opportunities and challenges related to market uptake & penetration in Western countries and in the Global South.

AVs market uptake & potential market failure in Western countries

An overwhelming majority of references reviewed regard the successfully development of AV technology as not a question of "if" but simply "when". A large online public opinion survey undertaken by Kyriakidis and colleagues, from Delft University of Technology, concludes that"69% of respondents estimated that fully automated driving will reach a 50% market share between now and 2050" (Kyriakidis et al, 2015). Growing investments in research and development by technology companies and more recently by major car manufacturers indicate that interest in AVs is increasing. Furthermore, recent changes in regulations are likely to accelerate the development and potential market uptake of AVs. In the USA, a growing number of states are following the footsteps of Nevada (the first state to authorise the operation of AVs in 2011), allowing the testing and operation of AVs on their roads. In 2016 several EU countries have successfully lobbied the United Nations[12] to amend the 1968 Vienna Convention on Road Traffic to allow a vehicle to drive automatedly providing a person is able to take back control of the driving at any time. This has been interpreted by some as a sign that European automobile manufacturers are ready to penetrate the market[13] . Thus, little doubt remains that the technology will be developed and introduced in Western countries.

However, several authors note that a number of obstacles could prevent AV market uptake. The barriers most frequently mentioned are the initial **high cost of AVs, liability issues, lack of business plan, and (lack of) consumer demand** (Fagnant et al., 2015; Clark et al., 2016b). As stated by Masoud and colleagues, from Cranfield University, "The **high price** and the consequent low demand may translate to less motivation for the automobile industry to move toward mass production, and it could take decades for the market to reach equilibrium." (Masoud et al., 2016). Think tank RAND also mention that "Absent sufficient demand, economies of scale and network effects will not reduce the marginal cost and the technology might wither" (Anderson et al., 2014a). Regarding liability issues, Le Vine and Polak[14], draw a parallel between vehicle manufacturers reluctance to invest in AV Research and Development in the event of frequent **lawsuits** following a car accident, to pharmaceutical companies unwillingness to invest in a vaccination before the Vaccine Damage Payment Scheme[15] was established in the late 1970s (Le Vine and Polak, 2014). Think tank RAND emphasises the risk of market failure linked to the uncertainty of AVs **business model** and the fact that AV systems might be too expensive for wide adoption (Anderson et al., 2014a). The difficulty of predicting **consumer demand** for AVs could also present a risk for wide AV uptake, as stated by consultancy company KPMG : "Ultimately, the shape of the automotive

[12] More precisely the Working Party on Road Traffic Safety

13 References: Reuters, Cars could drive themselves sooner than expected after European push, May 2014. URL: http://www.reuters.com/article/us-daimler-autonomous-driving-idUSKBN0DZ0UV20140519

[14] From Imperial College

[15] Introduced in 1979 by the UK government the scheme allows people who have been "severely disabled as a result of a vaccination against certain diseases, […] get a one-off tax-free payment of £120,000." URL: https://www.gov.uk/vaccine-damage-payment/overview

future will depend on customers - their needs, preferences, fears and their pocketbooks" (KPMG, 2013).

Potential **solutions to ensure wide market penetration** were discussed. Certain authors, such as think tank RAND stress the potential **shared AVs** have in overcoming some of these obstacles, in particular affordability concerns (Anderson et al., 2014a). In their report, Clark and colleagues 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" (Clark et al, 2016a). Therefore, shared AVs and the support of public authorities and key stakeholders could encourage AV market uptake.

Mass market penetration and socioeconomic impact

The potential socioeconomic impact of mass AV market penetration was debated in the literature. The general consensus is that for the AV industry to thrive, mass adoption is desirable, however, it is unclear what socioeconomic impact this may have. On the one hand certain authors, such as Fagnant and colleagues, from the University of Texas, argue that **the higher the market penetration is, the more positive the socioeconomic outcomes are likely to be** (Fagnant et al, 2015), such as cost of travel. On the other hand, Clark and colleagues **question whether a "commercially-viable market model for the production and adoption of AVs" would also be "socioeconomically desirable" if it leads to unwanted side effects such as, unemployment, congestion or increased car use.** Le Vine and Polak conclude by stating that: "Policy will need to balance supporting private sector innovation and protecting the public welfare" (Le Vine and Polak, 2014). Thus, it is unclear whether mass AV market penetration will automatically lead to desirable socioeconomic impacts.

Market uptake in non-Western countries

Some authors questioned whether AVs could be successfully commercialised outside of Western countries. On the one hand, certain authors argue that AVs are unlikely to be popular and suited to other parts of the world, in particular across the Global South. Le Vine and Polak quote Professor Urry[16] who suggested that: "automated cars may end up as a 'First World solution…not likely to be widespread throughout most of the world'", primarily due to their high cost (Le Vine and Polak, 2014). Furthermore, cultural and regional factors, such as dense mixed traffic conditions, might not be conducive to AV use (Brombacher, 2014; Young et al., 2014).

On the other hand, think tank RAND argues that **AV technology could allow countries in the Global South to accelerate transport technology uptake**: "Countries with limited existing vehicle infrastructure could "leapfrog" to AV technology. Just as mobile phones allowed developing countries to skip the development of expensive landline infrastructure, AV technology might permit countries to skip some aspects of conventional, human-driver centered travel infrastructure" (Anderson et al., 2014a). Therefore, though AVs may present an

[16] John Urry was a Professor at Lancaster University

opportunity for these countries, doubts remain regarding the affordability and the suitability of the technology.

Further research:

Further research is necessary to examine whether mass AV market penetration will lead to desirable socioeconomic outcomes or not. Similarly, it is important to understand to what extent negative externalities linked to the use of AVs could lead to a market failure. Further understanding the opportunities and challenges of introducing AVs in non-Western countries is needed.

iii. Consequences/Wider impacts

1. Traffic Flow

Introduction

The potential impact AVs might have on congestion has been frequently discussed in the literature. A number of references, particularly consultancy reports, stress AVs' potential in reducing congestion as one of the main advantages of AVs' uptake. However, this assumption is partially refuted by a number of authors and institutions. The potential impact AVs might have on traffic flow is not straightforward and depends on a number of variables. Further understanding the potential impact AVs might have on congestion is key, as it is one of the main selling point for the uptake of AVs and could determine consumer and public acceptance.

Potential increase in Travel Demand and in VKT

The majority of the references who discussed congestion and AVs – in particular academic studies - highlight the fact that **mass AV uptake could lead to increased travel demand and consequently a rise in Vehicle Kilometres Travelled** (Brown, 2016; Fox, 2016; Guerra, 2015; Bierstedt et al., 2014; LeVine & Polak, 2014; Fagnant et al., 2013). This scenario could in turn lead to increased congestion (Wadud et al., 2016; Clark et al., 2016a &2016b, Anderson et al., 2014a; Brown, 2016; Smith, 2012; Begg, 2014). This hypothesis is based on several assumptions.

The first assumption is that under highly automated scenarios (level 4 or 5) **'non-drivers' would want to use AVs for their travel**. The 'non-drivers' group describes part of the population that does not have a driving license or does not drive, such as under-age persons, persons with disability, or persons who do not feel confident enough to drive (such as elder persons). Professor Smith from Stanford University estimates that this section of the population represents more than 30% of USA citizens (Smith, 2012).

The second assumption that could explain an increase in travel demand linked to AVs is the potential **rise in popularity and convenience of AVs**. In his report investigating AVs in London, Professor Begg highlights the fact that the introduction of AVs could increase car use because AVs have the potential to become very attractive and a growing percentage of the population might rely on their use for travel (Begg, 2014). In their report, RAND, a USA think tank, highlight the fact that the decreased cost of driving in the case of a shared economy scenario mixed with the increase in AV popularity due to convenience, is likely to increase travel demand and VKT (Anderson et al., 2014a). LeVine and Polak from Imperial college London state: "it may reasonably be surmised that technology that makes it easier to move about by car will serve to stimulate its use" (LeVine & Polak, 2014).

Certain academic authors such as Guerra (2015), who reports on modelling work undertaken by various local authorities in the USA, have estimated that the increase in VKT could range from 5% to 20% in the USA (Bierstedt et al., 2014; Guerra, 2015). As summarised by consultancy company Fehr & Peers:

> "improved driver experience and the availability of robo-chauffering for those who would otherwise not be permitted to drive may increase VKT per capita as much as 35%, off-setting much of the efficiency gain"(Bierstedt et al., 2014)

Even though increased VKT does not necessarily lead to increased congestion, a number of authors mention that **it could well generate more congestion and associated negative impacts** (Wadud et al., 2016; Clark et al, 2016a; Anderson et al, 2014a; Smith, 2012; Begg, 2014). As highlighted by Smith and Fagnant and colleagues, for AVs to improve traffic flow, demand management strategies will have to be implemented at an early stage (Smith, 2012; Fagnant, 2015).

Potential to increase Highway Capacity

On the other hand, the **potential for AVs to increase highway capacity under certain scenarios** was highlighted by a number of authors and institutions. There is a general consensus amongst authors that AVs could optimise road transport networks, in particular providing the majority of the vehicles on the roads follow the following scenarios:

1. Full automation is reached
2. Vehicle to Vehicle and Vehicle to Infrastructure communications technology is widespread
3. Shared mobility is mainstream

Full automation and connectedness of the vehicles (V2V and V2I communication network) are key to optimise traffic flow as highlighted by a number of authors (Fagnant et al., 2015; Ticoll, 2015; LeVine & Polak, 2014; Smith, 2012; Wagner et al., 2014; Begg, 2014). As LeVine and Polak highlight: "coordination between automated vehicles could enable more sophisticated driving styles and greatly reduced traffic congestion" (LeVine & Polak, 2014). The potential to increase highway capacity, would be partly enabled thanks to vehicles' capacity in traveling closer to each other and in using 'traffic-smoothing algorithms' (Fagnant et al, 2015). Fagnant and colleagues from Texas University, also highlight that for optimum results, the system would have to be fully connected and: "implementation of cloud-based systems and city or region-wide coordinated vehicle-routing paradigms and protocols" will need to be in place (Fagnant et al., 2015).

