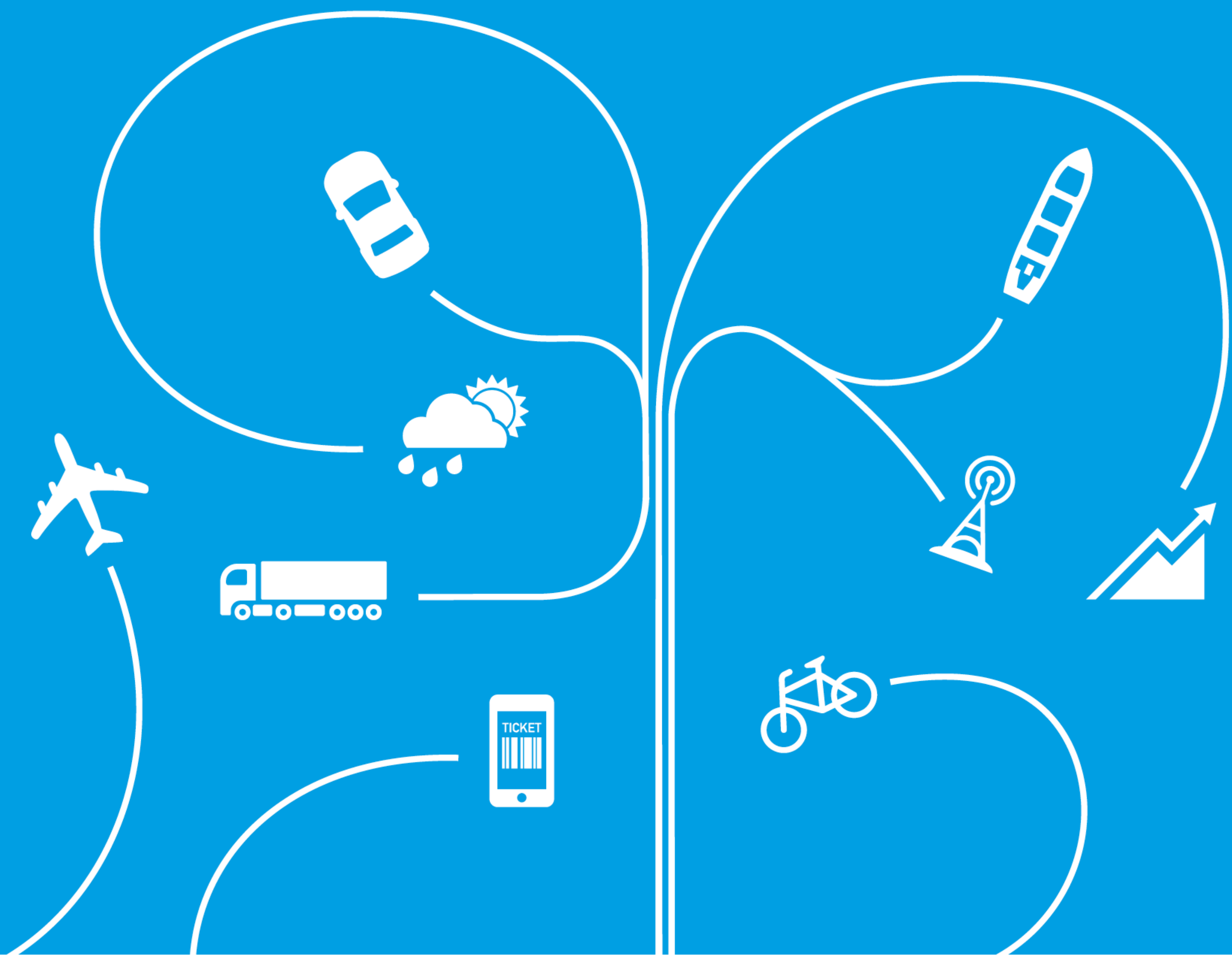
EXPLORING INTELLIGENT MOBILITY

CATAPULT Transport Systems

Future Proofing Infrastructure for Connected and Automated Vehicles

Technical Report

February 2017



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Disclaimer

This report has been produced by the Transport Systems Catapult under a Memorandum of Understanding with the Department for Transport. Any views expressed in this report are not necessarily those of the Department for Transport.

Acronym List

ADAS	Advanced Driver Assistance Systems
ALR	All Lane Running
AMOR	Asset Maintenance and Operational Requirements
APS	Assisted Parking System
BCR	Benefit-cost-ratio
CAV	Connected and Automated vehicle
CIHT	Chartered Institution of Highways and Transportation
DfT	Department for Transport
DMRB	Design Manual for Roads and Bridges
ECAP	European Car Assessment Programme
ERAP	European Road Assessment Programme
ERF	European Road Federation
EU	European Union
EV	Electric Vehicle
GLOSA	Green Light Optimal Speed Advisory
GPS	Global Positioning System
HE	Highways England
HGV	Heavy Goods Vehicle
IAN	Interim Advice Notes
ITS	Intelligent Transport System
I2V	Infrastructure to Vehicle
LSPTS	Low speed public transport service
LTP	Local Transport Plans
MCHW	Manual of Contract Documents for Highway Works
MfS	Manual for Streets
NIP	National Infrastructure Plan
NPPF	National Planning Policy Framework
NTS	National Travel Survey
OECD	Organisation for Economic Co-operation and Development
RNIB	Royal National Institute of Blind People
RWW	Road Works Warning
TASM	Transport Appraisal and Strategic Modelling
TSC	Transport Systems Catapult
SAE	Society of Automotive Engineers
V2I	Vehicle to Infrastructure

1 Introduction

1.1 Overview

This document has been prepared by the Transport Systems Catapult (TSC) for the Department for Transport (DfT) and the Centre for Connected and Autonomous Vehicles (CCAV). This report represents the deliverable of the Project – 'Future Proofing Infrastructure for Connected and Automated Vehicles'.

Any views expressed in this report are not necessarily those of the DfT or CCAV.

Highways authorities, public bodies, developers and other organisations rely on planning and guidance material to guide future transport provision and investment priorities. Connected and Automated Vehicles (CAVs) have the potential to revolutionise transport, but many planning and guidance documents remain silent on the issue.

In some cases, this is because the research that contributed to these documents pre-dates the technological progress that has been made in recent years in relation to CAVs. In other cases, there may be a reluctance to comment on a future which can appear to be unclear and rapidly changing. What is certain, however, is that the more we discuss the potential opportunities and issues that CAVs present, and the more strategies that are developed for maximising the benefits of them, the more likely it is that a positive outcome from their implementation can be achieved.

Enabling a vehicle to travel along the public highway with the human driver either partially or completely unengaged in the driving task, or even with no driver at all, is a fundamental change to how road vehicles operate. The extent to which the planning, designing, appraisal, implementation and operation of road infrastructure needs to or could adapt as a result of this change is uncertain, and is the focus of this study. Interviews, undertaken as part of previous projects, have highlighted this uncertainty amongst highway authorities and other stakeholders. Now, probably more than ever before, it is difficult to fully comprehend the vast array of technological changes that are underway and the impacts they may have on future transport systems and networks.

Figure 1 outlines the role of this project in taking the first steps towards future proofing transport systems and networks. The project aims to consider the gap between existing (and planned) infrastructure and the infrastructure required by CAVs. The gap between the two feeds into suggested areas of investigation for consideration in future iterations of planning and guidance documents.

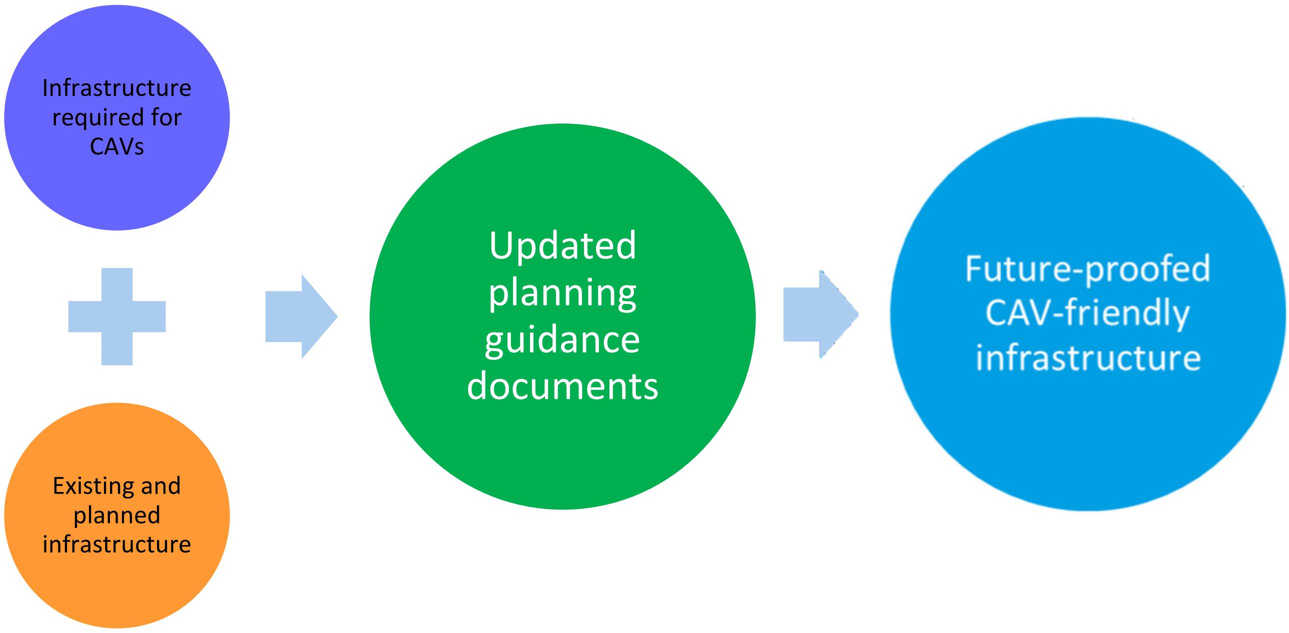


Figure 1: Project Areas of Study

1.2 Methodology

The following methodology was employed in undertaking this study:

- A review of the relevant planning and guidance material used by highways authorities, developers and other third parties to implement transport plans;
- Discussions with the authors of planning and guidance documentation to understand the status of those documents;
- Engagement with representatives from the CAV community (policy makers, highways authorities, operators, industry bodies, academics, consultants);
- Discussions around specific aspects of infrastructure, and how adaptation could to aid the introduction of CAVs.

Infrastructure adaptation opportunities discussed within this report generally fit into the following categories:

- Traffic Management Measures;
- Road Markings and Signage;
- Safe harbour areas;
- Role of service stations on the road network;
- Parking;
- Small Automated Demand Responsive Public Transport Vehicles;

- Crossings and Junctions;

The views and recommendations expressed in this report, particularly with regard to the infrastructure adaptations required for CAV introduction, are based on initial analysis and discussion and should be considered as points for consideration that could guide further research.

1.3 What is a CAV?

It is important to clarify what automated vehicles are, and to consider them in the wider context of connected vehicles. For the purposes of this study, Connected and / or Automated Vehicles (CAVs) are defined as follows,

- **Automated Vehicles** (also known as autonomous, self-driving or driverless vehicles):

  Vehicles with increasing levels of automation will use information from on-board sensors and systems so they can understand their global position and local environment and enable them to operate with little or no human input for some, or all, of the journey.

- **Connected Vehicles** (also known as Cooperative Intelligent Transport Systems (C-ITS)):

  Vehicles with increasing levels of connectivity which allows them to communicate with their surrounding environment (including the infrastructure and other vehicles). This could provide information to the driver / automated control system about road, traffic, and weather conditions, and on routing options and enable a wide range of connectivity services.

Expanding upon the above high level definitions, this study mainly focuses on the following types of CAVs:

- Privately owned road-based passenger vehicles with Advanced Driver Assistance Systems (ADAS);
- Highly automated privately owned road-based passenger vehicles;
- Highly automated road-based freight vehicles;
- Fully automated road / footway-based public transport vehicles.

2 Potential CAV Impacts?

2.1 Introduction

This section discusses the potential impacts of CAVs. Such information could be incorporated into planning and guidance documents to consider how CAVs could address existing issues with transport.

The potential of driverless cars has been discussed for many decades, but it is only in recent years that their development has moved at such pace. The anticipated benefits are hugely significant, and many anticipate that the move to CAVs will be as transformative as the move from the horse to the car more than 100 years ago. Some of these potential benefits are described as follows.

2.2 Reduced number / severity of road collisions

Over 90%[1] of road accidents are attributed to human error. The possibility of improving road safety as a result of reducing reliance on a human driver is often discussed. These discussions have already commenced in the case of the Tesla 'Autopilot' driver assistance system. Tesla has made claims that for their vehicles "the probability of having an accident is 50 per cent lower if you have Autopilot on"[2], although this claim is subject to debate.[3]

Improving road safety would be hugely beneficial for society as a whole. Firstly, there is the tragic loss of human life and serious injury associated with car accidents. Then there is the economic impact of road accidents. The value in the prevention of accidents is estimated by the DfT to cost £15.1 billion annually. Table 1 was taken from a DfT note summarising the value of prevention of road accidents for the year 2012[4] to the UK economy.

[1] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115
[2] http://www.telegraph.co.uk/technology/2016/04/25/elon-musk-teslas-autopilot-makes-accidents-50pc-less-likely/
[3] https://www.technologyreview.com/s/601849/teslas-dubious-claims-about-autopilots-safety-record/
[4] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/254720/rrcgb-valuation-methodology.pdf

£ million 2012

	Cost Elements						
	Casualty related costs			Accident related costs			
Accident severity	Lost output	Medical and Ambulance	Human costs	Police costs	Insurance and admin	Damage to property	Total
Fatal	1,040	9	2,042	29	1	19	3,139
Serious	526	315	3,582	44	4	108	4,578
Slight	389	165	1,854	67	15	381	2,871
All injury accidents	1,955	490	7,478	139	19	508	10,589
Damage only accidents	0	0	0	77	124	4,332	4,533
All accidents	**1,955**	**490**	**7,478**	**217**	**143**	**4,840**	**15,122**

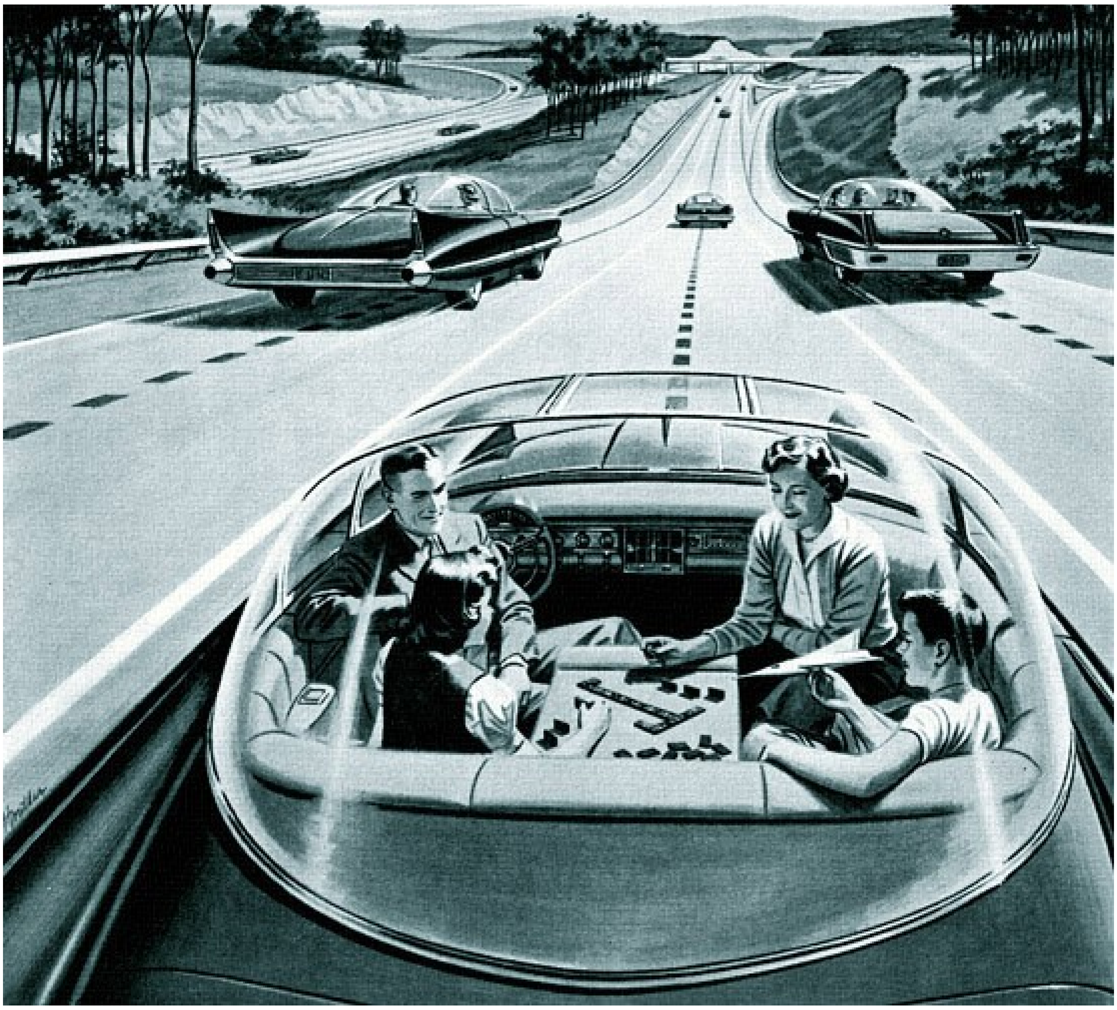
Table 1: Total value of prevention of road accidents by severity and element of cost: GB 2012 (Source: DfT)

Additionally, fewer road accidents would lead to reduced congestion. The presence of accidents on the roads can significantly worsen congestion[5]. Major collisions can close highway corridors for many hours, and even minor bumps and shunts often contribute significantly to congestion, as drivers stop to inspect their vehicles and exchange information with the other driver.

2.3 Releasing Driver Time

One of the selling points of CAVs for the consumer will be the time that they will gain as a result of not needing to drive. Instead of driving, people could work (for example, respond to emails, read documents, make telephone calls, participate remotely in meetings etc.), engage in leisure activities (watch movies or TV programmes, read, play games) or simply relax or sleep. Journeys by car could also become quality family time, as shown in Figure 2 below from the 1950's:

[5] http://epub.uni-regensburg.de/4535/1/Congestion_and_Accidents_WP.pdf



By Source (WP:NFCC#4), Fair use, https://en.wikipedia.org/w/index.php?curid=40458216

Figure 2: 1950's futuristic vision of automotive transport

The value of people's time has long been used in transport modelling and appraisal calculations, and the transition between the value of time associated with driving compared to being driven by an automated system has probably not been explored in great depth. Figure 3 is an extract from a study which references the extent to which people might value an hour of their time:

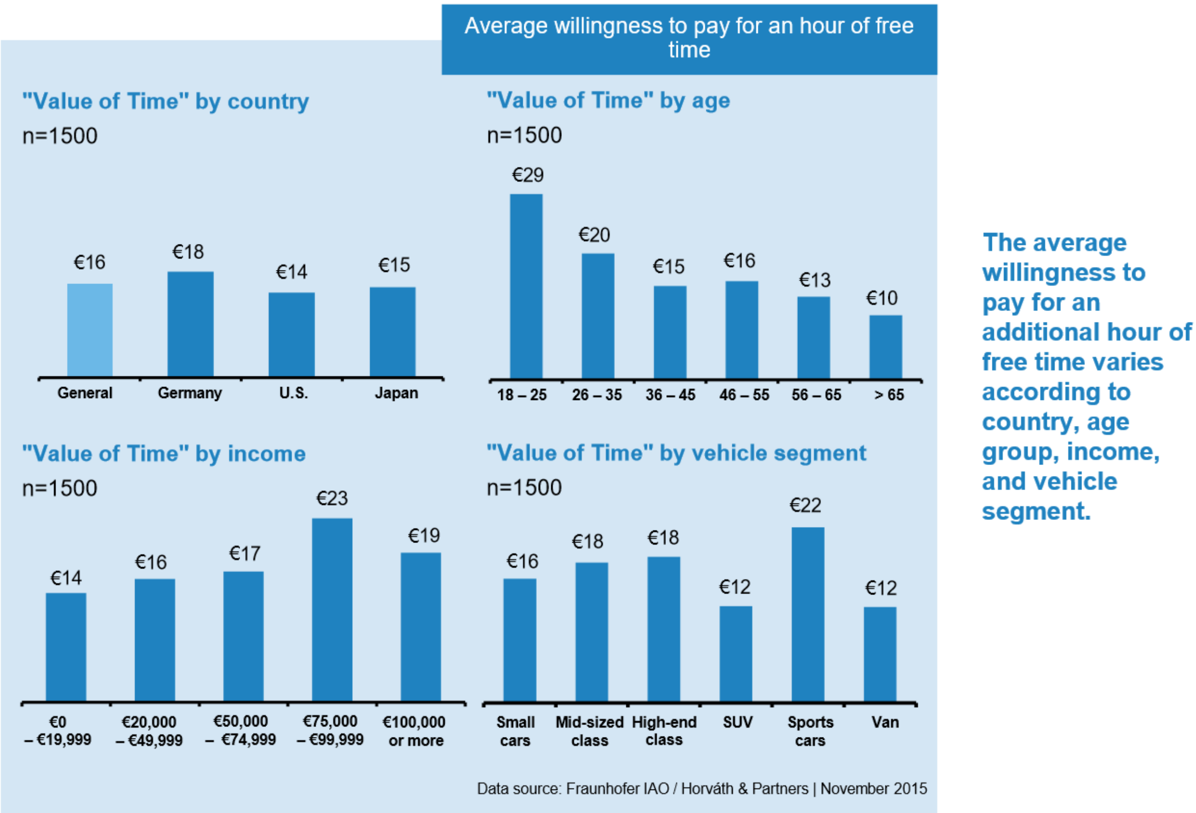


Figure 3: Average willingness to pay for an hour of free time

Source: "The Value of Time" Potential for user-centered services offered by autonomous driving, April 2016, https://www.horvath-partners.com/fileadmin/horvath-partners.com/assets/05_Media_Center/PDFs/englisch/Study_Value_of_Time_2016.pdf

The above research suggests that people may be willing to pay on average around 16 euros (£14) and up to 29 euros (£26) for 1 hour of free time, therefore there could be a strong business case supporting the move to vehicle automation.

There is also an economic benefit in releasing people's time. The workforce could be more productive, either due to the time spent working whilst in the vehicle, or they might be better rested and less stressed on arrival at the workplace.

According to the National Travel Survey (NTS), residents of England spent an average of 137 hours per year driving and 75 hours as a car passenger[6]. Therefore, each person could gain in the order of 22 minutes of time per day that is currently spent driving, and drivers and passengers combined could benefit to the extent of almost 35 minutes per person per day from greater connectivity within the vehicle.

As demonstrated in the '*Traveller Needs and UK Capability Study*', published by the TSC, solving the parking challenge is a key issue:

> *"On 12% of journeys in the UK, drivers find parking a significant pain-point (14% in cities and 19% in London), which cumulatively represent 4.3bn annual journeys. Other*

[6] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/456303/nts0310.xls

research in the UK has found that the average driver spends over 6.45 minutes searching for a parking space on each journey."

Traveller Needs and UK Capability Study, TSC

AVs offer the potential to drop their passengers off at their destination and then either go and park themselves, or go to pick up another passenger.

2.4 Environmental Benefits

Recently released research[7] indicated that air pollution, such as fine particles and nitrogen dioxide (the gas generated by diesel engines), may be contributing to the early death of 9,500 people in London. The case for CAVs leading to environmental benefits is unproven, but many believe that, certainly in the long term, the overall outcome will be positive. This could be due to several factors, such as:

- Vehicles driving more efficiently, using less fuel under acceleration. Over time, it may be possible to reduce safety gaps between vehicles which could lead to aerodynamic benefits.
- Vehicles routeing through the network more efficiently, with centralised vehicle routeing.
- The link between AVs and Electric Vehicles (EVs). Most CAVs currently under development have electric power trains. EVs emit no tailpipe pollutants, and therefore offer the potential of significantly improving air quality, especially in cities.
- The potential for the public to call on demand the most appropriately sized vehicle for their journey, rather than using a vehicle which may be larger than needed.

2.5 Reduced Congestion

People often talk about the potential for reduced congestion from CAVs, however the case is also still unproven. Certainly, AVs could help with traffic flow and accident reduction, and better routeing of traffic around the network could also greatly help reduce congestion. However, although flow could be better managed, AVs may worsen congestion by increasing demand, for example:

- Enabling people that are currently unable to drive to travel in AVs, could lead to more vehicle miles travelled. Young people, elderly people, disabled people, intoxicated people or simply those who don't have access to a car could have a new form of mobility in the form of a low cost automated taxi.
- Making travelling by car more pleasurable by removing the driving task might encourage people to travel more often and longer distances by car, increasing the vehicle miles travelled.
- AVs with the ability to travel empty could reposition themselves to where they are needed, creating new trips on the network that do not currently occur and increasing vehicle miles travelled.

[7] https://www.scribd.com/document/271641490/King-s-College-London-report-on-mortality-burden-of-NO2-and-PM2-5-in-London

2.6 Improved mobility for those without access to privately owned vehicles

Improved mobility for those that cannot drive or do not have access to a private car is one of the major long term selling points of automated taxis. Google were amongst the first to sell this vision in 2012 with their video[8] featuring a partially sighted man, Steve Mahan, travelling to collect a taco in an AV. In the video, Mahan states:

> *"You lose your timing in life, everything takes you much longer. There are some places that you cannot go, there are some things that you really cannot do. The way this would change my life is to give me the independence and the flexibility to go to the places that I both want to go and need to go when I need to do those things."*
>
> Steve Mahan, featured in Google Self-Driving Car video

The Transport Systems Catapult engaged with members of the visually impaired community at the RNIB Techshare event in Glasgow, which featured the LUTZ Pathfinder pod and a presentation by a representative of the Google Self-Driving Car team. It was clear from feedback received during the event that there is great excitement regarding the potential of this technology amongst this community.

The visually impaired community will not be the only ones to benefit. With an ageing population and an increasing tendency amongst young people to delay learning to drive there is a large and growing market for providing improved transport services for those that either cannot or choose not to drive, and most Governments have a responsibility to provide access to public transport for their citizens. However, AVs have the potential to go beyond providing mobility for those that cannot drive. A low-cost demand responsive system of automated taxis could fundamentally change the way public transport is delivered, which could extract trips from all other modes of travel, including private car, taxi, bus, train and (unfortunately) walking and cycling.

2.7 Potential Impact on Public Finances

CAVs will also affect Government tax revenue and spending in the UK. Much of the revenue collected through the use of road vehicles is used to maintain existing or build new infrastructure. Currently, revenue is raised from various sources including driving licences, vehicles registrations, fuel taxes, and fines. These sources may all be affected from the introduction of CAVs, as demonstrated in Figure 4 below.

[8] https://www.youtube.com/watch?v=cdgQpa1pUUE

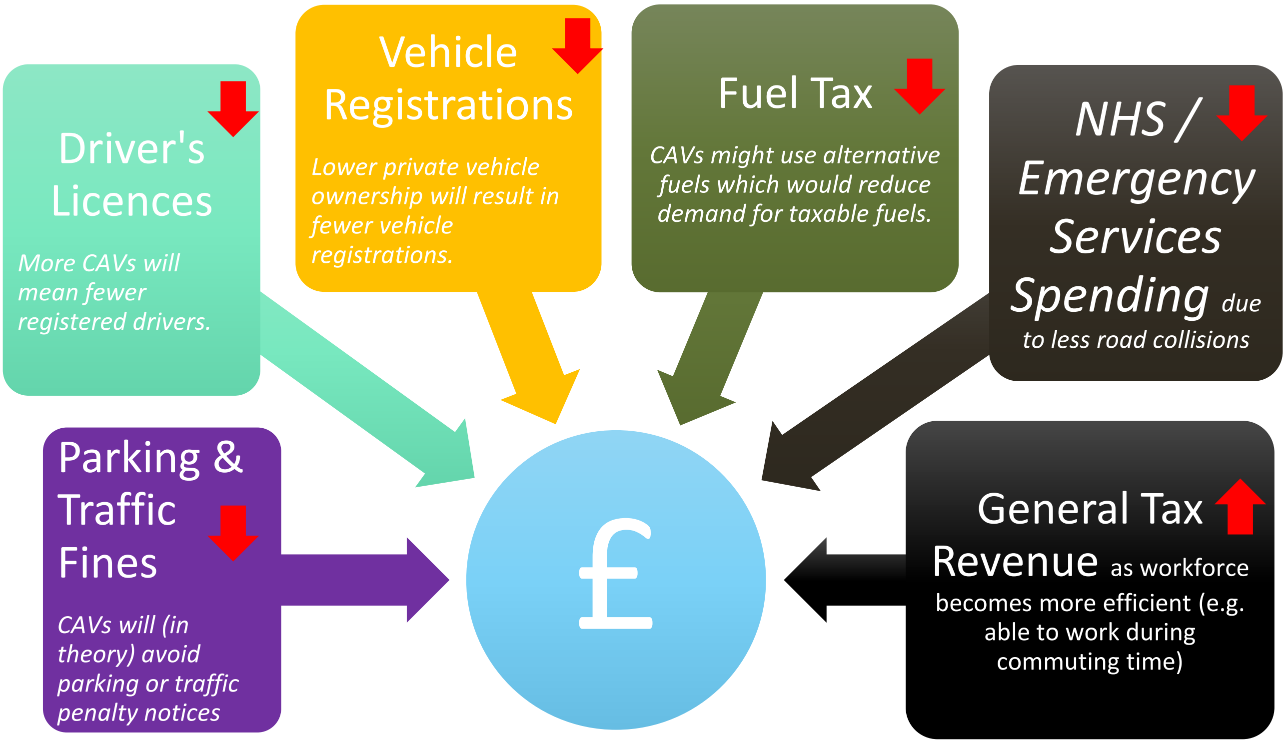


Figure 4: How the rise in CAVs may affect public finances

Predictions around future ownership models and uptake of CAVs tend to be speculative due to the uncertainty around deployment timescales, but it's probable that people may choose to own fewer cars as a result of having low cost demand responsive automated public transport services available (and as a result of 'Mobility as a Service' business models generally). The Organisation for Economic Co-operation and Development (OECD) published a report[9] suggesting that existing trips on the network could be serviced with a much smaller fleet of such vehicles, compared to privately owned passenger cars. This could start to have an impact on vehicle registrations, although it is recommended that a comprehensive study is commissioned into the financial implications and opportunities associated with CAV deployment and uptake.

2.8 Potential for Disruption to Established Industries

In addition to public finances, the potential for CAVs to disrupt established global industries is huge. They could completely shift business models, value chains and revenue streams in many sectors, including financial services, insurance, infrastructure, public transport, freight delivery and the automotive industry. Many existing jobs could cease to exist, whilst new ones will be created. These aspects are outside the scope of this report, but warrant extensive further study so that positive impacts can be maximised and the negative impacts mitigated against.

[9] http://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf

3 Review of Planning / Guidance Documents

3.1 Stakeholder Consultation Methodology

A significant part of this project was to gain insights from a sample of the stakeholders involved in or significantly affected by CAVs. The stakeholders that were engaged are as follows:

- DfT's Transport Appraisal and Strategic Modelling (TASM) team – responsible for the WebTAG[10] document;
- Chartered Institution of Highways and Transportation (CIHT) - responsible for Manual for Streets (MfS)
- Highways England (HE) – responsible for the Design Manual for Roads and Bridges (DMRB)

Each stakeholder was interviewed to understand the status and current usage of their particular document: with focus on future iterations of each document, and to highlight potential areas that may need to be amended, or areas that may need to be added.

Below is a list of the documents that were reviewed. Those marked with an * were documents where the stakeholder was also interviewed. Other documents were reviewed without comment from the authors.

- DMRB*;
- WebTAG*;
- MfS*;
- LTPs;
- National Planning Policy Framework (NPPF);
- National Infrastructure Plan (NIP);
- Traffic Signs Manual;
- Transport evidence bases in plan making and decision taking;
- Highways Act 1980;
- Traffic Management Act 2004.

3.2 WebTAG

The current status of WebTAG was discussed with members the WebTAG group from DfT's TASM team.

[10] WebTAG refers to the UK Department for Transport's web-based multimodal guidance on appraising transport projects and proposals. WebTAG reflects the New Approach to Appraisal that was developed in 1998 and initially applied to decisions on trunk road schemes and a series of major multimodal studies. WebTAG was first issued in 2003.

Current Situation

CAVs do not appear within WebTAG's existing scope. WebTAG relies on a strong evidence base and empirical research to provide input into the appraisal process. As a result, it is not possible to capture the full value of CAVs until the point where there is a strong evidence base regarding the specific benefits/impacts of CAVs.

It was recognised that there may be other mechanisms for quantifying the wider benefits of enabling technologies which have an initial limited application, but could lead to benefits in the future. This type of broad strategic evidence could be used to bolster the strategic case if CAVs were suitably identified in the respective strategic documents (for example, LTPs). Some input into the economic case of projects could also be made, since investment in the R&D world attracts further investment. While enabling technologies often have limited initial application, they may be significantly more beneficial in the future. Quantifying these future strategic benefits is crucial when building a case for CAV-related investment. It was recognised that there may be alternative mechanisms for quantifying the wider benefits of enabling technologies in WebTAG. Justification of a strategic case often relies on the extent to which a project aligns with priorities in related documents, such as LTPs. Thus, the importance of these documents supporting the introduction of CAVs should not be underestimated. Furthermore, investment in R&D draws additional investment and, as such, support for the economic case could also be argued.

Future Steps

The lack of empirical evidence regarding the specific benefits of CAVs makes it difficult to update the expert guidance sections of WebTAG to recognise their value. Despite this, it was acknowledged that at some point in the future, there is a possibility of having a chapter that specifically relates to CAVs.

A key area where a strong case could be made in the future is in time savings. WebTAG currently recognises the economic benefits of reduced journey times (from reduced congestion, less accidents, faster trains, etc.). It has been suggested that CAVs may reduce congestion and reduce the number of accidents[11]. Furthermore, the use of highly automated CAVs would enable people to do productive activities whilst driving (document review etc.), which has the potential to increase economic activities. If WebTAG were modified to be able to recognise these benefits, and sufficient empirical evidence existed, then it would significantly improve the chances of funding being awarded to CAV-friendly infrastructure projects. Further research is likely to be focused on the evidence gaps that would need to be explored before being able to provide definitive recommendations on the impact of introducing CAVs.

3.3 Manual for Streets[12]

The status of MfS1 and MfS2 was discussed with a representative from CIHT. MfS was published in 2007 and focuses on residential and streets, although some of the principles can be applied to other road types

[11] https://www.lta.gov.sg/ltaacademy/doc/J14Nov_p12Rodoulis_AVcities.pdf
[12] https://www.gov.uk/government/publications/manual-for-streets

where appropriate. The document is designed to accommodate the movement of motor vehicles, as well as meeting the needs of pedestrians and cyclists.

A follow up, MfS2, was published in 2010. Rather than replacing the 2007 document, MfS2 is considered to be a companion guide and as such should be read in parallel with the 2007 document. MfS2 fills the gap between the design advice that lies between the MfS and the design standards for trunk roads as set out in the DMRB.

The MfS and its sister document are targeted for use by stakeholders who have a part to play in the planning, design, approval or adoption of new residential streets, and modifications to existing residential streets.

Current Situation

A project proposal has been submitted to DfT to update and consolidate MfS 1 and MfS 2 into MfS 3. The new document will aim to address the gap between the DMRB and existing MfS documents (the main gap relates to the >50 mph non-trunk road network). To date, MfS3 had not been expected to include explicit references to designing for CAVs, but CIHT see that this as an opportunity, particularly given the timing of this TSC project (completing by end March 2017) and the start date for the CIHT activity (FY 2017/18).

Future Steps

During discussions, CIHT was interested in the concept of ‘classifying’ infrastructure based on its suitability for CAVs. The idea of an ‘umbrella document’ was discussed: CIHT also felt there could be significant benefit in a document that identified the challenges and opportunities that CAVs faced in relation to infrastructure design and management. This umbrella document could then input to the wider array of planning and policy guidance documents. It is hoped that the content of this report could feed into such a document.

It was discussed that shared space is one of the key points of discussion within further iterations of MfS, and how CAVs can operate in shared space environments is worthy of investigation.

3.4 Design Manual for Roads and Bridges[13]

Two representatives from HE met with the project team to explain the current status of DMRB and for the project team to establish whether consideration had been given to CAV needs.

The DMRB is a set of documents that contains a series of requirements for the design, construction and maintenance of the strategic road network. These requirements are distributed across different volumes of the document set, meaning that there is a degree of complexity in applying the DMRB for a given scheme. The average age of the DMRB documents is 16 years old. There are an increasing number of documents (currently approximately 300). This is making the DMRB document set increasingly complex to use and maintain.

[13] http://www.standardsforhighways.co.uk/ha/standards/dmrb/

Current Situation

A major revision to the DMRB is planned. This follows a review that HE conducted as a requirement of their Licence Agreement . The review was completed in April 2016 and covered the structure and content of the DMRB, with the focus on its usability. The review was undertaken in consultation with users of the DMRB and other stakeholders. A set of eleven recommendations will be taken forward and implemented over the first Roads Period. The scope of the updated DMRB will be consistent with the current version but will focus less on the prescriptive standards, and more on the use of performance standards. While the overall DMRB is being revised, the opportunity will be taken to rationalise the document set. The changes to the DMRB will be focused on creating a structure that is quicker to use, more flexible, and can almost generate a specific set of requirements for each project.

In addition to the DMRB, there are other key documents that HE and their supply chain use to design, maintain and operate the strategic road networks. These include the Manual of Contract Documents for Highway Works (MCHW) and the Asset Maintenance and Operational Requirements (AMOR).