However, a number of authors point out that these benefits only apply providing the **AV penetration rate is high**, and the majority of the vehicles on the road are fully automated and connected AVs. Indeed, as mentioned by some, a 'mixed mode' scenario where fully automated vehicles share the road with manually driven vehicles might not lead to substantial optimisation of the traffic flow (Fagnant et al., 2015).

The widespread use of fully automated vehicles has the potential to considerably reduce road accidents, which affect congestion. As stated by DiClemente and colleagues from Carnegie Mellon University: "delays and congestion as a result of crashes will possibly be eliminated due to low crash rate" (DiClemente et al., 2014). Consultancy company Fehr and Peers estimates that these benefits would only materialise post 2035 once those vehicles have been widely adopted (Bierstedt et al., 2014). In one of its reports KPMG mention that the potential for highway optimisation related to AVs is particularly high in the case of dedicated highway lanes (KPMG, 2013).

The potential for automated vehicles use in the context of **shared mobility systems** (ride sharing and car sharing) to optimise traffic flow was highlighted by many authors (McCarthy et al.,2015; De Almeida Correia & Van Arem, 2016; McKinsey, 2015; Bansal et al, 2016). The potential for improved traffic flow in the context of automated public transport, such as buses, was highlighted by several authors such as LeVine and Polak who state: "automation may be able to deliver increased passenger throughput far beyond the people-moving capacity of private cars, even automated cars" (LeVine & Polak, 2014).

However, as stressed by some academics such as Çolak and colleagues from MIT and De Almeida Correia and Van Arem from Delft, optimising the network does not automatically lead to a decrease in congestion. Çolak and colleagues warn that even though highly automated and connected AVs could improve congestion, even "in the best case scenario, time savings would be imperceptible for the majority of the drivers" (Çolak et al., 2016). In their study, De Almeida Correia and Van Arem (2016) model a shared AV network in Delft, the Netherland to assess the impact on congestion. They conclude that shared AVs have the potential to optimise the network, but could increase congestion slightly if car use increases.

Further research

Further modelling work is needed to ascertain the net impact AVs could have on traffic depending on different scenarios. Furthermore, limited research has been undertaken to assess the potential impact AVs could have in cities, where the roads will be shared with a range of other users. Could it improve traffic flow or could it slow it down?

2. Economy and Employment

Introduction

The use of automated vehicles has the potential to impact the economy and employment levels. In this section we review the written material which has discussed these topics and highlight the need for further research in this field.

Impact of AVs on the economy and employment

The potential positive economic impact AVs, in particular CAVs, could generate has been mentioned by several authors. Consultancy companies such as KPMG or Atkins highlight the economic gains CAVs could produce; as stated by Atkins the uptake of CAVs could: "generate £51bn benefit per year by 2030" in the USA (McCarthy et al., 2015). However, these assumptions do not appear to be supported by detailed evidence. Fagnant and colleagues from the University of Texas, estimate that in the USA each AV could save circa 2000 dollars if "crash savings, travel time reduction, fuel efficiency and parking benefits" are taken into account. However, their calculations assume that travel time and fuel efficiency is improved which, as discussed in this report, is by no means certain. Furthermore, their study does not take into account a number of potential additional side-effects - for instance negative impact on employment or on health – as discussed in this section below. In a report published by the city of Toronto, Ticoll, a research fellow, estimates that in the context of shared mobility scenarios: "were AVs to be at a 90% adoption rate in Toronto today, the result would be annual savings of $6 billion, or 4% of the City's $150 billion gross domestic product" (Ticoll, 2015). However, Ticoll only takes into account the positive impact AVs might have (such as reducing road accidents) but does not include potential negativities, such as increased VTM, job loss, urban sprawl, or health issues linked to inactivity. Therefore, even though several authors have highlighted the positive impact AVs might have on the economy, in particular linked to safety improvements, insufficient detailed data and comprehensive analysis make current estimates unreliable.

A few authors have mentioned the potential for AV industry and AVs use to generate employment. Atkins states that "CAVs could create 320,000 additional jobs in the UK by 2030" (McCarthy et al., 2015) but insufficient details and evidence is provided to back up this data. A report commissioned by DG Internal Policies highlights the potential CAVs have for creating jobs "in the automotive, technology, telecommunication and freight transport industry" (Frisoni et al., 2016). Enoch (2015) from Loughborough University also mentions notes that "electronics manufacturer employee" might benefit from the deployment of AVs. Therefore, even though CAVs could create new employment opportunities, limited data is provided to assess the levels of employment CAVs could generate.

On the other hand, many authors have stressed the **negative impact vehicle automation could have on employment**. In cases of self-driving vehicles (level 4 or 5 automation) professional drivers could become unnecessary. As stated by think tank RAND "it is likely that AV technology will eventually lead to the loss of commercial transportation sector jobs at considerable human cost. Ultimately, the lost jobs might be replaced by others, perhaps related to the AV industry, but there may be considerable economic disruption" (Anderson et al., 2014a). EU data suggests that close to 2.4 million employees work for the road freight sector[17], their employment could be affected should the presence of a professional driver become unnecessary (Frisoni et al., 2016). A team of researchers from Carnegie Mellon University acknowledge that AVs might replace millions of professional drivers; they estimate that in the USA, professional taxi, truck and water transportation drivers represent over 2 million people (DiClemente et al., 2014). Furthermore, a number of authors mentioned the risks trade union resistance would pose to the deployment of the technology and the importance of anticipating and addressing these issues (Enoch, 2015; Fagnant, 2015; DiClemente et al., 2014).

In addition to professional drivers, **a range of economic sectors might be negatively affected by the uptake of AVs**. The insurance industry is likely to experience significant disruption as highlighted by several authors. Think tank RAND report that "American consumers spend approximately $157 billion in automobile insurance premiums every year" (Anderson et al., 2014a), and if premiums become unnecessary as AVs become safer, the insurance sector could be profoundly affected. Consultancy company KMPG estimates that "within 25 years [...] the personal auto insurance could shrink to 40 percent of current size" (KPMG, 2015). Other economic and employment sectors that depend "on the current auto-mobility system", as described by Le Vine and Polak from Imperial College (2014), are likely to be disrupted too. This could include automobile repair centers/garages, the retail industry, jobs in the health sector previously associated with automobile accidents, such as specialised health practitioners, but also lawyers, and the parking industry (DiClemente et al., 2014; Anderson et al., 2014a; LeVine & Polak, 2014; Begg 2014). Public sector revenues could also be impacted in cities, should parking become unnecessary and 'traffic violations' decrease (Ticoll, 2015). Thus, a range of economic sectors, in the private and in the public sphere, might be negatively impacted by the uptake of AVs.

A number of authors have also highlighted the **risk automated vehicle uptake might pose to traditional vehicle manufacturers** (Ticoll, 2015). The development of automated vehicles, in parallel with the rise in shared mobility, challenge the conventional vehicle manufacturers' business model. As summarised by the Economist: "Incumbent manufacturers are recognising the double threat posed by technology, as car-sharing takes off and driverless vehicles come closer" (Economist, 2016). The business model might change from a system based on customers interested in buying a car as a "status symbol and expression of personal style" to clients who are more interested in software and in-car entertainments (Ibid). The risk highlighted by several authors, is that technology firms such as Google will dominate the market. However, an increasing number of OEMs, such as Ford, are investing in these new market opportunities and are already teaming up with technology firms. One question remains, as put by the Economist: "Will the sign on the dashboard say Ford (powered by Google) or Google (powered by Ford)" (Ibid).

[17] "in the 23 member states for which data are available" (Frisoni et al., 2016)

The need to **adapt and anticipate likely changes in employment generated by AVs** was mentioned by several authors. Fox, from Georgetown University argues that shared AVs should be encouraged provided all side effects are prevented or anticipated, such as loss of employment, she states: " Planning for the possible loss of employment for hundreds of people will be a crucial step toward adoption of driverless cars for any city" (Fox, 2016). The need for the education system to adapt to these new changes was mentioned. As stated by Docksai in the Futurist: "[people's] employability will depend on education systems becoming as adaptable as possible to incorporate vital new skills and deemphasize ones that no longer hold much relevance" (Docksai, 2013). A report commissioned by DG Internal Policies also stresses that: "education and training will have a crucial role either to train professional drivers and to prepare the new generations to work in a more technological society where new professions might replace ones that might no longer be needed" (Frisoni et al., 2016). Thus, anticipating and adapting to potential impact on employment, through training and education, might be necessary.

The need to **further assess the impact AVs might have on the economy** has been highlighted by several authors and institutions. **Comprehensive and thorough cost-benefit analysis** and other appraisal methods are needed to understand the potential economic impacts different 'AV uptake' scenarios might have. It is particularly important as the public could be sensitive to unemployment and inequality issues generated by AVs (Sciencewise, 2015). DiClemente and colleagues from Carnegie Mellon University, stress the importance of undertaking a cost-benefit analysis of AV introduction: " before making any attempts to take regulatory decision" (DiClemente et al., 2014). Wagner and colleagues, from Texas University, highlight that the 'economic case for AVs' is unclear and call for a 'robust and comprehensive cost-benefit analysis' (Wagner et al, 2014). The need to further understand the potential impact AVs will have on the economy was also highlighted in a report written by the OECD stating: "Economic impacts too will be important and it will be necessary to gauge these impacts in a common cost-benefit framework with other transport investments when assessing public expenditure on supporting infrastructure or services." (International Transport Forum, 2015). Further research is necessary to assess the potential economic implications of automated vehicles.

Further Research:

Further research is necessary to assess the potential impact vehicle automation could have on employment, in particular since it could be a public concern. Questions such as "How many jobs directly and indirectly related to AVs, across sectors, could be at risk? Comprehensive and thorough cost-benefit analysis, including all potential side-effects and impact, is also urgently needed.

3. Land Use

Introduction

Authors writing on AVs see two major shifts in land use patterns arising from AVs. First, most authors predict a drastic reduction in land used for parking, particularly under a scenario where the use of shared vehicles is high. This would come about as vehicles would serve many customers, and would not need to park for a large amount of the day. Second, most authors expect that AVs will result in an increase in urban sprawl. As road systems become more efficient, and travel time becomes more comfortable and less demanding, people might be encouraged to travel farther distances on a regular basis.