Similarly to WebTAG, the DMRB is evidence based in its approach. At present, highway asset related requirements for CAV are not in the scope of the DMRB, although if sufficient evidence was in place to provide specific guidance, it could be included in due course. The HE team emphasised that the procurement of equipment or services needs to be in accordance with public procurement rules.

The NIP and Budget announced that HE would be conducting trialling of both Heavy Goods Vehicle (HGV) platooning and autonomous private vehicles on the strategic roads network in the coming years. A specification for the platooning trial was, at the time of the meeting, being prepared by the Technology group within HE. The Invitation to Tender has since been published, and stated:

“The aim of this project is therefore to provide the Department for Transport (DfT) and Highways England (HE) with the quantitative and qualitative evidence which will enable us to better assess the long-term effects of such systems on road safety, the economy, the environment, and traffic congestion.”

It went on to state:

“UK roads have a higher volume of traffic and at certain points have far higher congestion rates than European equivalents. The design of our road network is also different due to our geography, being a smaller island nation. The distances between junctions are much shorter than compared to many European long-distance motorways. These factors may alter the outcomes predicted by other trials, and therefore a UK trial is required in order to provide the necessary evidence to support a UK policy and to determine whether platooning is viable on UK roads.”

At the time of writing HE are in the process of appointing a lead contracter for the trials.

Within the Innovation, Technology and Research Strategy[14] published by HE in April 2016, it is stated that the safety and welfare of all those who use, work on, or are indirectly impacted by the road network is the priority and at the core of everything that HE does. This is confirmed by the following extract:

[14] https://www.gov.uk/government/publications/highways-englands-innovation-technology-and-research-strategy

Safer roads	We want to improve the inherent safety and the protective quality of the network for the benefit of all road users.
Safer vehicles	We will actively support the deployment of improved vehicle safety technologies on our network. This includes connected and autonomous vehicles that could be the breakthrough innovation that we need to achieve the 2040 safety ambition. We will seek to trial autonomous vehicles on our network by the end of 2017.
Safer people	We will develop intelligence led, innovative programmes to improve road user behaviour. We will also look for innovative ways to make our own people safer when they work on the roads.

Figure 5: Extract from HE Innovation, Technology and Research Strategy, April 2016

Future Steps

It is recognised within HE that they need to play a role in ensuring the Strategic Road Network is suitable for use by CAVs, but given the general uncertainty as to the rate and capabilities of CAV technologies, there is uncertainty as to how this is achieved. The following points were identified as particular areas of interest:

- Potential for deploying traffic management measures and repairing the road network with less exposure to risk for construction workers on the ground;
- The role of safe harbour areas for CAVs (pertinent given the move to all lane running as part of the Smart Motorway agenda, and the provision of safe harbour areas up to every 2.5km);
- The need for connectivity and enhanced communications (with emphasis on the replacement and installation of new gantries for signage);
- The requirements that CAVs place on road markings.

3.5 National Planning Policy Framework (NPPF)[15]

The National Planning Policy Framework was published by the Department for Communities and Local Government in March 2012, and consolidated a considerable number of previously issued documents called Planning Policy Statements and Planning Policy Guidance Notes. The NPPF sets out the Government's planning policies for England and how these are expected to be applied. It provides a framework within which local people and their accountable councils can produce their own distinctive local and neighbourhood plans, which reflect the needs and priorities of their communities.

The most relevant section of NPPF is section 4, which is titled "Promoting Sustainable Transport." The text from this section has been edited and reproduced as Appendix A of this report to show how the document could be adapted to take account of CAVs. These are not intended as final amendments, but are provided to aid discussion and to show how these types of documents can start to take account of future technology.

3.6 Local Transport Plans

LTPs outline a local authority's transport plan. They are an important way of rolling out transport strategy changes to the UK. LTPs have a time frame of up to 20 years, so it is important for the authors to begin considering the use of CAVs soon. LTPs were analysed for ways in which they could integrate CAV technologies in the future.

3.7 Traffic Signs Manual[16]

The Traffic Signs Manual provides guidance to highway authorities on the use of traffic signs and road markings. Aspects of this would need to be investigated, as discussed in later sections of this report.

3.8 Transport evidence bases in plan making and decision taking[17]

This document is issued as part of the NPPF in order to guide local planning authorities to undertake an assessment of the transport implications in developing or reviewing their Local Plan so that a robust transport evidence base may be developed to support the preparation and/or review of that Plan. This document supersedes a previous document named 'Guidance for Transport Assessments'. It is considered that developers, transport planners and local authorities would benefit from guidance in how to plan new developments around CAVs.

3.9 Highways Act 1980[18]

The Highways Act 1980 deals with the management and operation of the road network in England and Wales. A detailed review of the act has not been undertaken as part of this study, but it is considered that further iterations of the act should begin to consider CAVs.

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[15] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf
[16] https://www.gov.uk/government/publications/traffic-signs-manual
[17] http://planningguidance.communities.gov.uk/blog/guidance/transport-evidence-bases-in-plan-making/transport-evidence-bases-in-plan-making-guidance/
[18] http://www.legislation.gov.uk/ukpga/1980/66/contents

3.10 Traffic Management Act 2004[19]

This act was introduced to tackle congestion and disruption on the road network. The Traffic Management Act places a duty on local authorities to make sure traffic moves freely and quickly on their roads and the roads of nearby authorities. The TMA gives councils more tools to manage parking policies, coordinate street works and enforce some moving traffic offences. The act would require investigation and discussion with CAV technology developers to enable CAVs to handle areas of traffic management. This is discussed in more depth in later sections of the report. Related to this could be other documents used as guidance in relation to road incidents, including 'Management of Incidents'[20] produced by the College of Policing and 'CLEAR'[21] produced by Highways England.

3.11 Review Summary

There is a clear need for the consideration of CAVs in planning and design documents. Currently, none of the documents analysed have taken CAVs into account, nor is it anticipated that they will cover CAVs in the near future. The reason behind this is often due to an uncertainty regarding the direction that CAVs will take, the rapid speed at which CAV technology is progressing, their timing, and what their infrastructure requirements will be. The general lack of clarity on what the infrastructure needs of CAVs will be is of concern. There is an overall need to understand the situations that CAVs might find challenging to ensure that information is fed into new iterations of these documents.

Most of the above documents are expected to be updated in the short term, which provides a suitable opportunity to integrate CAVs into their content. The documents, particularly those involved in the appraisal and design of schemes, typically require a strong body of evidence to be in place before any recommendations or changes in relation to CAVs can be introduced. Although the lack of strong empirical evidence may prevent full integration of the consideration of CAVs into these documents, high-level changes could be made (e.g. give due consideration to future transport modes and the needs of CAVs).

Finally, although not directly relevant to any of the above guidance documents, there is a general need to consider the changing revenue streams because of the introduction of CAVs, which will need to be taken into account when considering the planning of transport budgets and wider reaching economic impacts of CAVs.

4 Infrastructure Requirements for CAVs

4.1 Introduction

To provide updates to planning and guidance documents, it is first necessary to establish the nature of infrastructure requirements that might be helpful or necessary in supporting CAVs.

[19] https://www.gov.uk/government/collections/traffic-management-act-2004-overview
[20] http://www.app.college.police.uk/app-content/road-policing-2/management-of-incidents/?s=incidents
[21] http://library.college.police.uk/docs/APPREF/CLEAR-Leaflet-April-2015.pdf

The TSC team held a series internal workshops to explore the potential opportunities for infrastructure adaptation to support the introduction of CAVs. The series of workshops included a total of eight different aspects, listed as follows:

- Traffic Management Measures;
- Road markings;
- Safe harbour areas;
- Role of service stations;
- Car parking;
- Automated Demand Responsive Public Transport Vehicles;
- Crossings and Junctions;
- Impact on bridge structures.

Each aspect was considered from a planning, design, implementation and operations perspective. This section will explore each of the aspect in more detail.

4.2 Traffic Management Measures

4.2.1 Issues / Opportunities

Most CAV systems are expected to rely on detailed mapping of the road network, and compare the information received from sensors with the historical information within the maps to perform such tasks as localisation and determining which lane to use. Roadworks may alter the road layout, changing where vehicles are expected to travel. For human drivers, intuition and ability to interpret road signs allows them to navigate these areas. However, CAVs may not have the intelligence to interpret a new environment correctly, and as such may have difficulty navigating through these areas. Due to these difficulties, consideration needs to be given to future, design, implementation, and operations of traffic management measures.

Road works can generally be divided into two categories; planned and emergency.

- Planned roadworks might be scheduled weeks or months in advance.
- Emergency roadworks, which might also include disabled vehicles in the carriageway, occur on an ad-hoc basis and cones are placed on the carriageway by the first responders to the scene.

There is also a need to differentiate between roadworks that occur on high speed highways and those that occur on other roads. Roadworks can include a wide range of traffic management measures and alterations to the road. Some roadworks, for example, can include traffic control measures such as traffic signals or stop-go signs. Occasionally authorised persons or members of the public might direct traffic through an incident. There might be a need to merge in turn as two lanes turn into one. Traffic might be expected to use oncoming vehicle lanes under controlled or uncontrolled conditions.

4.2.2 Current Situation

There are guidelines regarding the design of planned temporary traffic management. Chapter 8 of the Traffic Signs Manual, titled “Traffic Safety Measures and Signs for Road Works and Temporary Situations”[22] provides guidance on permissible signage types and locations and general roadworks layouts for various scenarios. The document states that the primary objective of temporary traffic management measures is always to maximise the safety of the workforce and the travelling public. The secondary objective is to keep traffic flowing as freely as possible.

The document states:

> *“Upon completion of the detailed traffic management design, the proposals, as a whole, should be reviewed by the project designer and a formal risk assessment undertaken. At this stage the programme for the works should be finalised and the traffic management requirements confirmed.”*

Although well stipulated, the compliance of traffic management layouts with previously agreed designs can never be guaranteed as cones are placed manually by road workers and can move around during the lifetime of the traffic management measures. However, the final design layout for planned traffic management measures could be of use for CAV maps.

Roadworks.org, operated by Elgin, is described as the most comprehensive source of up-to-date information about roadworks, road closures and diversions, traffic incidents and other disruptions affecting the UK road network. Elgin provides basic details of any disruptions, such as its location, dates of disruption, and scale of disruption. It does not provide exact details of the layout of the roadworks site, or real-time information on when a site has been made active or has finished.

[22] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/203669/traffic-signs-manual-chapter-08-part-01.pdf

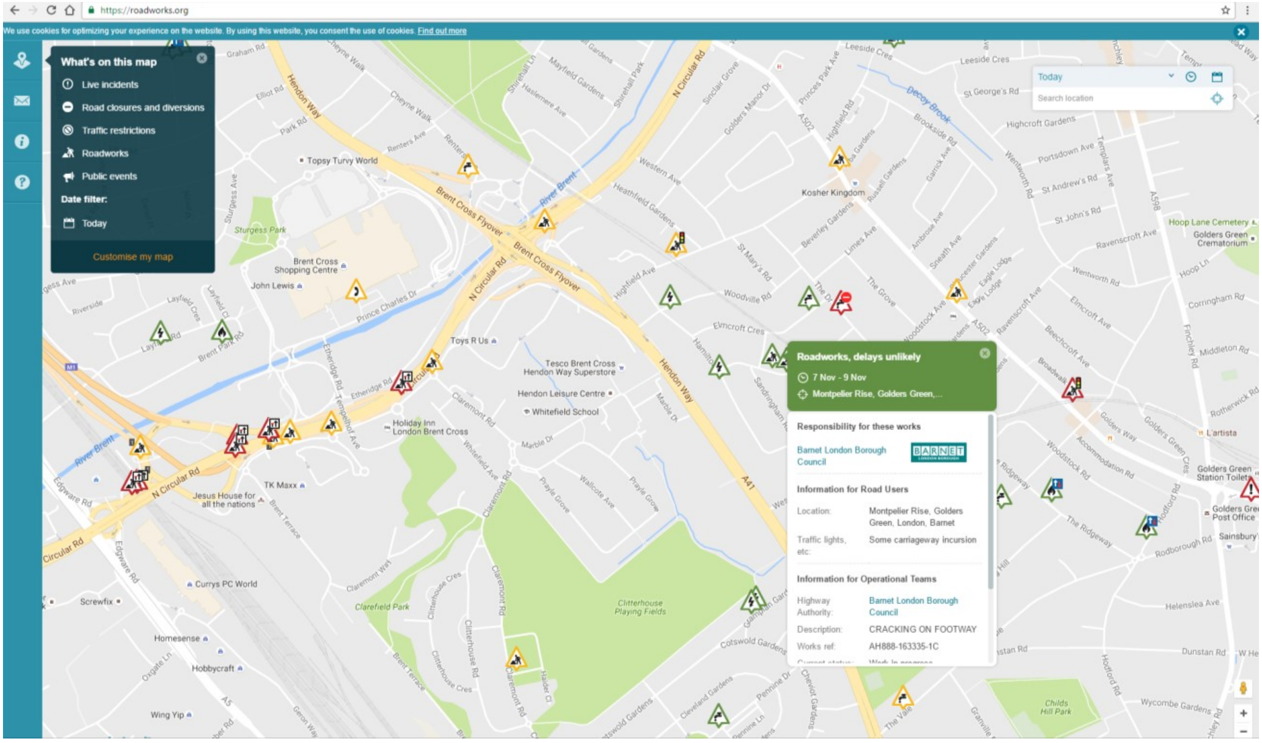

Figure 6: Screenshot from Roadworks.org

Immediate response/emergency road incidents present a different challenge to CAVs compared to planned traffic management measures. Police officers have a set of procedures to follow depending on the incident. Some information regarding live incidents is captured within the Roadworks.org database, with information from various data sources such as highway authorities. Another source of information is contained within databases such as Waze, which crowd sources data from a community of users. The following figures show the same live incident captured on Roadworks.org and on www.Waze.com.

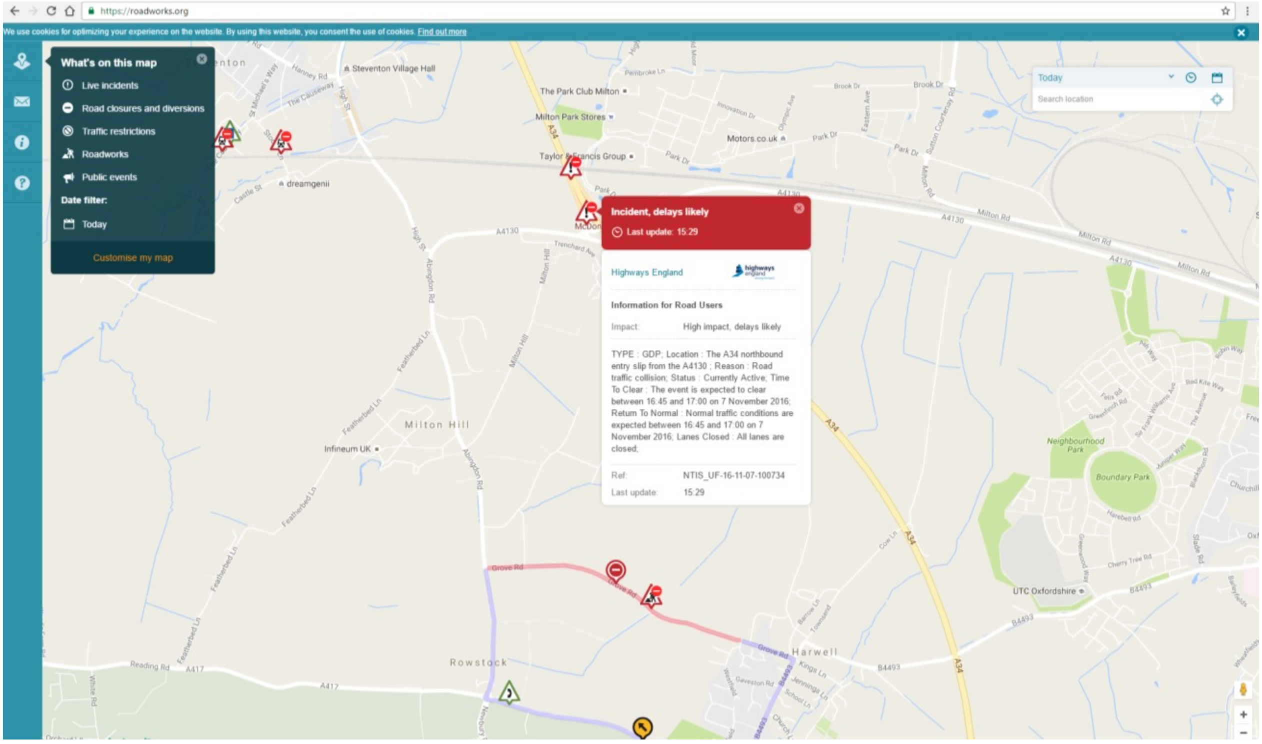

Figure 7: Live incident report on Roadworks.org

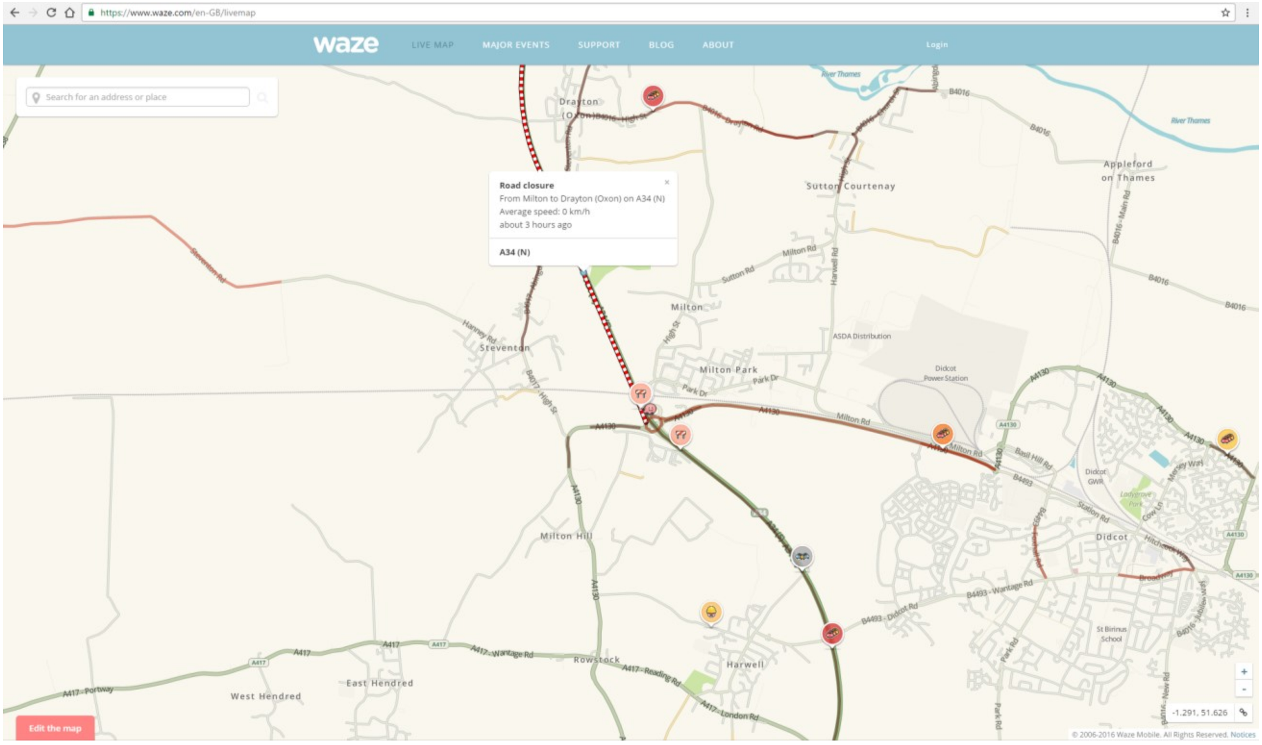

Figure 8: Live incident report on www.waze.com

The challenge for CAVs is that the scene around an incident may be difficult to interpret by a CAV. The normal rules of the road may give way to a common-sense approach in which vehicles navigate slowly around unusual obstructions, such as disabled vehicles or debris on the road. Drivers may be required to interpret hand signals from a police officers or other persons. Whilst live incident reporting may offer some details of the nature of the incident, the exact layout of any traffic management measures prior to the incident may not be known until the CAV arrives on the scene.

The A2/M2 connected vehicle corridor is exploring options for a connected Road Works Warning (RWW) system which communicates information about upcoming roadworks such as the location of roadside workers, the configuration of the worksite, and speed of vehicles near the site. It is expected that a system such as this would use a combination of temporary hardware such as worksite beacons and sensors and permanent infrastructure such as roadside communication devices to communicate data about the site to vehicles. The same system is being trialled for Green Light Optimal Speed Advisory (GLOSA), Signal Phasing and Timing, and Vehicle Flow systems. An illustration of this is shown in Figure 9 below:

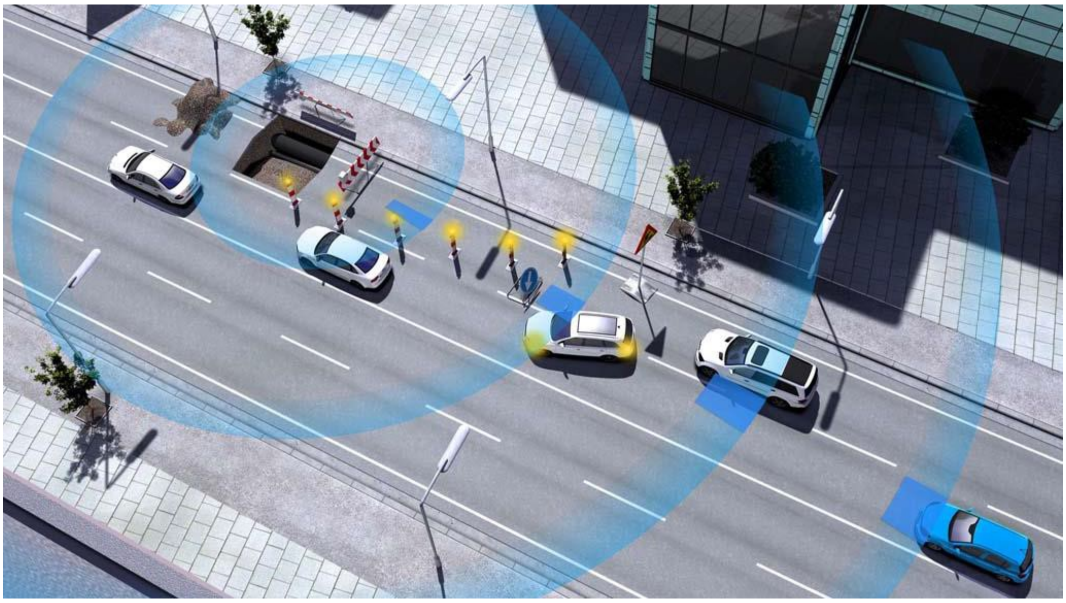

Figure 9: Example use of roadworks warning system [Source: http://www.telematicsvalley.org/assets/Guide-about-technologies-for-future-C-ITS-services-v1-0.pdf]

Netherlands, Germany, and Austria are currently building an Intelligent Transport System (ITS) G5 corridor from Rotterdam to Wien as shown in Figure 10. The first two applications are RWW and probe vehicle data.

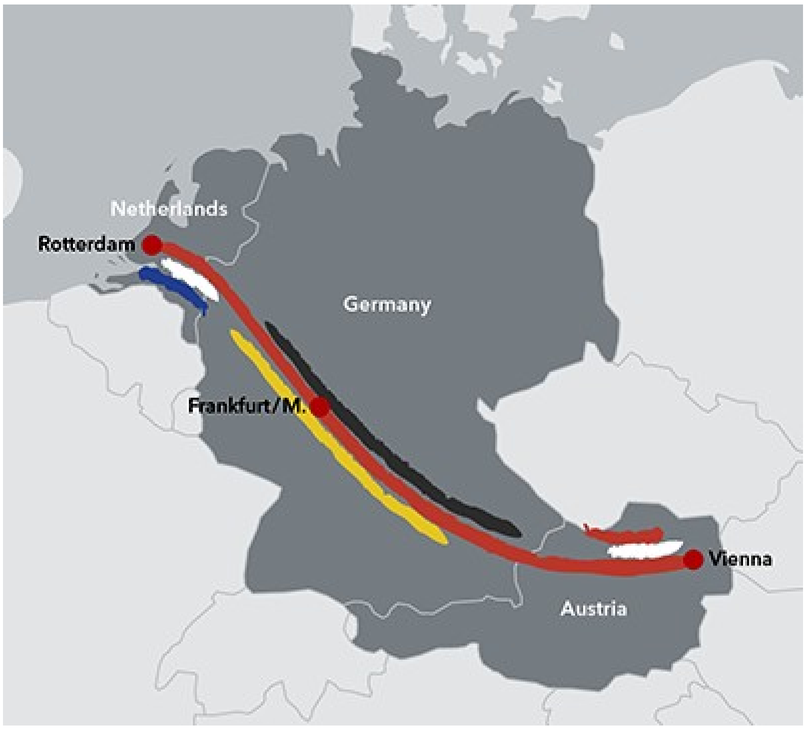

Figure 10: Cooperative ITS Corridor in Netherlands, Germany, and Austria [Source: http://www.telematicsvalley.org/assets/Guide-about-technologies-for-future-C-ITS-services-v1-0.pdf]

4.2.3 Future Considerations

Unless vehicle sensors and systems have the ability to detect and interpret traffic management measures with an extremely high degree of reliability and in a wide range of environmental conditions, then there will be a need to communicate details of temporary traffic management measures to CAVs. The details should include time of operation and the nature of the road layout and there needs to be a means to update the map used by the vehicle. Receiving real-time updates when sites have started and finished their work would be valuable. This could be communicated from the site manager at the precise time that the works are starting and finishing. This information could also be of use to human drivers as well as CAVs.

The mechanism for achieving this would require further investigation. It might involve geo-locating cones or barriers on a site, or setting up a virtual geo fence so that the CAV knows exactly where it can and can't drive. Consideration should be given to an Infrastructure to Vehicle (I2V) communications method to communicate areas of the highway that are closed for roadworks; in other words, areas (marked by co-ordinates) that the CAV cannot navigate using their normal operating modes. It should provide details of how the vehicle is expected to negotiate past the affected area, with rerouted traffic lanes and the nature and location of any traffic control measures. CAVs then either plan their route to avoid these areas altogether, switch to manual mode, or switch to a 'cautious roadworks' mode to navigate through the area if it has this capability, potentially with support from a human operator in a control centre. The level of detail that is required to be provided by the infrastructure will depend on how advanced the vehicle technology is: if vehicles are very advanced, they will need minimal guidance from authorities, and vice versa. Close cooperation would be required between the providers of CAV mapping data and road authorities (and their contractors).

It will be necessary to introduce a means for ensuring that vehicles are continuously checking that they are using the most up to date map versions for their journey. Therefore, the security of this data will be of paramount importance, so procedures would need putting into place to ensure the data is robust and accurate from the operative that inputs the data on site right through to delivery to the CAV.

Projects such as Compass 4D, and the A2/M2 Connected Vehicle Corridor, are beginning to explore options related to this, and further work in this area should be encouraged. However, it is suggested that connectivity needs to be considered as a failsafe for automated systems, rather than a non-critical additional piece of information. The overall system should provide complete confidence that a human driver can relinquish control and supervision and the system can handle almost any eventuality in almost any environmental condition.

Conveying this information requires some form of communication infrastructure; however, development in this area is still underway, and potential communication protocols are still being investigated. Currently, there are three primary contenders for the protocol of choice: mobile data (4G or 5G), ITS-G5 (a WiFi based technology with a reserved frequency range), or a hybrid of the two[23]. As discussed above, to act as a failsafe the information conveyed for CAVs will be safety-critical, and as such, the infrastructure used will need to be capable of conveying safety critical data. To date, a network capable of doing this has not yet been proven, but testing is underway. For example, ITS-G5 has been proven for use in tolling, but is still being tested for other services, such as conveying real-time safety-critical information. Mobile data technologies offer huge potential, due to their ability to utilise existing infrastructure and connect to back-offices/clouds, however, they have not yet been proven capable of handling safety-critical information. It is easy to imagine a future where multiple communication protocols are used, as shown in Figure 11 below. The unknown is knowing exactly what role each protocol will play.

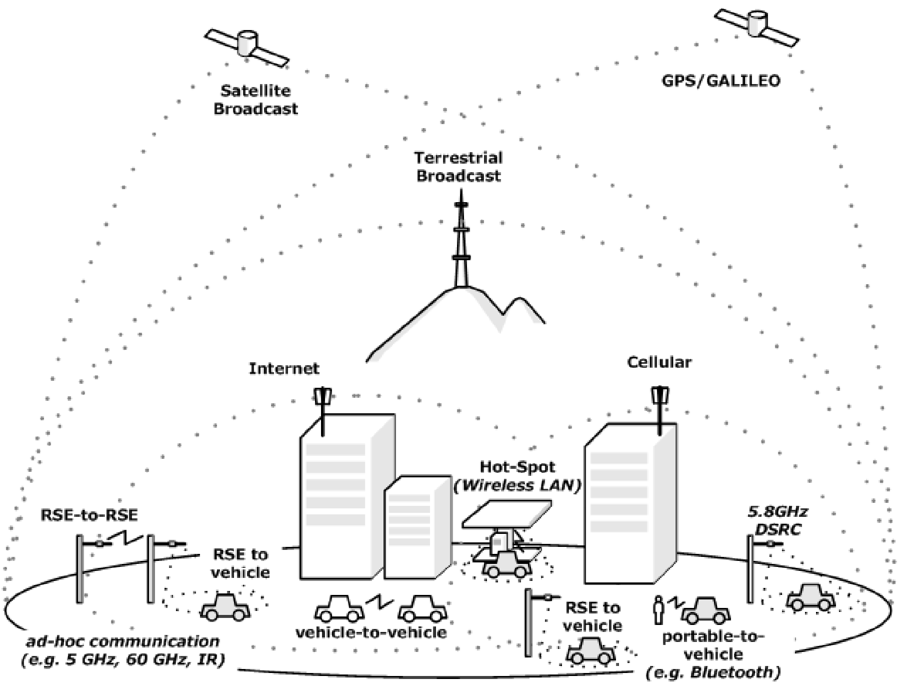

Figure 11: An example of multiple types of communication working alongside each other [Source: http://www.telematicsvalley.org/assets/Guide-about-technologies-for-future-C-ITS-services-v1-0.pdf]

An example showing utilisation of temporary and permanent infrastructure (for example, for road works) is shown in Figure 12 below:

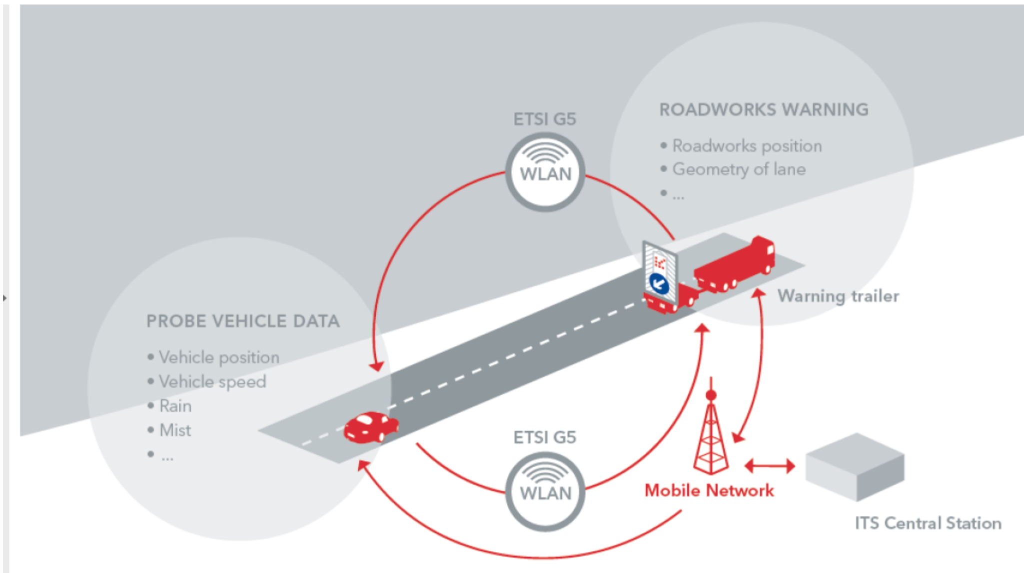

Figure 12: Example use of temporary and permanent communications infrastructure to communicate road works warnings. [Source: http://www.telematicsvalley.org/assets/Guide-about-technologies-for-future-C-ITS-services-v1-0.pdf]

It would not be advisable to proceed with installation of any of these choices until further decisions about the preferred technology has been made; however, fitting new major roads and key junctions with the infrastructure to support any of these choices (i.e. power and fibre-optic/copper cable connection) would allow for easy installation in the future once the technology has matured. Notably, ITS-G5 has a range of about 300 metres[23]. Many motorways already contain fibre-optic cables which could be utilised for these purposes.

Figure 13 below shows various examples of the infrastructure which may be required. These units were not installed for road works monitoring, but similar hardware could be used for such a purpose.

Figure 13: Connected Roads Infrastructure: Top-left: router and WiFi antenna, Right: Router, the external 3G antenna and stick antenna, Bottom-left: Roadside monitoring unit

Regarding immediate response/emergency situations, a "CAV Compliant First Respondent's Procedure" could be developed. This procedure will outline a series of steps that the first authority that arrives on site should follow. A suitable first step may be to set-up a warning sign/signal for CAVs which alerts nearby CAVs that the area is in an unusual state and that it should be avoided or navigated carefully. This sign/signal should easily be able to be identified by CAVs. Close corporation with organisations developing CAV technology would be required in developing such a procedure.

The V2I system mentioned above could also be used for immediate response situations; for example, CAVs could automatically send a signal to the system that they have broken down or that there is an incident

[23] https://eu-smartcities.eu/sites/all/files/docs/best-practice/Hybrid_cooperative_ITS_topic_description.pdf

nearby. This would allow wide-spread and fast dissemination of information about areas that CAVs should consider avoiding.

Finally, a comprehensive review of the Traffic Signs Manual, Chapter 8 could be undertaken by DfT. This includes a review of all roadworks signs/signals with in conjunction with CAV developers to ensure that they are all able to be interpreted by CAVs. This review could also consider a set of human traffic control hand signals, which first response teams can use to direct CAVs if necessary.

Such a review could form the basis for new international standards regarding CAV infrastructure. Agreeing on a set of human actions and signals will also assist developers as it provides them a strict set of items that they can test their vehicles against.

4.2.4 Summary

In summary, recommendations that could be considered, or could be researched further, include:

1. Consider methods to communicate areas to that are affected by roadworks to CAVs **to act as failsafe** for vehicle systems.
2. A methodology could be determined to establish the extent to which traffic management sites are CAV compliant, and these could be marked on the digital map. Consideration could be given to style and machine readability of markings, barriers, cones and general traffic control measures.
3. Detailed information could be provided on road layout and expected vehicle behaviour for traffic management measures (e.g. stop at traffic signal, merge in turn, use contraflow lane etc.)
4. Real-time updates to detail when traffic management measures are beginning and ending.
5. New roads and major junctions could be connected to electricity and fibre-optic/copper where practicable for road works communications (and other V2I applications).

For emergencies/first response situations:

6. Develop “CAV Compliant First Respondents” procedure.
7. Develop a warning sign/signal that can used warn CAVs of danger ahead.
8. Research into how humans can direct CAVs with hand signals, which could be used by incident first response teams.

For Traffic Signs Manual, Chapter 8:

9. Undertake comprehensive review of Traffic Signs Manual. Review of signs / signals with developers of CAV technology with a view of phasing out traffic management measures which are difficult for CAVs to interpret

10. Investigate procedures to ensure hardware is standardised and well maintained, particularly if used as failsafe for CAV systems.

4.3 Road Markings & Signage

4.3.1 Issues / Opportunities

Several CAV technologies rely on clear and consistent road markings and signage to navigate through their environment, hence, well maintained signage and markings are crucial. Significant deterioration or unusual use of road markings may confuse CAVs or even lead to an incident. Tesla's CEO, Elon Musk, and Volvo's North American CEO, Lex Kerssemakers, have both complained about the poor state of lane markings hindering the deployment of CAVs[24]. They have both stated that their vehicles find it hard to detect the lanes when the lane markings are faded.

It is possible that as vehicles use other forms of digital infrastructure and mapping to localise and navigate that the issue of road markings becomes less critical, but current advanced driver assistance systems (ADAS) already rely on road markings, and at least some highly automated systems are expected to rely on them for some time. In addition, until the day that manually driven vehicles are prohibited from the road network or all manually driven vehicles have some form of in vehicle signage display, physical signs will still be needed as part of the road infrastructure.

4.3.2 Current Situation

Road marking and signage standards are currently well defined. Traffic Signs Manual, Chapter 5[25] clearly outlines specifications for all types of lines, and Chapters 3, 4, and 7 outline standards for signs. Road markings and signage on private land are less well controlled, not coming under the jurisdiction of the Traffic Signs Manual. Areas such as private car parks and service stations can effectively use their own system of road markings and signage, and although often similar to Traffic Signs Manual standards, they may vary. Inconsistency may cause difficulties for CAVs attempting to navigate within these areas.

The importance of line markings and signage for CAVs is being recognised by some organisations. The European Road Assessment Programme (ERAP) and the European Car Assessment Programme (ECAP) released two papers:

- Roads that Cars can Read - a Consultation Paper, June 2011[26];
- Roads that Cars can Read - A Quality Standard for Road Markings and Traffic Signs on Major Rural Roads, November 2013[27].