Parking in Urban Areas

Many sources highlighted the idea that the **uptake of AVs is likely to reduce the need for parking in cities** (Frisoni et al., 2016; Fagnant et al., 2015; Anderson et al., 2014a). These authors all explored AVs' potential to reduce parking needs in the context of shared AVs. The academic team leading the CityMobil2 European project observe that once a journey is completed, shared AVs would move on to serve another passenger without the need to park (Alessandrini et al., 2015). They argue that this reduced requirement for parking space would "free public space, which can be used to improve livability of urban environments with re-qualification of public spaces for pedestrians, bicycles " (Alessandrini et al., 2015). A team from Carnegie Mellon University also agreed that AVs would reduce the need for urban parking space, allowing for an increase in public space (DiClemente et al., 2014). Zhang et al. (2015) attempted to quantify these space savings; they used an agent-based simulation model to determine the effects of different shared AV schemes. They found that for a minimum market penetration of 2%, shared AVs could "eliminate up to 90% of parking demand for clients who adopt the system" (Zhang et al., 2015). They also note that extent and spatial distribution of the parking reduction will depend on the operation strategies and client preferences.

This **optimistic viewpoint, wherein freed-up parking space is used to create more vibrant, livable cities, is challenged** by Professor Begg (2014), who questions whether this newfound space will "be used to accommodate more vehicles or will it free movement space to create more "living" or people space?". This question is both a policy question – what will planners decide to do with redundant parking space – and a question of the effect of AVs on travel demand. As discussed in the Ownership and Modal Share section, the increased efficiency of AV-dominated roads may cause such an increase in travel demand that the space and capacity that they free up are reabsorbed to accommodate this demand.

Increased Sprawl

Several authors (Frisoni et al., 2016; Anderson et al., 2014a; Bansal et al, 2016) discuss the **potential impact AV might have on land use, highlighting the risk of increased urban sprawl.** As summarised by RAND "Just as the rise of the automobile led to the emergence of suburbs and exurbs, so the introduction of AVs could lead to more dispersed and low-density patterns of land use surrounding metropolitan regions." (Anderson et al., 2014a). Fox (2016) warns that if AVs encourage greater urban sprawl, a number of negative consequences could result, including worsening environmental issues associated with increased energy use, and the loss of recent gains for smart growth urbanism. This view of a renewed flight from cities was echoed by participants of a workshop organized by the Institution of Engineering and Technology in 2016, who predicted a “return to the country-side” (Brown, 2016). Thomopoulos and Givoni (2015) take a less deterministic view of AV technology, noting that it “can have an important role in either sprawled or compact development, but building up on current use and experience with the private car, they will more likely contribute to sprawl and its effect on, for example, increasing per capita energy consumption by private passenger transport" (Thomopoulos and Givoni, 2015). Concerns about the potential for sprawl seem to be present in the public as well: in their study investigating public perception of AVs, ScienceWise conclude that members of the public have concerns that the use of AVs will generate increased urban sprawl (ScienceWise, 2015).

> *"Just as the rise of the automobile led to the emergence of suburbs and exurbs, so the introduction of AVs could lead to more dispersed and low-density patterns of land use surrounding metropolitan regions." Automated vehicle technology: How to best realize its social benefits (Anderson et al., 2014a)*

Shaping Future Land Use

Several authors also note **the role of regulation or the law to curtail the negative effects of AVs on land use patterns**. Smith (2012) cautions against AVs’ potential to increase urban sprawl, and calls for the law to prevent this. Measures proposed by Smith include road pricing to better internalize the cost of travel, and limiting suburban growth through land use measures. Fox (2016) calls for congestion pricing to deter long commutes, and for investment in mass transit to promote dense urban developments.

> *“My conclusion is that automated vehicles have great potential. But we must not allow them to shape our cities in the way the internal combustion engine was allowed to in the last century. In the 19th century, rail led to a concentration of population in city areas. In the 20th, the effect of the internal combustion engine was the opposite: high car ownership led to dispersal, seen at its most extreme in US cities. It will not be good for the economy or the environment if automated vehicles lead to lower density cities or higher car use.” A 2050 vision for London: what are the implications of driverless transport? (Begg, 2014)*

Further research:

To what extent could shared mobility scenarios save parking spaces in cities? How will the freed space be used?
To what extent could AV use increase urban sprawl? How to might one prevent this development?

4. Ethics

Introduction:

Results of this investigation suggest that ethical issues related to AVs have not been thoroughly addressed in the literature, yet AVs are being programmed to make ethical choices which could soon have real consequences. Ethical implications linked to AV use could have a significant impact on the way those vehicles are perceived by the public. This section summarises some of the key ethical debates mentioned in the literature.

Ethical considerations with AV programming

Authors who have discussed ethics linked to AVs acknowledge that **programming those vehicles to make ethical choices in case of unavoidable accidents is complex, yet unavoidable** (Coeckelbergh, 2014; Goodall, 2014). An example frequently given is: should the vehicle be confronted by two options 1) hitting a child who has run into the road or 2) veering to the side to avoid the child but hitting and elderly person instead, what should the vehicle be programmed to do? As stated by Bonnefon and colleagues: " **Defining the algorithms that will help AVs make these moral decisions is a formidable challenge**." (Bonnefon et al., 2016).

Protecting the drivers at all costs?

Some of the most problematic ethical issues that need to be urgently addressed **is to what extent should/could AVs prioritise the safety of their occupants to the cost of other individual's safety and should AV owners be permitted to choose? (**Fagnant et al., 2015). In a study based in the USA, Bonnefon and colleagues interviewed a range of participants to address these issues. Their findings indicate contradictory results. On the one hand results suggest that most participants "approved of **utilitarian AVs** (that sacrifice their passengers for the greater good)", on the other hand participants stated that they **would themselves prefer to buy a vehicle that protects them 'at all costs'**. Participants did not think that utilitarian AVs should be mandatory. Sandberg and Heather suggest a controversial proposal "To avoid the unacceptable removal of moral choices from human users of these technologies, we could program the vehicles to act in accordance with different moral theories and allow their owners to select their preferred behaviour" (Sandberg & Bradshaw-Martin, 2015). Thus, complex programming decisions in cases of accidents have serious ethical implications.

Call for an ethical debate

The seriousness of these issues and the potential impact it could have on public perception has led several authors to **call for an ethical debate to take place** (Frisoni et al., 2016; Bonnefon et al., 2016). As stated by Bonnefon and colleagues: "Manufacturers and regulators will need to accomplish three potentially incompatible objectives: being consistent, not causing public outrage, and not discouraging buyers" a combination which could cause 'moral inconsistencies' (Bonnefon et al., 2016). Bonnefon and colleagues argue that regulators have a role to play to ensure that the 'greater good' is prioritised in the programming of the vehicle but acknowledge that this might affect buyer's attitudes. Consequently, several authors highlight the need for an ethical debate to address these difficult issues.

Further research:

Further research and debate is necessary to identity and discuss the various ethical dilemmas arising with AV programming and to establish moral codes or guidance to programme these vehicles.

Two of the most important research questions are summarised by Fagnant and colleagues: " to what degree should AVs prioritize minimizing injuries to their occupants, versus other crash-involved parties? And should owners be allowed to adjust such settings?" (Fagnant et al, 2015).

5. Energy and Environment

Introduction:

This section discusses the potential energy and environmental impact AVs could have under different scenarios. This topic has been relatively well addressed in the literature but as described below, findings differ.

CAVs have the potential to decrease energy consumption and pollution generated by road transport

The potential AVs, and it particular CAVs, have to decrease energy consumption and pollution, was mentioned by several authors. A range of possible improvements which could enable "optimal energy utilisation and minimal emissions" (Begg, 2014) were frequently mentioned. As summarised by Wadud and colleagues, who have written one of the most comprehensive studies on these issues: "automated vehicles may enable the adoption of **energy-saving driving practices**, and facilitate **changes in the design of individual vehicles or the transportation system** as a whole that enable reductions in energy intensity" (Wadud et al., 2016). AVs could be programmed to drive in an energy or eco-friendly way leading to less energy consumption and emissions production (McCarthy et al., 2015). Changes in vehicle design could include using lighter, less energy demanding materials for building the vehicles, since vehicles are less likely to crash; this would allow energy saving gains (KPMG & Center for Automotive Research, 2012). But Prof Begg notes that this change would only occur under high AV penetration scenarios, once all manually driven vehicles have been phased out of the highway (Begg, 2014). In the context of connected AVs, all vehicles could be programmed to platoon. According to Zhao and colleagues this could lead to up to 10% reduction in fuel consumption (Zhao et al., 2013). CAVs, through synchronised driving and optimised routing, could also lead to “smoother traffic flows, greatly reducing stop-and-start conditions and hence reducing noise and emissions on a per vehicle-mile basis", as stated by Le Vine and Polak

(2014). CAVs also have the potential to reduce considerable time and energy spent driving around looking for parking spaces (Fagnant et al., 2015). Under high penetration scenarios, AVs could eliminate the need for street lighting at night reducing energy use (KMPG & Center for Automotive Research, 2012). Thus, a range of energy and emission saving improvements could be facilitated thanks to AVs, in particular through CAVs and under high AV penetration rates.

Potential energy and emission saving improvements through CAVs & high AV penetration rates	Potential outputs
Energy-saving driving practices (i.e. eco-driving) →	**Energy efficient driving**
Changes in the design of vehicles, such as lighter vehicles →	**Energy efficient vehicles**
Optimisation of the transportation system, in particular platooning, synchronised driving and optimised routing →	**Smoother Traffic flow**
Reduced need to search for parking space →	**Reduced energy consumption**
Reduced need for street lighting at night →	**Energy efficient Infrastructures**

Table Annex 2 Potential Energy and Emission Savings thanks to CAVs

The impact on energy consumption and pollution will depend on AV adoption and use 'scenarios'

However, as highlighted by several authors, **potential energy and environmental improvements are likely to depend on AV adoption and use 'scenarios'** (Anderson et al., 2014a, International Transport Forum 2015). The various scenarios are further described in the section on ownership and modal share.

As stressed by several authors**, the 'Business as usual scenario' might outweigh the potential environmental and energy benefits of AVs.** In Wadud and colleague's study (2016 modelling techniques were used to analyse the potential impact AVs could have on energy consumption and emission reduction under different scenarios. Their findings suggest that under the 'business as usual' scenario (see section on ownership and modal share), the potential energy and environmental benefits of AV use might be limited. As stressed by the authors, if AV use becomes extremely popular, travel demand by car could increase (potentially affecting rail and mass transit use) and "These travel demand and energy intensity related changes would have large total energy and carbon implications" (Wadud et al., 2016). In their study, Fagnant and colleagues, from the University of Texas, acknowledge that AV systems might contribute to increased VKT which might lead to other problems "such as increased emissions, greater gasoline consumption and oil dependence" (Fagnant et al., 2015). Other variables will determine energy and emission savings, such as vehicle speed; if AVs allow vehicles to drive faster as driving becomes safer, fuel consumption might increase. Thus, the gains road automation could bring could be outweighed if travel demand, speed and VKT increase (Wadud et al., 2016; Brown et al., 2014; Clark et al, 2016a).

On the other hand, a number of authors note that **CAVs used under 'shared mobility scenarios' could generate energy and environmental benefits**. Based on their modelling study, Fagnant and colleagues (2014) conclude that an automated shared collective taxi system could reduce the number of vehicles in use and therefore fuel consumption and emissions. Greenblatt and colleagues (2015) investigate the potential of automated shared electric taxis in reducing Green House Gas (GHG) emissions and conclude that despite increased VKT, automated shared electric taxis have the potential to significantly reduce GHG emissions. The authors also highlight that further emissions reductions could be achieved if taxis were used in the context of ride-sharing (more than one passenger sharing a vehicle). Thomopoulos and Givoni also acknowledge that "Using AVs to boost car sharing has the potential to reduce environmental impacts" (Thomopoulos and Givoni, 2015). Therefore, under the 'collective mobility scenario' where shared mobility has become mainstream, and all vehicles are CAVs, AVs could lead to a reduction in energy consumption and in emissions.

However, Wadud and colleagues warn that even in the best scenario there is a **risk that energy consumption and emissions could increase as a result of increased travel demand and VKT, possibly leading to a decrease in mass transit and rail use** (Smith, 2012). The authors highlight that there is a need to: "Identify opportunities **to support and guide an environmentally beneficial transition toward vehicle automation**" (Wadud et al., 2016).

Furthermore, the energy and environmental impacts AVs are likely to generate will depend on whether AVs are low or zero emission vehicles or not (Owczarzak et al., 2015). **There are uncertainties in the literature regarding the source of energy AVs will use** (ScienceWise, 2014). A team of academics from Carnegie Mellon University argue that the use of AVs could increase the uptake of electric vehicles since AVs could recharge 'themselves by driving to energy stations whilst not in use'. As stated by the authors: "A lighter and efficient automated car that potentially drives itself to refuelling areas would permit a viable system of electric and other alternative fuels with fewer refuelling stations than would otherwise be required" (DiClemente et al., 2014). This argument is also shared by the team of scientists leading the CityMobil project in Europe (Alessandrini et al., 2015). However, the assumption that AVs will be automatically low emission vehicles (Brown, 2015) has been debated in the literature. In their report, Clark and colleagues (2016) mention under the 'business as usual' scenario, if AVs replace conventional privately owned cars, vehicles owners are likely to choose non electric vehicles to ensure that potential long distance trips can be done. This argument is also shared by researcher Ticoll (2015) who wrote a report commissioned by the city of Toronto. Thus, the fuel choices for the use of AVs are likely to depend on the various AV adoption scenarios described above.

Further research:

The impact AV use is likely to have on energy and emission consumption is unclear. Further research is needed to ascertain – and better quantify - the various assumptions and hypotheses mentioned in this section, in particular:

- To what extent could AVs contribute to energy and emission reduction - under which use scenario?
- Similarly, under which scenario could AV use lead to an increase in vehicle emission and energy consumption?
- To what extent AVs have the potential to be low emission vehicles?

6. Road safety

Introduction

Road safety was the most mentioned topic in the literature review. The vast majority of authors discussing road safety highlighted AVs' potential to greatly decrease the number of accidents, and consider improved road safety to be among the chief benefits of AVs. The main controversy stems not from AVs' ability to improve road safety, but the extent of the improvement. While many studies predict a near-complete reduction on road accidents, other studies take a more moderate view. Understanding AVs' effect on road safety is a key issue; it is one of the major predicted benefits of automation, and is also an important factor in the public acceptability of AVs.

Reducing Human Error

In relation to road safety a great number of authors refer to one statistic: 'Over 90% of all accidents are caused by human error' (Smiley & Brookhuis, 1987). Fox highlights the importance of AVs' road safety benefits, stating that they will be 'lifesaving' (Fox, 2016). These articles seem to imply that 90% of road accidents could be eliminated, if human error could be eliminated. However, the OECD point out that improvements to road safety remain "untested at a large scale and may not be immediate or linear" (International Transport Forum, 2015), indicating that substantial safety improvements may only be achieved with widespread deployment of stage 4 or 5 AVs.

A number of authors question this common perception of extremely effective accident reduction, highlighting the fact that further research is needed to assess the safety of AVs (Bierstedt et al., 2014). Wagner and colleagues from Texas University (2014) also moderate the widespread road safety optimism, highlighting the fact that AVs will fail in preventing some accidents, and will have some system failure, but that they will generally be much safer than manually driven vehicles.

The academic leaders of the CityMobil2 project discussed road safety, believing that the widespread estimates of 90% reduction in accidents are likely to be too optimistic, estimating the real figures to be closer to 40% (Alessandrini et al., 2014). DG Internal Policies point out in their report that “the effective safety performance of automated systems has yet to be demonstrated and several technical challenges still need to be addressed, and little evidence is available on the potential emergence of new risky situations", and recommends a “thorough assessment” of AV deployment’s effect on road safety (Frisoni et al., 2016).

Fagnant and colleagues (2015) describe one of the main hurdles in improving road safety: recognizing objects on the road is currently better performed by a human being than by a machine. This remains one of the most complex safety issues to solve for AV systems, along with sensors not being able to cope with poor weather conditions. Wolmar (2016) also highlights the technological challenges associated with deploying AVs in mixed traffic, presenting skepticism of the widely accepted benchmark of AV deployment in the next four years.

Public Acceptability and Road Safety

Public perceptions also highlight the importance of AVs’ ability to make the road safer. Ipsos Mori found in a study in the UK that the majority of participants indicated safety improvements were an important issue (Ipsos MORI, 2014). In their study, ScienceWise (2014) conclude that the public has safety concerns, especially concerns over mixed automated driving where drivers might have to take back control. One risk of the widespread, extreme optimism of AV safety is that it may create unrealistic expectations. The need for the public to accept that there will be accidents with automated vehicles was mentioned as a key element of public acceptability by some participants of a workshop held by the Institution of Engineering and Technology in 2016 (Brown, 2016). Proving AVs’ ability to make the roads safer, is an important component to paving the way for public acceptability.

"Therefore we believe that a thorough assessment of safety implications of automated systems – including pilot tests and implementations – should be conducted in order to estimate their likely effects on traffic accidents’ frequency and severity, and identify potential risks from improper human behaviour." (Frisoni et al., 2016)

Further research:

In relation to safety, the most pressing need is to ensure that there is enough research undertaken in relation to the driver's reengagement with the vehicle, as this is likely to be the most problematic issue related to safety. To what extent are manufacturers addressing this issue? To what extent should the government further support Research and Development in this field?

7. Physical Activity

Introduction

The potential effect of AVs on physical activity, and by extension public health, is not widely addressed in the literature. The few authors who have addressed this topic, such as McCarthy et al. (2015) highlight that the impact AVs might have on physical activity are not sufficiently understood.

The popularity of AVs could negatively affect people's health

Most publications were concerned that **AVs would cause people to spend more time in their vehicles and consequently less time being physically active**. Clark and colleagues, from the University of the West of England, state that: "Greater physical inactivity would be a potentially growing problem for public health" (Clark et al., 2016a). AVs might lead to an increase in vehicle-miles travelled, which might in turn lead to lack of physical activity and increased obesity rates (Fagnant et al., 2015). They additionally point out that these health issues are not easily mitigated. Thomopoulos and Givoni concur, speculating that AVs may become more popular than public transport and active travel. This decreased level of physical activity increases the risk of adverse health impacts (Thomopoulos & Givoni, 2015).

Furthermore, consultancy company Fehrs and Peers highlight **additional health risks** associated with long amounts of time spent in AVs, stating: "Just sitting in the driving position for long periods of time can cause muscle cramps, back pain and lead to long - term spinal disc degradation" (Bierstedt et al., 2014).

Further research:

Changes in physical activity due to AVs is an under-researched area with wide-ranging public health impacts. Further research on this issue is related to AVs' effect on mode share: will the mass use of AVs reduce the share of walking, cycling, and public transportation use?

8. Accessibility and Equity

Introduction:

Accessibility and equity issues linked to AVs have not been widely addressed in the literature. Yet it is likely that the introduction of AVs could have an impact on both of these aspects. This section summarises the discussions found in the literature regarding these topics.

Accessibility

A number of authors have stressed the **potential AVs have to improve accessibility for a range of people.** Many authors report that the use of AVs could enable **elder persons, disabled and non-drivers,** such as underage children, to become more mobile (Fagnant et al., 2015; Ticoll, 2015). AVs could offer people with restricted mobility increased flexibility and **independence (**Bohm, 2015; Begg, 2014). As stated by consultancy company Atkins, the use of CAVs could "increase mobility options and travel horizons for large sections of the population, resulting in increased economic, social and wellbeing opportunities" (McCarthy et al., 2015). Furthermore, Alessandrini and colleagues (2015), argue that shared AVs have the potential to improve accessibility for people living in areas that are not well connected to collective transport. As stated by the authors, shared AVs "are considered useful in the transport mix as they can supply good transport service (individual or collective) **in areas of low or dispersed demand**, **complementing the main public transport network**" (Alessandrini et al., 2015). Thus, AVs, and in particular shared AVs, have the potential to better connect people with limited mobility or people who live in areas that are not well connected to collective transport networks.