Limitations for lane support systems where identified in the consultation report as follows:

[24] http://uk.reuters.com/article/us-autos-autonomous-infrastructure-insig-idUKKCN0WX131
[25] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223667/traffic-signs-manual-chapter-05.pdf
[26] http://www.eurorap.org/wp-content/uploads/2015/04/20110629-Roads-That-Cars-Can-Read-June-2011.pdf
[27] http://www.erf.be/images/Roads_That_Cars_Can_Read_2_Final_web.pdf

"Currently, the main limitations identified for lane departure systems because they rely on greyscale images are, other than mud, heavy rain, fog and snow:

- old road markings not completely obscured even if blacked out;
- Bitumen lines used to seal cabling or drainage in the roadway;
- faded indistinct lines on asphalt surfaces;
- slightly faded lines on concrete road surfaces which present poor contrast;
- lane markings not in normal use;
- discontinuous markings."

Figure 14: Failure Modes and Limitations, Extract from 'Roads that Cars can Read – A Consultation Paper', ERAP

The follow up paper calls for an "establishment of an intervention and maintenance policy to ensure that road markings on Europe's roads remain visible to the driver and the intelligent vehicle at all times, irrespective of weather conditions". The paper endorses the European Road Federation's (ERF's) definition of a good line marking, whose "minimum performance level under dry conditions is 150 mcd/lux/m² and which has a minimum width of 150 mm for all roads; for wet conditions, the minimum performance level should be 35 mcd/lux/m²". Currently, widths for line markings on UK roads vary between 100mm and 200mm depending on the use and location of the line[25].

ERAP and ECAP have called for EU Member States to investigate making safety critical road signs common across the EU to aid with recognition by CAVs. Figure 15 below shows several different implementations of the Vienna Convention signs in different countries:

ROAD SIGNS	Great Britain (GB)	Greece (GR)	Netherlands (NL)	Poland (PL)	Serbia (SRB)
Stop (and give way)	STOP	STOP	STOP	STOP	STOP
Give way (to traffic on major road)	GIVE WAY				
No entry for vehicular traffic					

Figure 15: Variance in road signage throughout countries in Europe [Source: http://www.erf.be/images/Roads_That_Cars_Can_Read_2_Final_web.pdf]

Finally, although the maintenance of road signs and markings are well stipulated[28,29], this does not ensure that signs and markings are currently maintained to the level likely to be required by CAVs. CAVs rely on road signs and markings to guide them whilst driving. Figure 16 below shows an example of line markings in disrepair.

Figure 16: Example of poorly maintained road markings that may be difficult for CAVs to interpret [Source: https://upload.wikimedia.org/wikipedia/commons/f/f1/Road_surface_deterioration_by_pavement_markings.jpg]

[28] P144, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223667/traffic-signs-manual-chapter-05.pdf
[29] http://www.standardsforhighways.co.uk/DMRB/vol8/section2/td2501.pdf

A similar problem is caused by poor maintenance of road signs. Although the sign in Figure 17 is not safety critical, it is an example of a sign that a CAV, and indeed a human, would have difficulty reading.

Figure 17: Example of a poorly maintained road sign that may be difficult for CAVs to interpret [Source: http://s0.geograph.org.uk/geophotos/01/66/92/1669239_d416144e.jpg]

The DMRB classifies dirty signs as 'Category 2' defects, which are deemed to be low priority and can take up to 6 months to be rectified[29]. Road signs are inspected every 12 months, meaning they could spend a significant period in a state that is unreadable by CAVs.

4.3.3 Future Considerations

Our initial investigations suggest that there is no real need for significant change to the design of road markings or road signs. This is predominately due to the fact that the current standards are well defined, and that CAV developers have made mention only to the inadequate state of road markings and road signs, and not their design. Despite this, ERAP and ECAP's proposals discussed above offer potential benefits if rolled-out across the European Union (EU) (or the world). If rolled out on a large scale, it offers uniformity for developers to programme their vehicles against. Similarly, any uniformity that can be given to safety critical road signs would be of benefit.

Although consideration should be given to the ERAP / ECAP proposals in terms of design, the most important aspect is to ensure lane markings and road signs are maintained at a high standard. This extends to more general road maintenance such as pot holes which may confuse CAVs. The current state of road signs and markings should be reviewed to ensure they are meeting the current standards, particularly for road types where CAVs are expected to operate first, such as motorways and high speed dual carriageways. During review, a collection of "worst-case" signs and markings should be catalogued to understand what the minimum standard or sign and marking is, and these could be used by CAV developers to understand what their requirements are.

An important opportunity for road maintenance is presented by CAVs. CAVs could use their sensors and communications equipment to report in real time any issues with signs, markings and other general road maintenance issues to the authorities. This could be extremely useful data that could shape how the road network is managed and maintained. To exploit this opportunity, authorities need to work closely with vehicle manufacturers and potentially telecommunications companies to ensure the information can be collected, communicated and utilised.

Areas of private land are more difficult to control. CAV-compatible zones may need to be established. These zones could mark areas that have been checked and certified as suitable for use by CAVs. Areas that do not meet these requirements may only be used in manual driving mode only. Issues regarding road markings around junctions will be discussed in Section **Error! Reference source not found.**.

4.3.4 Summary

For public roads:

11. Consider ongoing global research into appropriate road markings for CAVs.
12. With road markings forming the 'rails of automated steering systems', the procedures for maintenance of road markings may need to be improved and funding increased.
13. With some systems relying on visually detecting and interpreting traffic signs it could be important to ensure that they are maintained to a high standard in terms of cleanliness, clarity, deterioration, non-ambiguous positioning, and obscuration.

For private roads:

14. It may be necessary to work with land owners to ensure unadopted roads are checked and certified for use by CAVs.

4.4 Safe harbour areas

4.4.1 Issues / Opportunities

In full motorway / highway pilot mode, vehicles will be travelling at high speeds with the human driver disengaged from the driving task. It is possible that the driver is not ready to regain control of the vehicle before it reaches the end of its operational envelope. This could be due to several reasons, such as:

- Driver falls asleep, suffers some debilitating incident (e.g. heart attack) or becomes otherwise distracted;
- CAV system malfunction or mechanical problem;
- Deterioration of environmental conditions;
- Detection of incident ahead, such as disabled vehicles in the carriageway, which CAV is unable to negotiate.

In this situation the vehicle will need a safe area to stop and wait for the driver to be ready, or for conditions to improve to the extent where the automated control system is able to proceed.

4.4.2 Current Situation

Traditionally, hard shoulders have been provided along motorways, which provides a continuous strip of hardstanding for vehicles to stop in an emergency.

Figure 18: Example of continuous hard shoulder (left) and Emergency Refuge Area (right)

In recent years a number of sections of motorways been converted to All Lane Running (ALR). On these roads, the hard shoulder is permanently converted into a running lane, and the solid line which previously demarcated the hard shoulder is converted to a standard dashed line. Lane one (formerly the hard shoulder) is only closed to traffic via overhead and verge mounted cantilever signs in the event of an incident.

The ALR system provides safe harbour areas (referred to as emergency refuge areas as pictured above), which are spaced at intervals of up to every 2.5km. The design requirements and advice surrounding emergency refuge areas are governed by Interim Advice Note 161/13, which gives a design length of 100m, comprising an entry taper of 25m, a stopping area of 30m and an exit taper of 45m, with a width of 4.6m

The House of Commons Transport Committee released a report in June 2016 released a report highlighting concerns regarding ALR[30]. Specific points were made regarding the adequacy of Emergency Refuge Areas, and the fact that they are being misused. The report states:

> *"The level of emergency refuge area misuse is unacceptable. When combined with the scarcity of such areas, this can lead to a driver being forced to stop in a live lane in the event of a breakdown."*

Some motorways have been converted to 'Dynamic Hard Shoulder Running', which involves retaining the solid white line to indicate the presence of a hard shoulder, but opening the hard shoulder to general traffic during busy times via indications on overheard signage.

High speed dual and single carriageway roads currently have no requirement for safe harbour areas to be provided.

[30] http://www.publications.parliament.uk/pa/cm201617/cmselect/cmtrans/63/63.pdf

4.4.3 Future Considerations

Firstly, research is needed into the most appropriate form of safe harbour for CAVs. The advantage of a continuous hard shoulder is that there is always somewhere to stop at short notice. A disadvantage is that a hard shoulder is not necessarily a safe place to stop. Vehicles travelling in the nearside lane of the motorway can veer into the hard shoulder due to lack of concentration by the driver. Research by the AA indicates that 836 people on average in the UK have been killed or injured each year in incidents on the hard shoulder and lay-bys.[31] Advice on how to stop on the hard shoulder from the AA is:

> *"If you are forced to stop, safety is paramount, so exit the vehicle on the left, get far away from your vehicle and behind the barrier (if one is present) and then call for assistance – it's just not safe to remain in the vehicle."*

Clearly this does not appear to be an appropriate place for a CAV to stop, which could be for no other reason than the occupant has fallen asleep and is unable to retake control of the vehicle. It's possible that in such a situation the occupant could continue sleeping for some time whilst in a position of considerable personal danger.

Safe harbours need to be appropriately designed, and contain enough space for an appropriate number of vehicles to stop and frequent enough so that the CAV can access them when required. Provisions should be put in place to prevent misuse of these areas, taking into account concerns raised within the House of Commons Transport Committee report, but also recognising that CAVs could considerably increase the usage of such areas.

The location of stops needs to be well mapped and documented so that CAVs can plan to stop there before exiting if their occupant does not re-take control in time.

If CAVs are to be deployed on high speed dual carriageways and high speed single carriageway roads, the feasibility of providing safe harbours along these routes should be investigated.

4.4.4 Worked example

The following worked example considers the possible location of a safe harbour area along the M25 motorway, as shown in Figure 19 below:

[31] https://www.theaa.com/breakdown-cover/news/hard-shoulder-safety-reasons-for-stopping.html

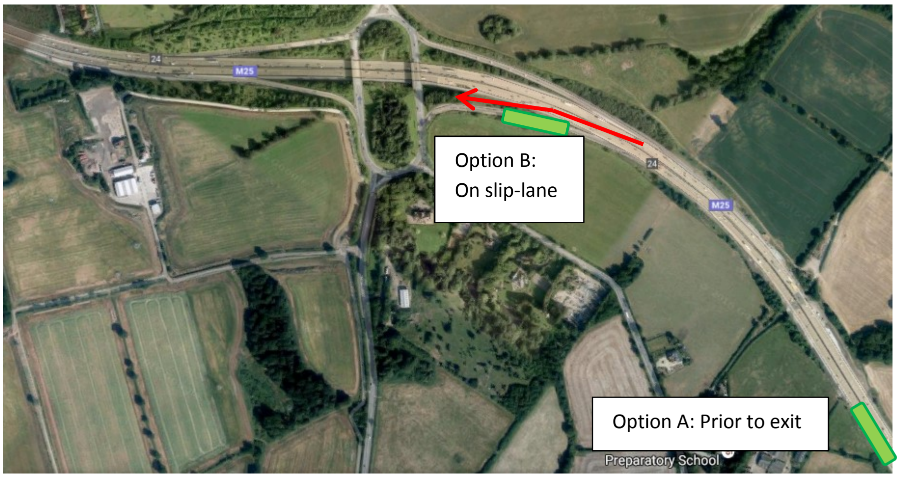

Figure 19: Safe harbour zone options for an example stretch of the M25 [Source: https://www.google.co.uk/maps]

Two potential options could be considered for a safe harbour in this example. Option A would involve CAVs stopping in a safe harbour area prior to the motorway exit. The important point is that the safe harbour is before the exit so that if the occupant is able to take the exit once proceeding from the safe harbour. An alternative is Option B, which is placing the safe harbour alongside the slip-lane. This could be a safer place to stop due to lower speeds. However, the details of any option will depend on local land constraints and appropriate design.

For situations where there are roadworks on the motorway, a temporary safe harbour could be provided before the roadworks.

4.4.5 Summary

15. Consider appropriate frequency and design of safe harbour areas on high speed roads of various type for CAVs.
16. Consider measures to avoid misuse of such areas.
17. Consider temporary safe harbour areas prior to traffic management measures.

4.5 Role of service stations on the road network

4.5.1 Issues / Opportunities

Service stations provide an important role in allowing drivers a safe place to stop, rest, get refreshments and use toilet facilities. It is interesting to consider how their role could adapt with the move towards vehicle automation.

4.5.2 Discussion of Options

Service stations could provide suitable high capacity and more suitable safe harbour areas. If a vehicle occupant had fallen asleep whilst the CAV is driving itself, it might be preferable to wake up in a service station car park, with all retail and toilet facilities available, prior to continuing with the journey. To enable this, the vehicle access to the service station and the CAV waiting area must be usable by CAVs, and the may need to be some adaptation to existing service station layouts to achieve this.

A further idea is to consider using service stations as a public transport hub, with new public transport service provision via fleets of 'automated motorway taxis'. This idea might be worthwhile pursuing if CAVs are able to operate within the more controlled environment of motorways, and less able to operate reliably in the more complicated urban environment for some time. Travellers could use public transport, taxi, or walk or cycle to a service station and then use an automated motorway taxi to continue their journey. This essentially reimagines the motorway network as the tracks of a new public transport system, with service stations as the new railway stations.

It is anticipated that many CAVs will be electrically powered and service stations will need to be able to charge CAVs alongside manually driven vehicles. It may be worth considering inductive charging stations that unmanned CAVs can access and use without the need for human intervention.

Highway authorities could begin to work closely with service station operators to discuss these and other options. There could be incentive for service station operators to offer services that will attract the growing CAV market in the future.

4.5.3 Summary

18. Consider the use of service stations as safe harbour zones for CAVs, and the necessary adaptions to achieve this.
19. Consider service stations a public transport hub that enables passengers to interchange to automated motorway taxis.
20. Consider enabling service stations to inductively charge CAVs with minimal human intervention.

4.6 Design of Parking for CAVs

4.6.1 Issues / Opportunity

The idea of 'autonomous valet parking' has been discussed for many years, and several car companies have demonstrated systems which show a CAV capable of searching for, detecting and manoeuvring into a parking space with no human intervention. This creates exciting opportunities both for the user and for the infrastructure provider. Firstly, for the user, this would enable a driver to park somewhere close to the entrance of a car park in a designated vehicle drop off area and continue directly to their destination without the time and stress of parking a car. The car could be subsequently summoned to a collection area.

For the infrastructure provider there could be an opportunity to significantly increase car parking provision within a given land area. In theory, when empty CAVs could park themselves very efficiently, without the need for human occupants to open the doors. This alone could enable 20% more spaces to be provided within a car park. Taking it one step further, CAVs could block each other in and let each other out when necessary. A study by Audi suggested 2.5 times the number of vehicles could fit into a car park using this method compared to human-controlled vehicles[32].

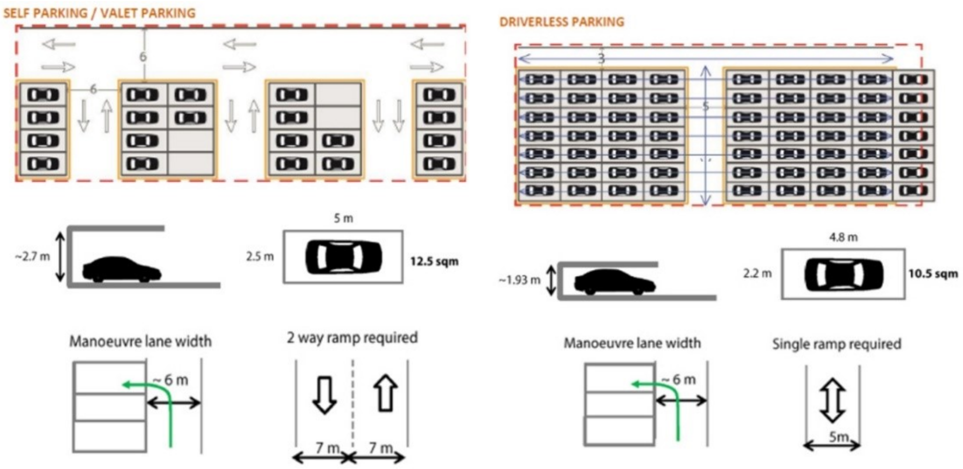

Figure 20: Conventional parking layout (left) vs possible CAV parking layout (right) [Source: http://audi-urban-future-initiative.com/blog/piloted-parking-future-mobility]

Figure 21 below has been captured from a video which simulates how CAVs could park themselves in a highly efficient manner. The idea of the layout shown is that each vehicle can be blocked in by up to two other vehicles. If that vehicle needs to exit, the other two vehicles will move out of the way to allow passage.

[32] http://audi-urban-future-initiative.com/blog/piloted-parking-future-mobility

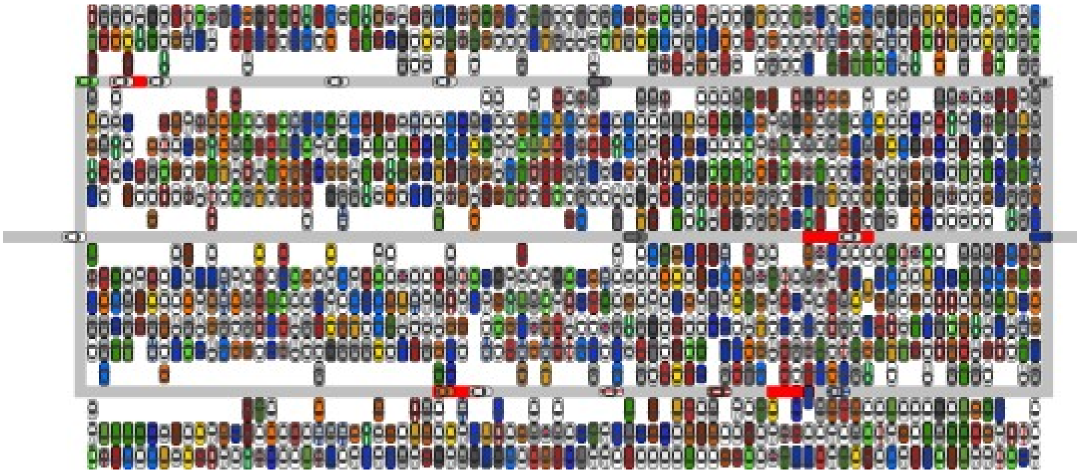

Figure 21: Potential layout of CAV carpark, achieving high parking density [Source: http://www.v-charge.eu/?p=1169. Video can be viewed at https://www.youtube.com/watch?v=pCzI-l8tsPY]

Enabling vehicles to manoeuvre as directed by the car parking system could be challenging. Some form of remote control access will need to be granted to the car park operator. Having vehicles that are capable of being controlled in this manner (which includes ignition, throttle, brakes, and steering), could expose the CAV to cyber security threats. Safe guards would also be needed in the event that a vehicle does not respond, and how to retrieve any vehicles that may be blocked.

In addition, since no driver may be present, any car park operator intending on allowing CAVs with no occupants into their car park would need to establish an automatic electronic payment method. This could be done via number plate recognition, an electronic tag, or V2I communication.