However, several authors have pointed out that **these assumptions need to be examined with caution**. First, **limited research has studied the level of social acceptance, desire and capability to use AVs amongst these potential users.** OEM executives interviewed in the context of a study conducted by RAND highlight their concerns "about how a 'senior' driver was going to interact with complicated new technology" (Anderson et al., 2014a). Second, Wagner and colleagues stress the fact that elder persons, disabled and non-drivers might **be the last persons to benefit from AVs**. Indeed, the technology will have to be completely safe and fully automated before these users can benefit from it which is unlikely to happen in the short and medium term. Thus, there is insufficient evidence to prove that these potential users will be able to, and will want to, use AVs and it is unlikely that they will benefit from this technology in the short term.

Potential impact of AVs on Accessibility and Equity	
Opportunities	**Limitations**
CAVs could improve accessibility and independence for elder persons, disabled and non-drivers, in particular children, and people who live in areas that are not well connected to collective transport	Social acceptance, desire and capability to use AVs amongst these users is under-researched and uncertain
	These users might be the last one to benefit from AVs because of safety standards requirements
Shared mobility could be affordable for many users	The initial high cost of AVs will restrict this vehicle to the wealthier and this could increase inequity issues

Table Annex 3 Potential impact of AVs on Accessibility and Equity

Equity issues

Moreover, **some question the extent to which groups of the population with accessibility restriction will be able to afford the use of AVs and whether the introduction of AVs could**

affect equity. On the one hand, a number of authors, such as Enoch (2015), mention that certain groups of the population, including the elderly, mobility impaired, young, poor and ethnic minorities, are usually the last group to benefit from the introduction of a new technology, often for financial reasons. Consultancy company Fehr and Peers highlight the fact that since the cost of AV will be initially high **their use might be restricted to wealthy users** (Bierstedt et al., 2014). Likewise, a report commissioned by DG Internal Policies note that: "With the initial introduction of automated vehicles, it is anticipated that the wealthy will be able to afford this technology before lower socio-economic segments of the population" (Frisoni et al., 2016). Thus, social inequity issues could be generated by the introduction of AVs, separating those who can afford to used AVs and those who cannot (Thomopoulos & Givoni, 2015). On the other hand, some argue that **shared mobility could allow a large number of people to have access to the technology** (McCarthy et al., 2015) and could end up reducing costs of using community transport (para-transit) (Beggs, 2014).

Further research:

Further research is needed to investigate the likely interactions between certain groups of the population, such as older people, and AVs. Similarly, potential social acceptance issues amongst these potential users need to be further studied. Will **elder persons, disabled and non-drivers,** such as underage children, have the capacity to use these vehicles? Will they want to/feel comfortable in using a vehicle without a driver? To what extent do AVs have the potential to improve the life of non-drivers, in particular the elderly and the disabled? Begg (2014) also wonders: "If automated cars come to supplement bus services, should public transport authorities get into the business of operating them?"

Further research is also needed to better understand the potential social inequity issues the uptake of AVs might generate. Will the uptake of AVs widen inequity? Or, on the contrary, will it improve accessibility for all through shared mobility?

iv. Stakeholders’ awareness & attitudes

Introduction:

Public acceptability and public opinion has been widely discussed in the literature on AVs. It is clear that it has the potential to impact the technological development and the roll-out of AVs. Therefore, it is crucial to assess public perceptions regarding this new technological development. A number of institutions have undertaken surveys to assess public opinion. This section summarises the main findings and highlights gaps in the literature and limitations of the methods used.

Key results:

- **Interest levels in AV technology**

The different surveys that have attempted to assess the public's interest and perception of AVs offer contradictory results. On the one hand, a number of surveys find that **the majority of the population surveyed show limited interest and enthusiasm for AVs and would be reluctant to use an AV**. In one survey undertaken in the UK by Ipsos Mori, results indicate that "Only 18 per cent of Britons believe driverless cars to be an important development for the car industry to focus on" (Ipsos MORI, 2014). A report commissioned by DG Internal Policies refer to the results of a Eurobarometer survey undertaken in 2015 that suggests that over 60% of respondents stated that they would not feel comfortable traveling in an automated car (Frisoni et al., 2016). In a survey undertaken in the USA by Schoettle and Sivak, from Michigan University, results indicate that the majority of the 500 drivers interviewed showed high concerns about driving in a driverless vehicle (Schoettle & Sivak, 2015). Similarly, in an online survey undertaken by McKinsey in 2015 - assessing 3,184 car owners' reactions to AVs in the USA, China and Germany - only 61% of the respondents favour legalising vehicles with automated functions (McKinsey, 2015).

On other hand, **some surveys suggest that a large percentage of the population would be willing to use AVs**. In the context of the CityMobil European project, an AV shuttle was trialled in la Rochelle where over 250 users where interviewed. Alessandrini and colleagues report that 'responses where very positive' and level of acceptance was high (Alessandrini et al., 2011). These results are significant as this is one of the few studies that have investigated 'real users' perception and not just 'potential users'. An online survey undertaken by Insurance.com in 2014 in the USA asked 2000 vehicle users whether they would consider buying a 'car with automated capabilities'. The majority of the participants showed interest and said they would consider buying such a vehicle, in particular **when told that insurance prices would be reduced**. Therefore, further research is necessary to assess and monitor the public's interest in AV technology.

One of the findings consistent across different surveys is that **men are more likely to be interested in AVs** compared to women, in particular men who live urban areas (Kyriakidis et al., 2015; Ipsos MORI, 2014; Schoettle & Sivak, 2014). In one survey undertaken in the UK, Ipsos Mori indicate that "23% of men see it [AVs] as important compared to only 13% of women" (Ipsos MORI, 2014). In the context of the European project CityMobil, Alessandrini and colleagues highlight that overall males showed a relatively higher interest in automated systems (Alessandrini et al., 2014). Similarly, results of a survey undertaken in Austin, USA, by Bansal and colleagues, from the University of Texas, indicate that males living in dense urban areas, in particular tech-savy and high income earners, showed a higher interest in AVs and were more likely to use shared AVs (Bansal et al., 2016). However, none of the studies highlighting these differences of perception between males and females have investigated the reasons.

Similarly, certain survey results indicate that **elder people are less likely to show an interest in AV** technology compared to younger individuals (Kyriakidis et al., 2015)**.** In their study in the UK, Ipsos MORI conclude that: "Older people (aged 55+) are less likely to embrace it than the youngest group (aged 16 – 24) – half (50%) of those aged 55 plus think it is unimportant compared to under a third of youngsters (30%)" (Ipsos MORI, 2014). Bansal and colleagues (University of Texas) suggest that older drivers might be less willing to use AVs as they might be concerned about how to use the technology and more reluctant to give up driving (Bansal et al, 2016). Therefore, as indicated by a number of surveys, younger males between the age of 20 and 40 are more likely to enjoy AV technology compared to those aged 55 plus.

Certain survey results seem to suggest **that public perception of AVs varies from one geographical area to another**. One study undertaken by KPMG found that "Californians were significantly more open to self-driving from the start" compared to inhabitants from Chicago (KPMG, 2013). This statement was shared by Kyriakidis and colleagues from Delft University who also mention that Californians seem to be more likely to use AVs compare to inhabitants of other USA states and that similar differences were observed between different countries; for instance, the authors highlight that some results suggest that Chinese and Germans could be more willing to adopt the technology compared to Japanese (Kyriakidis et al., 2015). These results suggest that public opinion varies from one geographical location to another depending on cultural and other contextual factors.

The **attachment to car driving** has been mentioned by some as a potential explanation for the reluctance to embrace AVs. Based on their survey results, Ipsos Mori suggest that individuals who enjoy driving are less likely to embrace AVs compared to those who are ‘not driving enthusiasts’ (Ipsos MORI, 2014). In a survey focusing on drivers in the USA, Schoettle and Sivak from the University of Michigan, find that most respondents prefer to retain manual control of their vehicle whenever they wish and express high concerns about driving in a driverless vehicle (Schoettle & Sivak, 2015). This contradicts results found by consultancy company KPMG who undertook a focus group in the USA and whose results indicate that even drivers attached to driving would be willing to use self-driving cars (KPMG, 2013). However, KPMG’s focus group targeted a limited sample of the USA population. Therefore, the most reliable studies that have investigated drivers’ attachment to driving suggest that those who are enthusiastic about driving are less likely to be interested in AV technology.

Participants’ interest in using/buying AVs	More likely to be interested in AVs
Gender	Men
Age	Young people
Inhabitat	Urban dwellers
Geographical location	California
Attachment to driving	People who enjoy driving
Personality	Technology enthusiast

Table Annex 4 Assessing participants’ interest in using/buying AVs – What survey results suggest

- **Importance of safety, security and trust**

The majority of studies indicate that the potential for **safety** improvements with AV technology is **one of the main ‘selling points’ or benefits** according to potential users or buyers. In a survey undertaken by Ipsos Mori in the UK, the majority of the participants indicated that safety improvements linked to AVs were more important compared to ‘freeing up driver time’ or ‘infotainment’ for instance (Ipsos MORI, 2014). Likewise, in a study conducted by Schoettle and Sivak from Michigan university, 1596 participants were surveyed in the UK, USA and Australia, over 80% of participants stated safety as the highest benefit from the use of AV (Schoettle and Sivak, 2014). Results from Howard and Dai’s survey (from Berkeley University) confirm these findings. In their survey Howard and Dai interviewed 107 'likely adopters' of AV to assess public perception of AVs in Berkeley. Their results indicate that participants are most attracted by the technology for the "potential safety benefits " (Howard and Dai, 2013). Thus, the safety benefits of AVs represent one of the most important advantages of AVs.

On the other hand, results across many surveys suggest that **safety concerns** related to AVs are high amongst participants. In the context of the CityMobil trial in la Rochelle, Alessandrini and colleagues undertook a survey investigating users’ opinion based on their experience of using an AV shuttle. Results suggest that many users were still concerned about safety, even after having used an AV vehicle (Alessandrini et al., 2011). In a survey undertaken by students in Worcester Polytechnic Institute, Massachusetts, out of 467 interviewees the study reports that over 80% respondents indicated that safety would be the most important factor affecting their decision to buy AVs and that participants were most concerned with potential safety issues (Casley et al., 2013). A number of authors (Enoch, 2015; LeVine & Polak, 2014; Frisoni et al., 2016) mention that safety issues and perception of safety linked to AVs are likely to influence public acceptability and determine market uptake. Le Vine and Polak from Imperial College, highlight the importance of a safe deployment of the technology as a priority above a rapid deployment to ensure that the public does not reject the technology. As summarised by Le Vine and Polak: “The worst possible outcome would be a major incident (or series of incidents) that discredits vehicle automation and stops commercialisation, leaving the efficiency and safety gains as merely prospective for many years to come. Preventing such a turn of events is far more important than the pace of deployment” (Le Vine & Polak, 2014). Thus, one of the main concerns related to AVs is the link to potential lack of safety of these vehicles.

The safety issues referred to by participants seem to be mostly related to **potential software malfunction** whilst the vehicle is in motion (KPMG, 2013; Kyriakidis et al., 2015; Schoettle & Sivak, 2014). In their internet-based survey undertaken in Austin, Bansal and colleagues, from University of Texas, indicate that out of 347 participants surveyed 50% were concerned with AVs 'equipment or system failure' (Bansal et al, 2016). Similar results were found by Howard and Dai (2013), from Berkeley University, in their survey targeting Berkeley’s residents. A study undertaken by the Motor Vehicle Safety in Canada conducted safety pilot tests with participants in cases of level 3 or 4 automation and conclude that the public needs to be further involved when **testing safety aspects of AVs** to assess reactions and expectations, as stated in the report: “Results highlight the importance of including real users in safety assessments to gain a more accurate understanding of the consequences of vehicle system failures." (Harbluk et al., 2014). Therefore, potential software failure seems to be the most concerning issue related to AV’s safety.

Several surveys indicate that another cause for concern amongst participants are potential **cybersecurity** issues related to AVs (Frisoni et al., 2016; McKinsey, 2015; Kyriakidis et al., 2015). Kyriakidis and colleagues, from Delft University, report on the results of an internet-based survey sent to 5000 participants across more than 100 countries. The authors highlight that survey respondents, in particular in Western Countries, are concerned with "software hacking and misuse' (Kyriakidis et al., 2015). Likewise, consultancy company McKinsey highlight that ‘cyber security of connected cars’ is one of the issues most frequently mentioned by interviewees (McKinsey, 2015). Thus, certain surveys report that a high percentage of participants worry about potential cybersecurity issues related to AVs.

The importance of **trust in AVs** was highlighted by a number of authors (Verberne et al., 2012; Choi et al., 2015) as it is likely to be a determining factor in the use of AVs (Choi et al., 2015). Results of an online survey undertaken by Insurance.com in the USA indicate that out of 2000 vehicle users surveyed, 70% of the respondents said 'they would not trust a driverless car to take their children to school' (Insurance.com, 2014). A report commissioned by DG Internal Policies stress the importance of address the public’s main concerns – in particular safety – in order to gain public trust (Frisoni et al., 2016). Certain studies highlight the fact that "anthropomorphic features such as name, gender, and voice" embedded in a driverless vehicle has the potential to increase trust in AVs (Waytz et al., 2014; Verberne et al., 2015). Therefore, addressing public trust in AVs is key to ensure AV uptake.

- **The importance of perceived benefits of AVs**

Many studies and surveys have found that the perceived usefulness of AVs has an impact on public perception and trust in AVs. Choi and colleagues from Yonsei University in South Korea surveyed over 500 drivers and conclude that **perceived usefulness** is a major 'determinant of intention to use automated vehicles' (Choi et al.,, 2015). In their report on AVs, Clark and colleagues from University of the West of England imply that public acceptability is likely to stem from "perceptions of the usefulness and ease of use of AVs" and that the public is likely to expect certain benefits from the use of AVs (Clark et al, 2016). A report commissioned by DG Internal Policies stresses the need for public authorities and private stakeholders to prove "the environmental, economic, social and safety benefits of driving automation in order to gain public trust and set the ground for the diffusion of automated driving." (Frisoni et al., 2016). Decreased travel time was found to be one of the key benefits expected by potential AV users ((KPMG, 2013; Clark et al, 2016). Based on surveys undertaken in the context of the CityMobil project, key conclusions indicate that: "automation is, on average, not necessarily perceived as valuable, if the travel time […] is the same […] of a conventional bus" (Alessandrini et al, 2014). In addition to travel time, reduced fuel consumption, and environmental improvement were frequently mentioned as expected benefits by potential users (KPMG, 2013; Clark et al, 2016). Therefore, the potential wider benefits AVs might bring to future users are likely to have an impact on how the public perceive and adopt AVs.

- **Cost**

A number of surveys report that participants were either **concerned about affordability or unwilling to pay more money** to buy or use an AV. Bansal and colleagues from the University of Texas report that out of 347 online respondents, circa 40% were concerned about affordability (Bansal et al, 2016). Participants' concern about AV costs was reported in several surveys undertaken in the USA (Howard and Dai, 2013; Casley et al, 2013). Their survey also indicate that participants were unwilling to pay more than the price current E-hailing companies (i.e. UBER) charge for shared AVs (Ibid). Similar results were found by Schoettle and Sivak, from Michigan University, whose survey results suggest that out of 1596 participants surveyed in the UK, USA and Australia, over 55% respondents stated that they would not pay more to add automation in their vehicle (Schoettle & Sivak, 2014). On the other hand, Bansal and colleagues' study based in Austin suggests that the participants: "[...]average willingness to pay (WTP) for adding full (Level 4) automation ($7253) appears to be much higher than that for adding partial (Level 3) automation ($3300) to their current vehicles" (Bansal et al, 2016). Thus survey results suggest that overall participants are concerns about high costs of AVs and do not seem prepared to pay more to use the technology.

Methods used to survey participants

- **Limitation in surveys' representativeness**

The **majority of the surveys assessing public perception and acceptability of AVs were undertaken in the USA** (Bansal et al, 2016; Kyriakidis, 2015; Schoettle and Sivak, 2014; Casley et al, 2013; Howard and Dai, 2013; Insurance.com, 2014). However, one of the most reliable and robust survey was undertaken in the UK surveying a sample of 1000 British citizens (Ipsos MORI, 2014); and one of the few surveys assessing participants' reaction in the context of a real life pilot project was conducted in France in the context of the European project CityMobil (Alessandrini et al., 2014).

Another limiting factor in the way surveys have been conducted is the fact that many surveys have focused on **assessing drivers' opinions only, such as the survey undertaken by Insurance.com** (Kyriakidis et al., 2015; McKinsey, 2015). Bansal and colleagues from the University of Texas recognised that their internet-based survey sample "over-represented […] middle-aged persons (25–44 year-old)" (Bansal et al., 2016) therefore not representing the views of younger or elder persons. However, one of the arguments often mentioned in favour of automated vehicles use is the potential benefit it could have for non-drivers, such as disabled citizens, young or elder persons. Furthermore, the majority of the survey have been conducted online which might mean that the results are not necessarily representative of citizens who tend to be less well connected to the internet (such as elder people). To date no surveys have focused on public perception of non-drivers.

- **Rigor and Bias**

The rigor of the methods used to conduct public opinion's survey seem to vary significantly from one study to another. It is difficult to assess the quality of the methods used by many non-academic institutions, in particular consultancy companies, who have not published sufficient details about methods used. However, a number of surveys targeting large samples have used rigorous methods as illustrated in the table below.

Authors	**Kyriakidis and colleagues**	**Schoettle and Sivak**	**Cyganski and colleagues**	**Ipsos Mori**
Institution	Delft University of Technology	Michigan University	German Aerospace Center, Humboldt -University Berlin	Ipsos Mori
Date	2015	2014	2014	2014
Country	109 different countries	USA, UK and Australia	Germany	UK
Type	Crowd-sourcing Online survey via Crowdflower	Crowd-sourcing Online survey via Survey Monkey	Crowd-sourcing Online survey	
Respondents	5000	1533	1000	1001

Table Annex 5 Relevant Surveys targeting large samples

- **Relying on people's imagination**

One of the limitations common across most surveys is the fact that public opinion on AVs is assessed relying on respondents' imagination (Nordhoff et al., 2016; Kyriakidis et al., 2015; Alessandrini et al., 2014). Indeed, due to the limited number of pilot projects in public spaces, only a small number of studies have assessed participants 'real' experience and reactions to AVs. In their comprehensive review of public perception of Electric vehicles (EVs), Rezvani and colleagues from Umeå University, Sweden, highlight the importance of interviewing participants who have had an experience with EVs otherwise they might be "psychologically distant from EVs" and as a consequence survey results are likely to be biased (Rezvani et al., 2015). It is therefore important for public opinion to be assessed in the context of real life pilot projects.

Further Research:

Further research should be undertaken to determine under what conditions and scenarios would the public be most likely to use and accept AVs. Public' opinion on AVs should be **assessed specifying conditions of use** (Clark et al, 2016b; Cyganski et al., 2014). In other words, specific scenarios should be presented when surveying participants' opinion. As stated by ScienceWise[18]: "Further study on the specific situations in which the public would or wouldn't find vehicles acceptable and whether they would be willing to drive alongside automated or driverless cars would add to understanding of public attitudes" (ScienceWise, 2014).

As AV technology develops, public opinion needs to be **regularly assessed and monitored**. As stated by ScienceWise: ""it would be valuable to track public attitudes to the technology as it becomes more of a reality, to see how this affects positive or negative perceptions of the technology" (Science

Wise, 2014). Clark and colleagues from the University of the West of England stress the key role social science should play in examining the population's expectations and reaction to the development of AVs (Clark et al., 2016b).