4.6.2 Regulations

Regulations relating to CAV parking are advancing quickly. ISO/DIS 16787, "Intelligent Transport Systems — Assisted Parking System (APS) - Performance requirements and test procedures", has been drafted. The standard "…establishes minimum functionality requirements that the driver can expect of an APS, such as the detection of suitable parking spaces, calculation of trajectories, and lateral control of the vehicle…". This standard also sets minimum requirements for failure indication as well as performance test procedures. It includes rules for the general information strategy but does not restrict the information type or display system." Referring to this ISO can aid authorities and car park operators in better understanding what is required for a car park for CAVs.

4.6.3 Infrastructure Requirements:

One challenge with regards to CAVs in car parks relates to consistency. As many car parks are privately operated, they do not always use conventional road markings. They often incorporate one-way systems and other traffic controls, and signage and markings can be inconsistent from one car park to the next. CAVs may struggle to navigate these environments, and this issue also is relevant to service stations. It may be advantageous in the longer term to agree international standards for CAV compliant car park signage and markings. A short-term measure would be for CAV developers to map individual car parks digitally to ensure their systems work in that particular car park.

To start achieving some of the benefits of CAVs within car parks, areas of car parks could be designated as CAV only. This area would have clear and compliant line markings, and be free from pedestrians and human-operated vehicles. Operators could be incentivised by the ability to fit more vehicles into an area, although uptake initially could be low as not many vehicles might have the necessary technology in the early years – a classic chicken and egg problem.

There might be ways to address this problem in the early years. A company that owns a fleet of vehicles, and would benefit from more efficient parking of them, could introduce vehicles with the self-parking technology or an organisation which provides company cars for staff could think about using cars with the technology, and designating areas of the company car park for its use.

A future vision for car park design can be seen in a drawing published by US architect firm Arrowstreet, reproduced below. The top level of the carpark is for use by CAVs (since it is the furthest away), with the remaining levels still used for conventional parking.

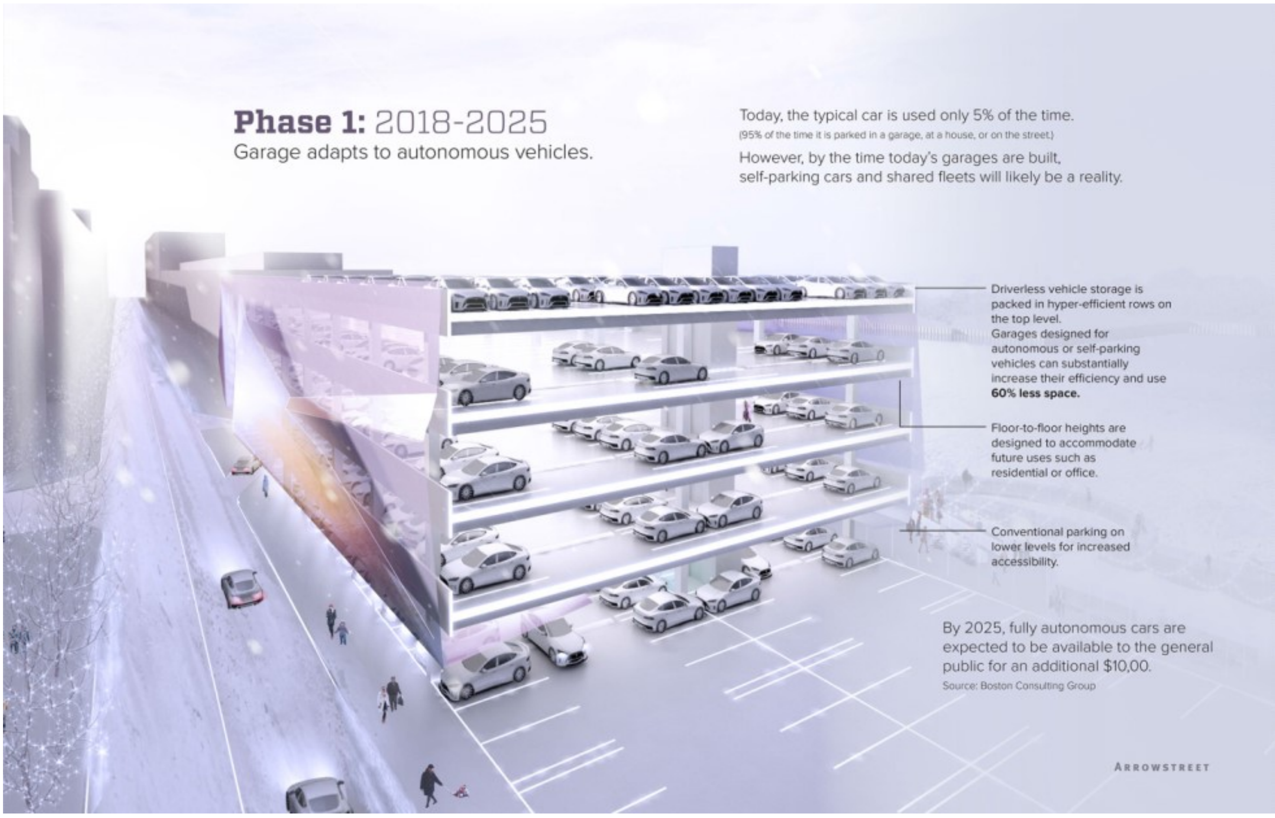

Figure 22: An example of a segregated area of the carpark for use by CAVs [Source: http://www.arrowstreet.com/portfolio/autonomous-vehicles/]

To compliment CAV-compliant parking areas, valet pick-up/drop-off areas should be considered. This is a designated area where people can drop-off and collect their CAVs. They must be designed with safety in mind and with sufficient capacity to allow for peak use. It may be that a small area is required initially which can expanded in the future as uptake of CAVs increases. Figure 23 below shows an example of a valet parking area and how a charging system may work within a carpark. A small number of electric charging spaces are provided and owners can move their cars in and out as required.

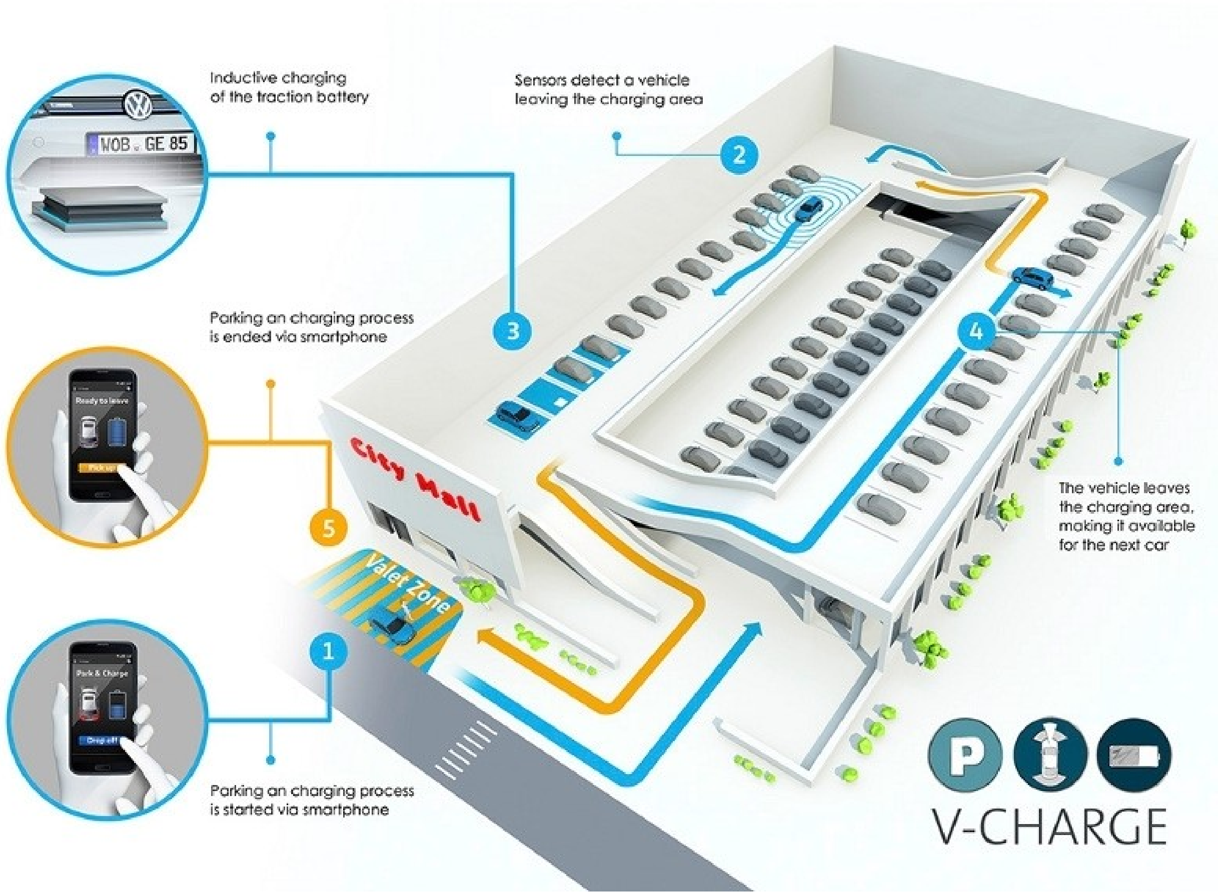

Figure 23: Carpark showing use of a 'Valet Zone' and charging areas [Source: http://www.volkswagenag.com/content/vwcorp/info_center/en/news/2015/07/charge.html]

At a government level, a guidance document for carpark operators could be produced, providing a list of recommended processes to follow, and their associated benefits. The guide could give suggested layouts/designs for CAV-compatible carparks and infrastructure that could be fitted to enable more advanced automated parking solutions. It could discuss the potential benefits of fitting communications equipment to enable infrastructure to vehicle communications, data collection systems such as car park monitoring sensors which keep track of which spaces are available in real-time, or automatic electronic payment systems. Close collaboration would be needed with the vehicle technology developers in producing such a document.

Establishing a CAV parking test area in the UK would allow developers to begin testing their CAVs in different car park layouts and scenarios. This could accelerate the development of CAV valet parking by allowing operators and developers to work together, as well as allowing the government and car park operators to observe progress in this technological field.

4.6.4 On Street Parking (and narrow streets)

Within the UK it is common for parking to occur on street and for this parking to limit traffic flow so that there is insufficient space for two-way traffic. In these situations, drivers need to decide amongst themselves who will go first, and this can often be communicated by a hand gesture or a flash of the headlights. CAVs are expected to struggle with this form of traffic arbitration. If CAVs are going to negotiate narrow streets with significant levels of on street parking, it might be necessary to consider several options, such as removal of on street parking so that two vehicles can pass each other, or conversion of streets to one-way operation.

Figure 24: Example of where a CAV may struggle to determine whether to proceed through a street narrowing caused by on street parking with a vehicle approaching from the opposite direction [image source: Google]

4.6.5 Parking Demand

Parking demand will significantly impact the way in which we plan, design, and build car parks in years to come. Predicting the effect that the introduction of CAVs may have on parking demand is difficult, particularly in the short-to-medium term. This is due to the number of unknowns, including rate of technology development (to reach SAE Level 4 and 5), cost of CAVs, and rate of CAV market penetration. It is not possible to confidently forecast the impact that CAVs will have on the future demand of traffic and parking. Victoria Transport Policy Institute expects that although some impacts, such as independent mobility, may begin in the 2020s and 2030s, significant network impacts will only be realised between the 2040s and 2060s[33].

[33] http://www.vtpi.org/avip.pdf

In the long-term, when CAVs become common place, most experts agree that although the overall number of journeys may increase, demand for parking in central areas will decrease. Researchers from Eno, Center for Transportation, believe that by replacing personal vehicles with CAVs, parking costs will significantly reduce[34]. Other studies, such as 'Potential Impact of Self-Driving Vehicles on Household Vehicle Demand and Usage' by University of Michigan predict that CAVs serving multiple residents within a household could reduce vehicle ownership by up to 43%, but, at the same time, increase travel per vehicle by up to 75%[35]. Reduced parking demand, but increased mileage, is as a result of CAVs either continuously circulating to pick up and drop off passengers, or driving themselves to a car park in a non-central area to park. Cars could be aggregated into large car parks located away from central areas.

Space that is freed up from central parking areas and suburban streets could be considered when planning land use for the future. Milton Keynes, for example, has over 20,000[36] car parks in central areas. The future wide spread use of CAVs could make much of this space available for redevelopment.

Given that the transition to less demand in central areas may not occur for decades, and it will be a slow transition, an adaptable approach to car park design could be considered. In the example shown in Figure 25, which forms phase 2 of the car park vision produced by US Architect firm Arrowstreet introduced earlier, the area of the structure that was previously used for as car parking space is converted for alternative uses, such as residential, offices, recreation and a roof top garden. They even suggest an area to accept delivery by unmanned aerial vehicles, which could be another interesting area of study which is outside of the scope of this report. The important point here is that the multi-storey car park originally built is done so with floor heights that enable the structure to be adapted to other purposes as car parking demand decreases over time.

34 https://www.caee.utexas.edu/prof/kockelman/public_html/ENOReport_BCAofAVs.pdf
35 https://deepblue.lib.umich.edu/bitstream/handle/2027.42/110789/103157.pdf
36 https://www.milton-keynes.gov.uk/streets-transport-and-parking/parking/parking-maps-for-central-milton-keynes

Figure 25: Transforming existing car parks into multi-purpose buildings [Source: http://www.arrowstreet.com/portfolio/autonomous-vehicles/]

4.6.6 Summary

21. Operators could begin to consider the potential benefits of CAV valet parking solutions. Benefits include those to the customer and to the operator in terms of parking density.
22. A guidance document for carpark operators should be considered.
23. Consider creation of a CAV parking test areas in the UK for developers to use for testing.
24. Consider options for allowing CAVs to pass oncoming vehicles where on street parking limits flow to one direction. Options might include removal of parking or conversion of the street to one-way operation.
25. When planning future land use consider that, over time, parking demand could decrease and space currently used for parking could be available for other uses.
26. Architects and planners could adopt a flexible approach to car park design and planning, acknowledging the potential for less demand in future decades.

4.7 Small Automated Demand Responsive Public Transport Vehicles

4.7.1 Opportunity

The concept of demand responsive public transport vehicles has been discussed for many decades, as evidenced by a useful paper by Lisa Davison, Marcus Enoch, Tim Ryley, Mohammed Quddus and Chao Wang.[37]

As defined in the article, "public transport can be categorised as being Demand Responsive Transport (DRT) if

- *the service is available to the general public (i.e. it is not restricted to particular groups of user according to age or disability criteria or place of employment);*
- *the service is provided by low capacity road vehicles such as small buses, vans or taxis;*
- *the service responds to changes in demand by either altering its route and/or its timetable; and*
- *the fare is charged on a per passenger and not a per vehicle basis."*

The prospect of demand responsive transport using automated vehicles is particularly appealing. Not needing to employ a human driver will clearly improve the business case, and could also greatly improve the flexibility in terms of fleet operations, as there would be no need for vehicles to stop for the driver to take breaks and vehicles could operate 24 hours per day.

4.7.2 Minibuses vs Taxis

There is a choice between vehicles that are used by individuals, and vehicles that are shared among multiple passengers. Uber has already developed both types of solution with manually driven vehicles. The normal Uber service allows passengers to ride individually (or as a single group of travellers that know each other) whilst the uberPOOL service picks up multiple passengers heading in the same direction and splits the costs between them.

The same two options could become a reality for fleets of automated vehicles, and in some respects the size of the vehicle, and number of passengers that can be accommodated, may not be critical in some areas. In more built up areas, however, where road space is limited, authorities may wish to take steps to encourage vehicles with multiple occupants. This approach may not only help reduce congestion, but could also help reduce emissions and energy use associated with transport.

Interesting studies have already been completed in this area, such as Urban Mobility System Upgrade[38], which looked at the changes that might result from the large-scale uptake of a shared and self-driving fleet of vehicles in the City of Lisbon. The study explored two different self-driving vehicle concepts, for which they used the terms "TaxiBot" and "AutoVot". TaxiBots are self-driving cars that can be shared simultaneously by several passengers. AutoVots pick-up and drop-off single passengers sequentially. The

[37] http://ac.els-cdn.com/S0967070X13001704/1-s2.0-S0967070X13001704-main.pdf?_tid=e57d5d3e-a7fd-11e6-a979-00000aacb35e&acdnat=1478862140_d5b33c19047442f2f02b4ceb047e594d
[38] http://www.internationaltransportforum.org/Pub/pdf/15CPB_Self-drivingcars.pdf

report looked at impacts on car fleet size, volume of travel and parking requirements over two different time scales: a 24-hour average and for peak hours only.

What they found is that TaxiBots, combined with high-capacity public transport, could remove 9 out of every 10 cars in a mid-sized European city. Even in the scenario that least reduces the number of cars (AutoVots without high-capacity public transport), nearly eight out of ten cars could be removed.

In terms of impacts on congestion, a TaxiBot system in combination with high-capacity public transport uses 65% fewer vehicles during peak hours. An AutoVots system without public transport would still remove 23% of the cars used today at peak hours. However, overall vehicle-kilometres travelled during peak periods would increase in comparison to today. For the TaxiBot with high-capacity public transport scenario, this increase is relatively low (9%). For the AutoVot car sharing without high capacity public transport scenario, the increase is significant (103%). While the former remains manageable, the latter would not be. This suggests that where congestion is an issue, travellers should be encouraged to travel within the same vehicle as others.

Small automated buses operating along dedicated routes, rather than taxis that can go anywhere, would have significant technical advantages which enables them to be deployed quicker. The following quote from Luca Guala of the Italian consulting firm Mobility Thinktank summarises this idea[39]:

> *"Why minibuses and not taxis? Firstly, because it is much simpler to teach a robot to follow a fixed route, rather than teach it to go anywhere the passengers want to go. Such a system is already operational in Rotterdam and it works well, but it has one drawback: the tracks are segregated and they represent an ugly severance in the urban tissue.*
>
> *But if the vehicles are allowed to run with cars cyclists and pedestrians, a public transport route can be "adapted" with unobtrusive measures to accept driverless vehicles, and the people sharing the road will quickly learn to live with them. The main problem here was not technical, as legal."*
>
> Luca Guala, Mobility Thinktank

4.7.3 Gradual integration into existing urban areas

Typically, traditional bus services for medium sized towns and cities are focussed around a town centre. It might be possible to catch a bus from a residential area to the town centre. This involves waiting at the stop a certain period of time (the length of which depends on the service frequency, but could typically be around 10-15 minutes in urban areas). The bus then follows a route to the town centre which might not be direct and can be quite circuitous. If you wish to go to a destination other than the town centre that is not along the route, then you need to change services at the town centre, which adds significantly to the journey time and inconvenience.

[39] http://www.humantransit.org/2014/11/luca-guala-driverless-buses-will-be-more-transformative-than-driverless-taxis.html

Consider introducing a fleet of automated minibuses along a route. The route could be mapped in detail, and special arrangements could be put into place to manage road works, obstructions, junctions and crossings (junctions and crossings are discussed in more detail later in this report). Communications equipment could be installed along the corridor to enable the vehicle to see beyond its sensors.