Finally, further research is needed to assess **non-drivers**' perception and expectations of AVs. Likewise, it is necessary to further understand older people's perception of AVs and their potential reluctance to use the technology. It is also important to further understand why a large percentage of females seem less interested in AVs compared to men.

18 "the UK's national centre for public dialogue in policy making involving science and technology issues"

v. Public Sector's Role

Introduction:

In this section we review the literature that has discussed the role, influence and responsibility of public authorities in relation to AVs. The first part discusses regulatory and legal issues related to AVs deployment and adoption, in particular at the national level. The second part raises issues regarding urban planning in relation to AVs.

- **Regulatory and legal issues related to AVs**

The **lack of regulations** on AVs and the **importance of legally enabling AV development**, in particular in the context of shared mobility, was mentioned by several authors from different countries. As highlighted by the International Transport Forum, even though regulatory frameworks exist in many countries to enable the testing of those vehicles: "We could not find evidence of anticipatory regulatory action addressing the potential use cases that could result from large-scale deployment of highly automated vehicles, such as the provision of quasi-public transport or taxi-like operations" (International Transport Forum, 2015). The legal barriers preventing the establishment of shared or 'collective' AV systems was also highlighted by Alessandrini and colleagues in the context of the CityMobil project (Alessandrini et al, 2014). Furthermore, the lack of cooperation between different jurisdictions within the USA and between different countries who are developing AVs was mentioned as a potential issue that could prevent the uptake of the technology (International Transport Forum, 2015). However, in Europe, a significant step towards the regulation of AV use was taken in April 2016 with the Declaration of Amsterdam, that saw the 28 EU member states agreeing to support AV technology and to collaborate to develop regulations and rules to allow AVs on EU roads and ensure interoperability and compatibility between countries (The Netherlands EU Presidency, 2016). In their study Wagner and colleagues, from Texas University, concluded that public authorities should be developing 'standards, regulations and definitions' which should be set at an international level as well (Wagner et al, 2014). These regulations and standards should be gradually developed in close collaboration with private-sector organisations, such as insurers and manufacturers, and with consumer groups (Wagner et al., 2014; Anderson et al., 2014a). The need to establish a common regulatory framework across countries to harmonise the deployment of AVs was mentioned by several authors (Brown, 2016).

The role public authorities should play in shaping the deployment and in particular the 'adoption path' of AVs was highlighted by several authors. Enoch, from Loughborough University, stresses the fact that AVs are likely to have a profound impact on transport systems and that any public policies interventions could have 'significant implications' (Enoch, 2015). Therefore, as highlighted by Enoch, policy intervention and legislation needs to be carefully thought through, and in particular potential side-effects need to be thoroughly understood and assessed. The importance of "government leadership" in relation to AVs, in particular linked to the different roll-out scenarios, was highlighted by Clark and colleagues[19], as stated by the authors: "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" (Clark et al., 2016a). Thomopoulos and Givoni[20] echo Clark and colleagues' message and argue that government has a key role to play in regulating and incentivising the right deployment model for AV roll out, to make sure it is aligned with key objectives, such as emission reduction (Thomopoulos & Givoni, 2015). Therefore, the importance of public policy intervention in shaping AVs' adoption path to ensure optimum societal outcomes, was highlighted by a number of authors.

The need to further understand the potential impact AVs could have on transportation systems and society before legislating on highly automated vehicles was highlighted by a number of authors (Bohm, 2015; Anderson et al., 2014a; Fagnant et al., 2015). Fox, from Georgetown University, argues that regulators in the USA should assess the 'cumulative impact' of AV use before legislating as a number of negative side effects linked to AV uptake might need to be anticipated (Fox, 2016). As stated by Bohm, from Uppsala University, before commercialising highly automated vehicles (level 4), it is important to undertake further research to better understand "What influences the AVs will have " (Bohm, 2015). The need to actively regulate the use of AVs and not just to cater for AV use was highlighted by several authors, such as Professor Begg (2014). This message is also emphasised by the think tank RAND, who state: "Relying strictly on the free market may not maximize social welfare and could even lead to market failure" (Anderson et al., 2014b). One of RAND's key messages is to: "avoid moving too quickly to regulate this technology without better information about its benefits and costs" and to support further research (Anderson et al., 2014b). Thus, the need for further research to better understand the impacts AVs are likely to have is needed to better inform policy-making.

One of the biggest legal concerns in relation to AVs is the legal responsibility in an accident. Indeed, the question 'who is responsible in the case of an accident' is a much debated issue. As explained by Le Vine and Polak, AVs "may be under the combined control of a number of entities, such as the manufacturer of the sensors, the designer of the algorithms that make real-time driving decisions, the designer of the digital map the control software is using, the public agency responsible for the roadway, the human in the driver seat, etc." (Le Vine & Polak, 2014). Most authors who discussed legal responsibility argue that manufacturers are likely to bear most of the responsibility. Wagner and colleagues, from University of Texas, interviewed a range of OEM[21] in the context of their study on AVs. The majority of the interviewees stated that liability was the biggest concern facing the industry and that it would likely to "dictate how automated vehicle development proceeds." (Wagner et al, 2014). The significant legal costs vehicle manufacturers could be facing in cases of accidents were mentioned by several authors as a possible threat to the development of the industry (Begg, 2014; Fagnant et al., 2015; DiClemente et al., 2014). DiClemente and colleagues from Carnegie

[19] from the University of the West of England
[20] From London School of Economics and Tel-Aviv University
[21] *Original Equipment Manufacturer*

Mellon University, argue that if 'massive damage costs' threaten the adoption of AVS: "the federal government is expected to intervene with subsidies and tax incentives, to lower the price and facilitate consumption" (DiClemente et al., 2014). Fagnant and colleagues, from the University of Texas, stress the importance of better clarifying liability issues to prevent potential market deployment problems (Fagnant et al., 2015).

- **In relation to urban Planning**

The review of the AV literature indicates that **few authors have discussed AVs in the context of urban planning and that there is a general lack of conversation and planning regarding AVs in urban areas**. Guerra, from University of Pennsylvania, examined urban transport plans in 25 metropolitan areas in the USA and concludes that almost none of the transport plans reviewed mention AVs (Guerra, 2016). To further understand why AVs are not acknowledged in local transport plans, Guerra went on to interview local policy-makers. Conclusions from his analysis suggest that even though policy-makers are aware of AVs, the uncertainties surrounding the deployment and use of the vehicles explain why it has been kept out of urban plans. As summarised by Guerra: "There is a great deal of uncertainty about what technologies will prevail, how much and when they will penetrate the market, whether regulation will hinder or support deployment, what the direct impacts will be on capacity or safety, and how consumers will respond" (Guerra, 2016). Therefore, despite the potential disruptive impact AVs could have at the local level, it has not been widely addressed in the literature and in local planning.

The need for local authorities to be involved in conversations and policy-making processes regarding AVs and to consider integrating AVs into their planning was mentioned by several authors (Alessandrini et al., 2015; McCarthy et al., 2015). In a report commissioned by and for the city of Toronto, Canada, research fellow Ticoll argues that local authorities should be involved in regulating AVs and in hosting pilot projects (Ticoll, 2015). One of Ticoll's key recommendations to the city of Toronto is to: "Develop an overarching vision and point of view on the impact and role of AVs for the City of Toronto." (Ticoll, 2015). In one of their reports, the International Transport Forum stresses the importance for local authorities to regulate and adapt to ensure the "deployment of the urban mobility pathway for automated vehicles" (Ticoll, 2015). Thus, local authorities should be involved in national and international conversation processes regarding AVs.

AVs have the potential to improve urban transport systems, but their development and use in urban areas need to be carefully managed by public authorities. The potential role AVs could play in urban areas was highlighted by Alessandrini and colleagues in the context of the European project CityMobil 2. The authors designed a vision or 'matrix' for using and integrating AVs in urban areas. They distinguish different urban contexts and locations - city centre, Inner suburb, outer suburb, suburban centre - and highlight the potential use of AVs depending on the context in combination with other modes of transport. One of their main conclusions is that car-sharing is the most effective use scenario in the context of urban areas (Alessandrini et al., 2015). Despite the potential AVs have, a number of authors stress the importance of carefully managing their development in urban areas. In a detailed report investigating automated vehicles in the city of London, Professor David Begg stresses the importance of not allowing them to: "to shape our cities in the way the internal combustion engine was allowed to in the last century"(Begg, 2014), highlighting potential risks such as increased urban sprawl and higher car use. Fox, from Georgetown University, warns that urban efforts to increase density and promote smart cities and sustainable mobility might be disrupted by the arrival of AVs (Fox, 2016). She recommends integrating AV planning in master plans to prevent unwanted side effects, in particular urban sprawl (Fox, 2016). Therefore, further urban planning is necessary to anticipate the arrival of AVs, integrate them in the most effective way, and prevent potential negative side effects.

Further Research:

Further research is urgently needed to investigate the role of AVs in urban areas, from an urban planning perspective. Potential research questions include: What role should AVs play in cities? How can AVs contribute to urban areas and improve urban mobility systems?

Annex D – List Codes

Below is the list of codes used to categorise references in EPPI-Reviewer 4

- **Academic Source**

  1. Peer Reviewed Articles
     Academic articles published in a journal
  2. Books
     Academic book or book chapter
  3. Other
     E.g. Peer reviewed expert report

- **Grey Literature**

  1. Official Report
     Published by Public Authorities or Public Agency either at the supranational, national or sub-national level
  2. Consultant/Industry Report
     Reports published by consultancy companies or the industry
  3. Serious Broadsheet or Magazine
     A serious newspaper or magazine such as the Times or the New Scientist
  4. Light Tabloids or Magazine
     Newspaper or magazine popular in style and dominated by sensational stories, e.g. Daily Mail, the Sun
  5. Marketing Material
     Such as leaflets
  6. Audio Material
     Such as TED talk videos
  7. Visual Presentation

  8. Other
     Such as Blogs

- **Reference Country**

  1. No specific Country

2. UK
3. USA
4. Singapore
5. China
6. Netherland
7. France
8. Sweden
9. Finland
10. Sweden
11. Germany
12. Spain

- **Relevant Topics**

1. Behavioural
   Discusses Behavioural impact related to AVs, e.g. relating to behaviours, the response of an individual, group to its environment. How does/will AVs affect people's behaviours? How do/will people react to AVs? Will it change their behaviour? Here all behavioural issues are included except in-car behaviour
   Search "behav"*
2. Psychological
   Discusses psychological impact or issues related to AVs linked to the mental and emotional state of a person
3. Public Acceptability/Perceptions/Expectations
   Discusses public acceptability, perceptions and expectations of AVs
4. Health/Well-being
   Discusses issues related to people's mental and physical health and their well-being i.e. state of being comfortable, healthy or happy
5. Physical activity
   Discusses the likely impact AVs will have on people's level/type of physical activity
   Search Phy and activ**
6. Mobility for older people
   Discusses the likely impact AVs will have on older people's mobility

7. Mobility for disabled
   Discusses the likely impact AVs will have on disabled people's mobility
   Search "disabl" "physical limitat"*
8. Mobility for children
   Discusses the likely impact AVs will have on mobility for children
9. Accessibility
   Discusses the links between AVs and transportation accessibility e.i. the ease of reaching goods, services, activities and destinations, which together are called opportunities
   *Search access**
10. Ethics
    Discusses moral principles related to AVs
    search "ethi" "moral" "principles"*
11. Jobs/Employment
    Discusses the likely impact AVs will have on job and employment, industrial structure etc.
    Search "employ" "Job*" "Unemploy*"*
12. Wider Economy
    Discusses the likely impact AVs will have on the economy and industry
13. Cost of travel
    Discusses the likely impact the intake of AVs will have on the cost of travel and mobility, including the cost of the vehicles
14. Modal Share
    Discussest the potential impact AVs may have on modal share, i.e. percentage of travellers using a particular type of transportation or number of trips using said type
    Search "mode" Search "modal"*
    "More traffic" or "Less traffic"
15. Travel Demand
    Discusses the likely impact AVs will have on travel demand
    Search "demand" "VMT" Vehicle miles travelled
16. Impact on Congestion/Network capacity
    Discusses the potential impact AVs will have on congestion and how it will affect network capacity
17. Transport Systems
    Discusses AVs from a systems perspective, for instance discussing mobility as a service and impact of AV, ITS, how AVs will fit in an urban transport system/network, or communication system such as internet of things
    Systems Engineering
    Systems thinking
18. Mobility As A Service
    Discusses MAAS in relation to AVs
    Synonym "door-to-door mobility"
    "MAAS"

"Mobility as a service"
"Mobility on demand"

19. Ownership models
Discusses ownership models related to AVs
Search "Shared" " Private"
20. Support Shared Mobility
The reference clearly favours shared mobility in cities
21. Road Infrastructure
Discusses highway engineering i.e. the planning, design, construction, operation, and maintenance of roads, bridges, and tunnels to ensure safe and effective transportation of people and goods
"Infrastructure"
22. Urban Planning
Discusses AVs from an urban planning perspective; what the authorities decide/constrain/demand, discusses the urban environment and how it will be affected by AVs
"Urban mobility planning"
"planning"
"Urban"
23. Land Use
Discusses AVs effect on the land use system, settlements patterns, or dispersal, what individual actors may do, e.g. build new homes in the country)
Keyword: "Space""Country-side" "Sprawl"
24. Freight & Delivery
Discusses the impact AVs will have on Freight and Delivery
"Deliv" "Truck*" "Van*" "Goods" "Merchandise*" "Logistics"*
25. Design
Discusses the design of AVs and infrastructures that will cater to AVs
26. Interaction with Pedestrians
Discusses the potential impact and interactions between AVs and Pedestrians
27. Interaction with cyclists
Discusses the potential impact and interactions between AVs and Cyclists
Search "bike" "Cycl*"*
28. Interaction with other road users
Discusses the potential impact and interaction between AVs and other road users such as public or private vehicles, motorbikes, etc.
Search "driver" "conventional" (car, vehicle, automobile)*
29. Global Environmental issues
Discusses Global Environmental issues related to AVs, such as climate change
Search words such as emiss , Pollu*, "carbon"*
30. Local Environmental Issues
Discusses local environmental issues related to AVs, such as air quality or noise
Search words such as emiss , Pollu*,*

31. Energy Impact
    Discusses the likely impact AVs will have on energy, such as energy consumption, energy efficiency, etc.
    Seach words such as fuel and efficiency
32. Road Safety
    Discusses the likely impact AVs will have on energy, such as energy consumption, energy efficiency, etc
33. Drivers Interaction with AV
    Discusses how drivers will interact with the car, their skills, usually in partial automation cases. E.g. integrating automated systems into the workflow of driving and implication for stress, fatigue and safety
    "workflow" "stress" "attention"
34. Driving experience and In-car behaviour
    Discusses the potential convenience and confort AVs could bring to users such as stress free driving, being able to do something else whilst driving
    Discusses Convenience/Confort inside the vehicle, free time, etc.
    Discusses Driving experience, including drivers who enjoy driving and might not like AVs
35. Cybersecurity/Data Security/Privacy
    Discusses issues related to cybersecurity, i.e. criminal or unauthorised used of electronic data or data security, i.e. digital privacy measures that are applied to prevent unauthorised access to computers, databases, control systems, and websites, e.g. concerns over privacy of personal data
    discusses driving experience
    Search all key words in title + "Hack"*
36. Data Ownership
    Discusses data ownership in relation to AVs. Who will own data? How will data be shared? Is there a need for Data Ownership?
    Seach "data own" and "data" "V2V"*
    Usual questions are who owns the data?
37. Personal security
    Discusses issues such as physical crime, illegal activity or anti-social behaviour related to AVs
    *Search crim**
38. Legal & Regulatory Issues
    Discusses legal issues, in particular liability, i.e. who is legally responsible in case of a problem? Discusses regulations
39. Insurance
    Discusses insurance issues related to AVs
40. Pathways to automation
    Discusses How will we get there? Gradual automation...
41. Legacy early generation AVs
    Discusses the effect of early generation AVs on later generations
    "legacy" "generation"

42. Potential Market Failure
    Highlight the fact that the technology might not take up
43. Gaps in the literature
    Highlights gaps in the literature that need to be addressed. Search "Research"
44. Other social/societal issues
    Relating to society and its organisation

- **Quality**

1. Thorough
   An accurate, meticulous document/study/report, well-written and argued
2. Questionable quality
   The quality of the document is questionable and lacks rigours in the methods or conceptualisation
3. Unsure/Unclear
   The quality of the document is unclear
4. Neither Rigorous not questionable

- **Content**

1. Conceptual
   Concerned with the definitions or relations of the concepts of some field of enquiry rather than with the facts
2. Includes Evidence
   Includes facts and information
3. Primary Evidence Based Research
   Reference discusses primary research results, such as survey results or modelling
4. Includes primary research
   The document includes primary research. E.g. Modelling, surveys...
5. Comprehensive
   Includes/covers many elements or aspects of AV
6. Specific/Narrow
   Focuses on a specific topics related to AV

- **Outlook on CAV**
  Is the article positive, negative or neutral on the prospects of AVs?

1. Positive and Enthusiastic
   Optimistic on the future of AVs and its impact
2. Positive but cautious
   Describes potential positive outputs and outcomes linked to AVs but highlights potential negative side-effects
3. Negative and Worried
   Critical or sceptical of the effects of AVs on their prospects of being implemented
4. Mixed or Neutral
   Describes positive elements and negative elements, does not support either side of the debate
5. Unclear

- **Type of AVs**

1. Fully automated
   The vehicle handles the driving task in its entirety
2. Partially automated
   "Transitional" issue of routinely having to do some of the driving in a car that can't handle all highway environments
3. Highly Automated
   The vehicle makes decisions entirely for itself
4. Highly connected
   the vehicle is dictated to by a central control system
5. Private
   Privately owned by individuals
6. Collective/Shared
   Shared economy either public or private
7. Personal travel
   The AV is used by an human being to move
8. Freight
   The AV is used to transport goods
9. All types
   The sources discusses all types and scenarios of AVs

- **Extremely Relevant**
  Reference that is comprehensive, rigorous (conceptual or fact based), have a unique angle.
- **Contains NOTES**
  Notes/Comments have been added

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Annex F - Glossary

Glossary
ADAS: Advanced Driver Assistance Systems ADAS are technological systems within vehicles that support the driver in the driving task. ADAS aim to improve safety and driving experience. For instance, automated braking can help the driver to avoid or reduce the severity of a collision.
Human factors Human factors in automation relate to understanding the interaction(s) of humans with all aspects of an automated road transport system (according to the International Transport Forum).
'Liveable city' In the context of this literature review the term 'liveable city' refers to the liveability index developed by the Economist. Reference can be found following this link: http://www.eiu.com/public/thankyou_download.aspx?activity=download&campaignid=Liveability2016
OEMs: **Automotive Original Equipment Manufacturers** In this report the acronym OEM mainly refers to large car manufacturers.
Platooning In the context of this literature review the term 'platooning' refers to AVs following one another closely on the road.
PRT: Personal Rapid Transit In this report the acronym PRT refers to existing or future public or privately owned small automated vehicles providing on-demand transport, such as the Heathrow pods, serving one client/user at a time.
SAVs: Shared Automated Vehicles In this report the term shared automated vehicles refers to automated vehicles (of all forms and shapes) shared by multiple users either simultaneously or at different times.
VKT: Vehicle Kilometer Travelled VKT is a measure of the distance travelled in kilometres by (motorised) vehicles
VMT: Vehicle Miles Travelled VMT is a measure of the distance travelled in miles by (motorised) vehicles
V2V: Vehicle to Vehicle communication V2V refers to wireless systems within automobiles that allow vehicles to communicate with each other
V2I: Vehicle to roadside infrastructure communication V2I refers to wireless systems within automobiles and fixed infrastructure that allow vehicles to communicate with other infrastructure, such as highway infrastructure.