Figure 26: Small automated buses (Left – Navya Arma, Right – Easymile EZ10) [Source: http://navya.tech/?lang=en#gallery-en, http://easymile.com/demonstration-senboku-japan/]

It is possible that due to decreased operating cost from the absence of a driver it becomes economically viable to service the route with more vehicles than would be used with traditional public transport. It might then be possible to operate a service more akin to a personal rapid transit network and offer a more demand responsive service. For example, buses could be waiting for passengers, rather than the other way around. The passenger could input their destination, and the vehicle could bypass certain stops and take a more direct route. Buses could serve sparsely populated areas only when needed, rather than on a set timetable.

This model could then evolve and grow. Public transport services would no longer be limited to their existing routes, but could route along other public transport corridors (or any street that was adequately mapped and certified). The network could then evolve to offer a town wide public transport solution, which combines the efficiency and low passenger cost of the bus operating model with the flexibility and service level of the taxi operating model.

4.7.4 Existing PRT solutions – segregated infrastructure

In the past, the above type of personal or group rapid transit solutions have been reliant on dedicated infrastructure. Such infrastructure has clear benefits for public transport vehicles in terms of journey time reliability and simplifies the operating environment, but can be costly both financially and environmentally. The sensing capability, processing power and intelligence of Automated Control Systems (ACSs) in the vehicles is enabling them to mix with either general traffic or with pedestrians, and as such, it may be beneficial to investigate fully automated public transport solutions that are not reliant on dedicated infrastructure, and as such could be rolled out far more widely. Segregation of automated public transport vehicles should be considered on a case-by-case basis.

Fully automated public transport solutions have been with us for some time. In the UK, the Heathrow POD entered full service on 7th May 2011 and continually transports passengers between Heathrow Terminal 5 and the business car park.

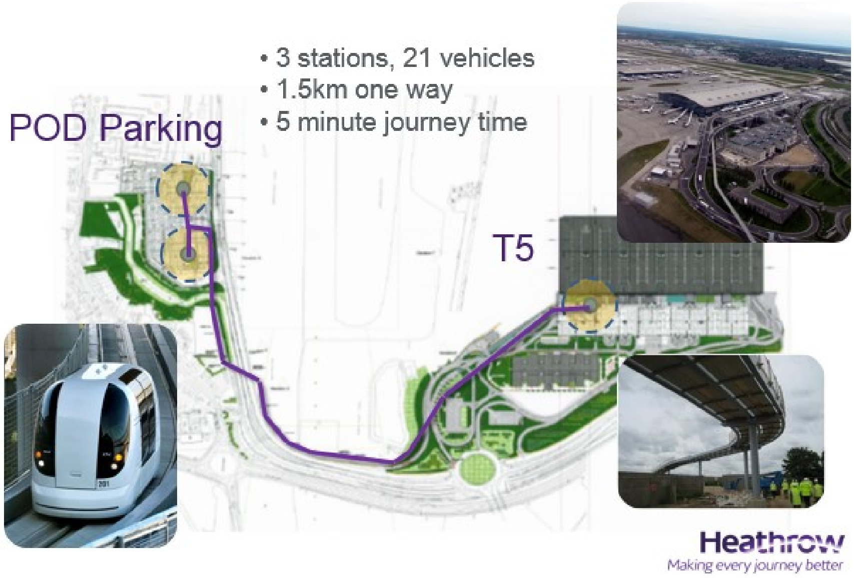

Figure 27: The Heathrow POD Route (source: Heathrow POD presentation)

As described by the operators, the POD is an environmentally sustainable, low energy, low noise and zero emission system. Other examples of public transport systems which involve automated road-based vehicles include:

- An automated people mover connecting the Rotterdam metro station Kralingse Zoom with the Rivium business park in the neighbouring new town of Capelle aan den Ijssel, which has been in operation since 1999 and is operated by 2getthere. Over 2,500 people use the system daily.[40]
- The Masdar Personalised Rapid Transit (PRT) system opened to the general public on November 28, 2010, with 13 pod/cars transporting passengers along an 800m route. The system was an initial trial of a system which was originally planned to be much larger with 80 stations and thousands of vehicles, but financial constraints limited the project to just the trial system close to the Masdar Institute of Science and Technology.[41]

Existing PRT solutions have a proven safety, environmental and passenger service record, and may be appropriate for further applications particularly where a fully segregated solution is possible or desirable. The Heathrow POD, at least in a private campus setting, offers evidence of a favourable business case and this could be taken into consideration by local authorities and developers. According to the POD operators, in terms of infrastructure cost it compares favourably with other public transport options such as light rail.

[40] http://www.2getthere.eu/projects/rivium-grt/
[41] http://www.2getthere.eu/projects/masdar-prt/

Figure 28: Automated public transport vehicles already in use (with high degree of segregation) at Heathrow Terminal 5 [source: http://www.ultraglobalprt.com/photos-videos/]

Grade separated infrastructure, such as that used for the Heathrow Pod shown above, could be an effective way for automated public transport vehicles to penetrate highly built up areas such as large, busy rail stations, where the number of complex variables make otherwise make the introduction of automated vehicles extremely challenging.

Existing busway infrastructure already offers the segregation that would make automation relatively simple.

Figure 29: Existing busway infrastructure could be an early opportunity for automation [source: https://en.wikipedia.org/wiki/Cambridgeshire_Guided_Busway]

4.7.5 Privately owned vehicles as automated taxis

There is a possibility that privately-owned vehicles, which would otherwise be parked when not used by the owners, could be released into a fleet of vehicles that can be used by members of the public. This has been discussed for several years on CAV forums, and is included by Teslo CEO Elon Musk within the latest Tesla Masterplan[42]:

> *"You will also be able to add your car to the Tesla shared fleet just by tapping a button on the Tesla phone app and have it generate income for you while you're at work or on vacation, significantly offsetting and at times potentially exceeding the monthly loan or lease cost. This dramatically lowers the true cost of ownership to the point where almost anyone could own a Tesla. Since most cars are only in use by their owner for 5% to 10% of the day, the fundamental economic utility of a true self-driving car is likely to be several times that of a car which is not."*
>
> Master Plan, Part Deux, Elon Musk, CEO, Tesla

Such a system, which leverages the advantages of the sharing economy, could greatly increase the supply of automated taxis on the road network in much the same way that Airbnb has increased the availability of short term residential accommodation. However, such a solution requires CAVs to be able to drive empty within urban areas in mixed traffic, which may be some years away.

4.7.6 New Developments

When planning new developments, or redeveloping existing urban areas, consideration could be given to the opportunities presented by automated public transport vehicles. For example, there may be advantages for designing for automated public transport rather than conventional bus services. Conventional buses may continue to operate on main roads, whilst smaller automated vehicles could provide the last mile leg of the journey, penetrating narrower residential streets or into the heart of business parks.

4.7.7 Infrastructure Requirements

There are several issues that need consideration for the implementation of automated demand responsive transport. Pick-up and drop-off areas must be carefully considered. Potential safety and congestion issues could arise if automated vehicles are permitted to pick-up and drop-off passengers anywhere. Provisions could be made for pick-up/drop-off areas based on pedestrian/traffic density, type of development, type of road, and the availability of space. For example, in quiet, spacious areas, vehicles may be permitted to pick-up and drop-off in an ad-hoc manner; however, in busier central areas, designated pick-up/drop-off bays may need to be created. Areas such as outside shopping centres, train stations, hospitals, and other busy areas would benefit from designated areas. Consideration for where these pick-up/drop-off zones should be located, and how big they need to be, should be considered for new areas of development. In conjunction with defining areas where CAVs can pick-up/drop-off passengers, areas of operation must also be defined.

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[42] https://www.tesla.com/en_GB/blog/master-plan-part-deux

Pedestrian areas could be an early use case for such vehicles, which could enable vehicles to penetrate right into the heart of shopping areas or other pedestrian environments. The Transport Systems Catapult has been developing vehicles that can operate within pedestrian areas of Milton Keynes as part of the LUTZ Pathfinder project, and the report, '*Pods on Pavement'*, was published by the TSC in March, 2016. Within the report, infrastructure issues relating to the pod trials were discussed. One issue is potential undue wear and breaking of pavement surfaces because pavement based vehicles. Since loaded vehicles are significantly heavier than any individual person/cyclist, they have the potential for causing damage to the pavement over and above that of normal footfall. The controlled interaction of different types of traffic is another potential issue. Different types of interactions between pods and other road users such as pedestrians (including wheel chair users, pedestrians with push chairs, etc), cyclists, mobility scooters, and regular vehicular traffic that needs to cross pedestrian areas occasionally (for example service vehicles) need to be considered. Also, consideration should be given to the need of the vehicle to make reasonable progress. Researchers at the University of Leeds found that most people would prefer CAVs to be operating within clearly marked lanes[43].

In terms of maintenance and operations, it is highly likely that a control centre will be needed as part of the day-to-day operation of an automated fleet of vehicles. The control centre would be responsible for managing the vehicles, including moving vehicles to match demand (which could be an automated process), arranging maintenance and cleaning, and responding to incidents. Control centres could be located remotely, or be combined with service centres (similar to bus depots). Control centres would need to have adequate communications infrastructure to support the monitoring and control of CAVs. CAVs may need communications capabilities for transmitting video and/or audio feeds to enable a CAV occupant to talk to someone at the control centre. CAV's may need a 'call for help' button if the occupants find themselves in a broken down or blocked vehicle, or to report any issue with the service. Service centres would be responsible for charging vehicles and performing basic maintenance and cleaning. Finally, as demand will fluctuate throughout the day, underutilised vehicles will be present at times throughout the day. Consideration should be given for a safe area where these vehicles can park and maybe charge themselves whilst waiting for customers.

4.7.8 Summary

27. In more built up areas, where road space is limited, authorities may wish to take steps to encourage automated public transport vehicles with multiple occupants to avoid exacerbating congestion. This would also help reduce emissions and energy use.
28. New developments could consider the opportunities associated with using automated public transport vehicles.
29. Consider location and size of pick-up/drop-off zones for automated public transport vehicles when designing urban areas.
30. Consider segregation of automated public transport vehicles when appropriate.

[43] https://www.theguardian.com/sustainable-business/2016/sep/09/machine-smarts-how-will-pedestrians-negotiate-with-driverless-cars

4.8 Crossings and Junctions

Crossings and junctions are a key part of the road network. This section discusses the issues associated with CAVs at junctions and crossings, and potential strategies for addressing them.

4.8.1 Pedestrian Crossings

Pedestrian crossings are perhaps one of the most challenging everyday aspects of operating a CAV in an urban area. The pedestrians are not a compliant part of a system who can be directed and controlled and will exercise free will which will be experienced as a random and chaotic variable to the automated system. Unlike many of the potential obstructions on motorways which are quite rare but still need to be addressed, pedestrians are vulnerable and will be frequently and routinely encountered by urban CAVs yet offer many behavioural and detection challenges. This is described in an article by Colin Sowman (Debunking the driverless delusion - ITS International, Oct. 2016):[44]

> *"Also relevant are the figures obtained by the UK's Institute of Advanced Motorists which show that despite the potentially fatal consequences, almost half of pedestrians knocked down by a vehicle did not take enough care before stepping into the road. If pedestrians and cyclists know vehicles (ADAS or driverless) will not hit them, they will walk or cycle across roads at will which could bring city-centre traffic to a near standstill. While the increased safety is to be welcomed, additional measures or legislation will be needed to control pedestrians cyclists in order to keep the traffic flowing."*
>
> Colin Sowman

This is a form of automation bias. The thresholds of expectation may move so that by trial and error people begin to step out in front of moving vehicles that are moving at greater speeds with much less physical clearance than before. This may be accelerated when coupled with the fact that people won't need to worry about the social side upsetting an empty running vehicle by forcing it to slow down or stop. There is also the malicious aspect to defeat any cautious strategy which is put in place:

> *"By simply walking out in front of a driverless vehicle, braking sharply ahead of it or placing cones across a road, criminals could divert a driverless vehicle to hijack it, steal the cargo or rob the passengers. This is particularly the case where the 'driver' cannot assume control."*

From mischievous teenagers looking for a prank to impress their friends through to people with more malevolent intentions, knowing when to stop whilst keeping vehicle occupants secure could present a challenge for CAV operations.

C-ITS solutions are emerging now which may offer significant steps forward with the pedestrian detection challenge for controlled crossings, as referenced in a press release by Neavia Technologies[45]:

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[44] http://www.itsinternational.com/categories/utc/features/the-downside-of-driverless-vehicles/
[45] http://www.neavia.com/2016-11-neavia-unveils-worlds-first-v2x-pedestrian-warning-solution/?lang=en

> "…vehicles equipped with V2X technology can automatically receive alerts when pedestrians are crossing or about to cross a road. This represents a significant step forwards for road safety: In many situations, pedestrians are not visible by to car drivers. They can be hidden due to the road configuration, or by other vehicles. They can also be less visible in case of fog, or under poor lighting conditions. In those situations vehicles' ADAS systems (Advanced Driver Assistance Systems) are less relevant, or reacting extremely late."

The main concern for these approaches is their potential for inconsistency, as they are being offered to bolster the vehicle's own performance rather like ADAS does for a human driver. If they are to be relied upon then they need to be designed with this in mind so that the vehicle's systems place the same level of reliance on the infrastructure support each and every time a crossing is approached. This mean that both the pedestrian detection and the communication mechanism need to meet agreed minimum performance standards rather than taking the current approach of: 'it will help when it can.'

Infrastructure adaptation could lower the risks on dedicated crossings. Informal crossing on arbitrary sections of road will still incur risks from sensing limitations, but these could be mitigated by improving public understanding and updating the Highway Code and laws in respect of these technological limitations. In the same way that it is accepted that you do not have a right to roam on railways, rather it is a form of trespass, some consideration to obstructing traffic flow by being in the road may have to be given on the grounds of both safety and disruption.

Three forms of crossing are considered; fully signal controlled, Zebra crossings and to general uncontrolled crossing which can take place almost anywhere.

Zebra crossings

Zebra crossing could present a challenge to CAVs. One issue, particularly from a CAV point of view, is understanding who has right of way. Vehicles are required to stop when pedestrians step on to the zebra crossing, however pedestrians should wait for an approaching vehicle to slow significantly (to make sure it can and does stop) before crossing. If these rules were applied literally by all parties, then either pedestrians would never be able to cross on busy roads or there would be a stalemate whilst one waits for the other. It is left to the judgement of the pedestrian (who may be a child with limited ability to judge) as to whether a vehicle has enough time and distance to comfortably stop without hitting them on the crossing.

The technically simplest approach to zebra crossings may be to replace them with signalled crossings which are far more deterministic and do more to discourage people just stepping out or even running out on to the crossing. However, it may not be practical or cost effective to remove or upgrade them.

One question is how to discourage pedestrians stepping out in front of a CAV at the wrong moment. It should be borne in mind that any CAV pedestrian sensing system no matter how good may fail at some point so prevention is better than cure in that pedestrians need to wait for the vehicle to demonstrate that it is going to stop for them in particular, or in sufficient and for sufficient time for them to cross. This could be achieved via an external visual/audible human machine interface on the vehicle, or via a similar system which is post mounted on the crossing. There would need to be some conformance in the approach such that pedestrian become accustomed to one clear message rather than a range of solutions (for example different vehicles using different graphics / sounds). For this reason the crossing infrastructure (post mounted) approach has some appeal, but it adds the additional complexity of requiring a failsafe mechanism for cars which do not announce themselves to the crossing. This would likely employ a similar mechanism to signalled junctions where the vehicle must always know when it is encountering a crossing and expect a handshake before continuing though at full speed. Further confusion may result from the mixture of legacy vehicles with CAVs. Just because every approaching CAV has announced it will stop does not mean a manually driven vehicle's driver has noticed a pedestrian is on the crossing. A proceed to cross with caution message may help with this as a reminder to crossers that they should make the final visual check themselves. More thought may need to be given to people being led by guide dogs.

The other part of the equation is pedestrian detection. This could be done from post mounted infrastructure, or from the approaching vehicle. The issue with a vehicle based strategy alone is that it may fail to detect pedestrians under some conditions, not least due to the limited field of view from the vehicle. A technically superior solution would be to do the detection from the infrastructure with vehicle based detection also used as a final resort in case a pedestrian runs out onto the crossing. Time-of-flight and infrared camera pedestrian detecting sensors are being developed for infrastructure mounting and these offer the reliably and robustness to weather and light conditions and well as field of view when appropriately mounted. Also, infrastructure based vehicle detection is already common practice. This makes having the crossing itself as the one source of the truth to perform the crossing arbitration seem an attractive option for an assured system.

Signalled Crossings

This covers Puffing, Pelican and Toucan crossings and their other derivatives. The approaching CAV would need to be sure of the signal status. Pedestrians may not wait for the correct signal phase and may cross late or early and run out to try to make it in time before cars pull away. Electric vehicles will not have the running engine revving or restarting as an early indicator that vehicles are starting to move off. For these reasons, much of the same logic is needed as for Zebra crossings where pedestrian will attempt to cross at will so it can be treated as a traffic signalled Zebra crossing. It is also suggested that the flashing amber phase is removed entirely since with pedestrian detection the red phase can be extended as longer if require. Having the ambiguity of the flashing amber phase only provides opportunity for problems leading to the vehicle needing to detect itself if there are any stragglers on the crossing which may be prone to error. Different vehicle would potentially have different implementations of this and it could be better left to the infrastructure with wider and dedicated sensing capabilities to make the final judgement to proceed if clear.

Uncontrolled Crossing

This presents the most challenging in that as with other infrastructure crossings, there are no guarantees the vehicle will sense every pedestrian every time. However the lack of infrastructure means it will either have to be handled from the vehicle or pedestrians are restricted from crossing away from designated places. That would imply a Jaywalking law which, from experiences from the USA, are often not adhered to or rigorously enforced. There is also the issue of public acceptance of such a law as pedestrians hold on to the notion of a right to cross anywhere except motorways and railways. This is perhaps one area where a drop in absolute safety (human to automated) may have to be conceded and might be addressed by a public education programme to raise awareness. The real danger is one of automation bias because in the vast majority of cases the automated system may perform as well or better than a human driver. This will nurture a false sense of security and the general public may start to assume an unrealistic margin of safety when attempting to cross. As the threshold is pushed with regard to stopping distance and running across roads, the risk of being hit due to a sensing and perception insufficiency will increase. Ultimately the pedestrians hold their fate in their own hands, but it may help to clarify the legal position away from the unrealistic position of expecting a software based system to detect pedestrians 100% of the time under all conditions, and strongly encourage the use of official crossings where they are provided.

4.8.2 Junctions

The junctions considered within this report include signal controlled, priority controlled, level crossings, with further consideration to what happens when a signalled junction has a fault failure.

Signalled Junctions

Starting with signalled junctions, the main concern is being able to detect the signal status both in time to stop for a red signal and also to not pass through a red signal at any time. The means of detection falls into two categories. The first is to use machine vision (normally CMOS cameras) to see the signal lamps in the same way as human drivers do. The second is to use the more direct method of V2I radio communications.

It is suggested by the authors that whilst is may at first appear to be convenient strategy to use vehicle mounted cameras to view existing traffic signals, it is conceptually flawed and problematic. Humans are capable of vision fixation and tracking of a visual target through a variety of means such as owl type head and body movement, as well as saccadic eye motion. The human eye also has variable aperture and focus so together can cope with resolving the detail from very complex scenes in challenging light conditions. Beyond this humans are capable of contextual perception so that for instance a green balloon held in front of a signal by a pedestrian waiting to cross would not be mistaken for a green traffic signal. The windscreen mounted cameras used on vehicles are fixed focus and aperture and cannot be directed. This is primarily for keeping cost, complexity and reliability at their optimums, but adding variable focus, aperture, and a mechanic servo means of directing the camera would tend to add more than it solves. All of these things take time to actuate and you need to know in advance where to direct the area of interest to which requires perception. Notwithstanding that these technical challenges could perhaps be solved with time, it is still an inferior and unnecessarily challenging strategy. The signal status is known to the traffic signal controller. The notion of converting this to an analogue optical signal then attempting to convert that back to a digital signal using optical sensing from a moving vehicle under any possible light condition does not hold up to reason when the outcome of that process is preventing life threatening crashes from occurring.

Various V2I schemes are emerging around the world (DSRC) to make traffic signal phasing available wirelessly to vehicles. However, this information is being transmitted as a driver advisory, not as a mission critical piece of information. This exchange of information needs to be developed to be failsafe. The source of the information is already failsafe but how it is propagated may not be and further analysis and development may be needed. In addition, the communication needs to be allowed to fail (be absent when expected) without harmful consequences to the approaching vehicle. For this to be allowed, the vehicle needs to know when to expect a transmission. For this to work the vehicle system need to know where it is against a digital map to realise that it is approaching a signalled junction and needs to have the real-time signal status for the junction so that it can stop the vehicle if this information cannot be obtained for whatever reason. This places a high level of dependence on digital map integrity and on the performance of localisation. Both have to be *'correct'* commensurate with the risk of *running* a red light. This is also true where cameras are used since a missed signal needs to be noticed in its absence.

Signal junctions in which signals have failed

Some consideration to signal failure is given also. Currently signalling systems cannot fail in such a way as they show a green light to two of more conflicting directions. This is covered by TR 2500 and BS EN 12675:2001. Generally Red signals are redundant and a red failure results in all signals being extinguished to avoid ambiguity. Some other countries use a flash red-amber sequence to indicate a fault. Problems may still arise for partial failures and CAVs where the CAV may not be aware of green/amber failures. This is another benefit to using a wireless radio V2I approach where rather than trying to infer a fault, the exact status can be transmitted to vehicles so that they may proceed with caution.

Priority controlled junctions

Priority controlled junctions are another significant challenge for which it is difficult to offer a general strategy beyond that of proceeding with caution. A move towards wirelessly managed junctions, possibly signalled junctions would assist with resolving the technical challenge, but may be impractical in practise.

Again, communications equipment may assist CAVs. Rather than relying solely on the suite of sensors within the vehicle, they could link to mast-mounted cameras around the junction to get a much better view of traffic approaching from various directions.

4.8.3 Summary

31. Crossings and junctions are expected to be challenging for CAVs. Infrastructure mounted sensors and V2I communications to CAVs could assist, but should be developed to deliver robust, mission-critical failsafe information rather than advisory information.
32. Signal controlled junctions and crossings are expected to be easier to handle by CAVs than other forms of junction and crossing. Highway authorities could consider moving to signals where practical, or along routes where CAVs are expected to operate.

4.9 Impact on Bridge Structures

The following concern was raised from a representative from Highways England.
"Highly automated road-based freight vehicles have the potential for platooning, which involves two or more vehicles connected with vehicle to-vehicle communication, allowing them to effectively operate as a single unit. Reducing the headway between vehicles allows them to benefit from reduced aerodynamic drag and increased fuel efficiency. Platooning could also has the potential to free more road space and improve traffic flow.

A particular concern would be for traffic loading on long span bridges, which tend to be of critical importance to the strategic road network. Current loading models used for the design of bridges assume that there will be a "dilution" of heavy vehicles by light vans and cars. Platooning could potentially invalidate these assumptions by creating large blocks consisting only of heavy vehicles. It would be necessary to consider whether the load models used in the design of structures (particularly for long span bridges) would be adequate for this change. If not, it may require an extensive programme of assessment of the country's long span bridge stock and depending on the results of the assessment, potentially strengthening of bridges.

Other aspects of loading on bridges that would need to be reviewed would include collision on supports, collision on decks, centrifugal forces on curved decks and braking forces. All of which may require assessment of the current standards to this change and potentially an extensive programme of assessment and strengthening of the country's bridge stock.

These issues could potentially take a long time (years) and substantial financial outlay to resolve (£ millions)."

The TSC agree that this warrants further investigation, and could form part of Highways England's upcoming trial into platooning. It is suggested that a first step would be to consider, through modelling, the potential of platooning to significantly alter the density of HGVs, and then to consider to what extent particular bridges might be sensitive to this change.

4.9.1 Summary

33. Platooning of heavy goods vehicles could change the loading on long span bridges. It would be necessary to consider whether this impact will be significant and whether the load models used in the design of structures is will be adequate with this change.

5 Summary of Recommendations

5.1 Introduction

The following chapter summarises the recommendations / suggestions highlighted in Chapter 4, and maps the key stakeholders that could be critical in implementing them, and some of the guidance and planning documents which could take them into account:

Item	Category	Summary	Key Stakeholders	Key Documents
1.	Traffic Management Measures	Consider methods to communicate areas that are affected by roadworks to CAVs to act as failsafe for vehicle systems.	➢ AV mapping providers ➢ Highway Authorities ➢ Road work operators ➢ Telecoms providers ➢ CAV tech developers ➢ DfT	➢ Traffic Management Act ➢ Traffic Signs Manual ➢ DMRB
2.	Traffic Management Measures	A methodology could be determined to establish the extent to which traffic management sites are CAV compliant, and these could be marked on the digital map. Consideration could be given to style and machine readability of markings, barriers, cones and general traffic control measures.	➢ AV mapping providers ➢ Highway Authorities ➢ Road work operators ➢ Telecoms providers ➢ CAV tech developers ➢ DfT	➢ Traffic Management Act ➢ Traffic Signs Manual ➢ DMRB
3.	Traffic Management Measures	Detailed information could be provided on road layout and expected vehicle behaviour for traffic management measures (e.g. stop at traffic signal, merge in turn, use contraflow lane etc.)	➢ AV mapping providers ➢ Highway Authorities ➢ Road work operators ➢ Telecoms providers ➢ CAV tech developers ➢ DfT ➢ Elgin (or similar)	➢ Traffic Management Act ➢ Traffic Signs Manual ➢ DMRB
4.	Traffic Management Measures	Real-time updates to detail when traffic management measures are beginning and ending.	➢ AV mapping providers ➢ Highway Authorities ➢ Road work operators ➢ Telecoms providers ➢ CAV tech developers ➢ DfT ➢ Elgin (or similar)	➢ Traffic Management Act ➢ Traffic Signs Manual ➢ DMRB

5.	Traffic Management Measures	New roads and major junctions could be connected to electricity and fibre-optic/copper where practicable.	➢ Highway authorities ➢ DfT	➢ DMRB
6.	Traffic Management Measures	Develop "CAV Compliant First Respondents" procedure for road incidents.	➢ Highway Authorities ➢ Road work operators ➢ CAV tech developers ➢ DfT ➢ Emergency Services	➢ Traffic Management Act ➢ Traffic Signs Manual ➢ 'Management of Incidents' – College of Policing ➢ 'CLEAR' – Highways England
7.	Traffic Management Measures	Develop a warning sign/signal that can used to warn CAVs of danger ahead.	➢ Highway Authorities ➢ Road work operators ➢ CAV tech developers ➢ DfT ➢ Emergency Services ➢ AV mapping providers	➢ Traffic Management Act ➢ Traffic Signs Manual ➢ 'Management of Incidents' – College of Policing ➢ 'CLEAR' – Highways England
8.	Traffic Management Measures	Research into how humans can direct CAVs with hand signals, which could be used by incident first response teams.	➢ CAV tech developers ➢ DfT ➢ Emergency Services	➢ Traffic Management Act ➢ Traffic Signs Manual
9.	Traffic Management Measures	Undertake review of Traffic Signs Manual. Phasing out traffic management measures which are difficult for CAVs to interpret.	➢ CAV tech developers ➢ DfT	➢ Traffic Management Act ➢ Traffic Signs Manual
10.	Traffic Management Measures	Investigate procedures to ensure hardware is standardised and well maintained, particularly if used as failsafe for CAV systems.	➢ Highway Authorities ➢ DfT	➢ DMRB ➢ Traffic Management Act ➢ Traffic Signs Manual
11.	Road signs and markings	Consider ongoing global research into appropriate road markings for CAVs	➢ Highway Authorities ➢ DfT ➢ CAV Tech Developers	➢ DMRB ➢ Traffic Signs Manual ➢ Manual for Streets

12.	Road signs and markings	With road markings forming the 'rails of automated steering systems', the procedures for maintenance of road markings may need to be improved and funding increased.	➢ Highway Authorities ➢ DfT	➢ DMRB ➢ Traffic Signs Manual ➢ Manual for Streets
13.	Road signs and markings	With some systems relying on visually detecting and interpreting traffic signs it could be important to ensure that they are maintained to a high standard in terms of cleanliness, clarity, deterioration, non-ambiguous positioning, and obscuration.	➢ Highway Authorities ➢ DfT	➢ DMRB ➢ Traffic Signs Manual ➢ Manual for Streets
14.	Road signs and markings	It may be necessary to work with relevant stakeholders to ensure unadopted roads are checked and certified for use by CAVs.	➢ Highway Authorities ➢ DfT ➢ Developers ➢ Car park operators ➢ Private land owners	➢ Manual for Streets ➢ Traffic Signs Manual
15.	Safe harbour zones	Consider appropriate frequency and design of safe harbour areas on high speed roads for various types of CAVs.	➢ Highway Authorities ➢ DfT	➢ DMRB ➢ Manual for Streets
16.	Safe harbour zones	Consider measures to avoid the misuse of such areas	➢ Highway Authorities ➢ DfT ➢ Police	➢ DMRB ➢ Manual for Streets
17.	Safe harbour zones / Traffic Management Measures	Consider temporary safe harbour areas prior to traffic management measures.	➢ Highway Authorities ➢ DfT ➢ Police	➢ Traffic Management Act ➢ Traffic Signs Manual ➢ 'Management of Incidents' – College of Policing ➢ 'CLEAR' – Highways England

18.	Role of service stations	Consider the use of service stations as safe harbour zones for CAVs, and the necessary adaptions to achieve this.	➢ Service Station Operators ➢ Highway Authorities ➢ DfT	➢ DMRB ➢ Traffic Signs Manual
19.	Role of service stations	Consider service stations as public transport hubs that enable passengers to interchange to automated motorway taxis.	➢ Service Station Operators ➢ Highway Authorities ➢ DfT	➢ DMRB ➢ Manual for Streets ➢ Local Transport Plans
20.	Role of service stations	Consider enabling service stations to inductively charge CAVs with minimal human intervention.	➢ Service Station Operators ➢ Highway Authorities ➢ DfT	
21.	Car parking	Operators could begin to consider the potential benefits of CAV valet parking solutions. Benefits include those to the customer and to the operator in terms of parking density.	➢ Car Park Operators ➢ Highway Authorities ➢ DfT ➢ Transport Planners	➢ NPPF ➢ Manual for Streets ➢ Local Transport Plans ➢ Transport evidence bases in plan making and decision taking
22.	Car parking	Production of a guidance document for car park operators should be considered.	➢ DfT ➢ CAV tech developers	➢ Traffic Signs Manual ➢ Manual for Streets
23.	Car parking	Consider creation of CAV parking test areas in the UK for developers to use for testing.	➢ Car Park Operators ➢ Highway Authorities ➢ DfT	
24.	Car parking	Consider options for allowing CAVs to pass oncoming vehicles where on street parking limits flow to one direction. Options might include removal of parking or conversion of the street to one-way operation.	➢ Highway Authorities ➢ DfT ➢ Transport Planners	➢ Traffic Signs Manual ➢ Manual for Streets
25.	Car parking	When planning future land use consider that, over time, parking demand could	➢ Highway Authorities ➢ DfT	➢ NPPF ➢ Manual for Streets ➢ Local Transport Plans

		decrease and space currently used for parking could be available for other uses.	➢ Transport / Urban Planners ➢ Car park operators ➢ Developers	➢ Transport evidence bases in plan making and decision taking
26.	Car parking	Architects and planners could adopt a flexible approach to car park design and planning, acknowledging the potential for less demand in future decades.	➢ Highway Authorities ➢ DfT ➢ Transport / Urban Planners ➢ Car park operators ➢ Developers / architects	➢ NPPF ➢ Manual for Streets ➢ Local Transport Plans ➢ Transport evidence bases in plan making and decision taking
27.	Small Automated Demand Responsive Public Transport Vehicles	In more built up areas, where road space is limited, authorities may wish to take steps to encourage automated public transport vehicles with multiple occupants to avoid exacerbating congestion. This would also help reduce emissions and energy use.	➢ Highway Authorities ➢ DfT ➢ Transport Planners	➢ Manual for Streets ➢ Local Transport Plans ➢ Transport evidence bases in plan making and decision taking
28.	Small Automated Demand Responsive Public Transport Vehicles	New developments could consider the opportunities associated with using automated public transport vehicles.	➢ Highway Authorities ➢ DfT ➢ Transport / Urban Planners ➢ Developers / architects	➢ Manual for Streets ➢ Local Transport Plans ➢ Transport evidence bases in plan making and decision taking
29.	Small Automated Demand Responsive Public Transport Vehicles	Consider location and size of pick-up/drop-off zones for automated public transport vehicles when designing urban areas.	➢ Highway Authorities ➢ DfT ➢ Transport / Urban Planners ➢ Developers / architects	➢ Manual for Streets ➢ Local Transport Plans ➢ Transport evidence bases in plan making and decision taking
30.	Small Automated Demand Responsive Public Transport Vehicles	Consider segregation of automated public transport vehicles when appropriate.	➢ Highway Authorities ➢ DfT ➢ Transport Planners	➢ Manual for Streets

31.	Crossings and junctions	Crossings and junctions are expected to be challenging for CAVs. Infrastructure mounted sensors and V2I communications could assist, but should be developed to deliver robust, mission-critical failsafe information rather than advisory information.	➢ Highway Authorities ➢ DfT ➢ CAV Tech Developers ➢ ITS Providers	➢ DMRB ➢ Manual for Streets
32.	Crossings and junctions	Signal controlled junctions and crossings are expected to be easier to handle by CAVs than other forms of junction and crossing. Highway authorities could consider moving to signals where practical, or along routes where CAVs are expected to operate.	➢ Highway Authorities ➢ DfT ➢ Transport Planners	➢ DMRB ➢ Manual for Streets
33.	Impact on Bridge Structures	Platooning of heavy goods vehicles could change the loading on long span bridges. It would be necessary to consider whether this impact will be significant and whether the load models used in the design of structures is will be adequate with this change.	➢ Highway Authorities ➢ DfT ➢ Freight operators ➢ Transport Planners	➢ DMRB

Table 2: List of recommended changes/areas for further investigation

5.2 Document Changes

The following sections will provide a summary of the way that planning and guidance materials could be adapted to assist in the introduction of CAVs. The findings from Chapter 4, along with the stakeholder interviews, were used to generate the list of changes.

Commercial sensitivities and the fast-moving nature of CAV technologies means that there are a large number of uncertainties relating to CAVs and the infrastructure required to assist in their introduction onto UK roads. Furthermore, any recommendations need to take into account the deployment context of CAVs (e.g. whether the vehicles are effectively operating autonomously, or as part of a wider managed service). Due to these significant levels of uncertainty and different operating contexts, the recommendations have been presented at a high level. Many of the recommendations focus on identifying areas that require further consideration/investigation before specific changes can be recommended.

6 Conclusions

This document has explored and identified several key areas and policy documents that require further consideration regarding the introduction of CAVs. The document has highlighted key areas of importance to aid in the introduction of CAVs to the UK road network.

The project involved engaging with a number of key planning policy and documentation stakeholders. This consultation identified concern amongst stakeholders regarding what the introduction of CAVs will mean for infrastructure and their planning guidance policies and documents.

The project has produced two key outputs. Firstly, a table, that summarises points for various infrastructure types. The table identified over 30 action points which fall into the following themes:

- Traffic management measures;
- Road markings and signage;
- Safe harbour zones;
- Role of service stations;
- Car parking;
- Small Automated Demand Responsive Public Transport Vehicles;
- Crossings and junctions;
- Impact on Bridge Structures.

Secondly, it is recommended that a guidance umbrella document is produced. The document would aid all authorities to consider CAVs in future document iterations. The umbrella document would explain the expected use of CAVs, key benefits, and the infrastructure aspects required to support their introduction.

Enabling vehicles to operate with limited or no human input is a fundamental change to the transport system. This study focused on the extent to which the planning, design, appraisal, implementation, and operation of road infrastructure may need to change as a result of CAVs. The number of unknowns relating to CAVs and their development make this area one that is constantly changing. It is crucial that authorities continue to monitor the areas identified in this report, and to work closely with infrastructure providers, CAV technology developers and other stakeholders to understand their requirements.

Appendix A – Example Changes to NPPF

The following extract is from Chapter 4, Promoting Sustainable Transport, from the NPPF. The underlined sections in bold have been modified to demonstrate how the NPPF may be required to be updated to assist the authorities in planning their infrastructure for the introduction of CAVs.

The changes aim to educate the reader about the potential benefits of CAV technologies, and encourage the owners of the NPPF to consider the operation of CAVs in their work. The changes refer to:

- Communicating with research groups and telecommunications providers;
- Use of new technologies to increase accessibility and sustainability;
- Consideration for telecommunications infrastructure and safe harbour areas;
- Use of non-traditional public transport systems, such as on-demand vehicles;
- Changing ownership models of cars.

The changes / additions are highlighted with bold, underlined italic text below.

> *"29. Transport policies have an important role to play in facilitating sustainable development but also in contributing to wider sustainability and health objectives. Smarter use of technologies can reduce the need to travel.* ***New technologies might be capable of offering transport modes that are more sustainable and accessible than traditionally used options****. The transport system needs to be balanced in favour of sustainable transport modes, giving people a real choice about how they travel. However, the Government recognises that different policies and measures will be required in different communities and opportunities to maximise sustainable transport solutions will vary from urban to rural areas.*
>
> *30. Encouragement should be given to solutions which support reductions in greenhouse gas emissions and reduce congestion****, whilst maximising accessibility****. In preparing Local Plans, local planning authorities should therefore support a pattern of development which, where reasonable to do so, facilitates the use of sustainable modes of transport.*
>
> *31. Local authorities should work with neighbouring authorities, transport* ***providers and other stakeholders such as research organisations and telecommunications providers*** *to develop strategies for the provision of viable infrastructure necessary to support sustainable development, including large scale facilities such as rail freight interchanges, roadside facilities for motorists or transport investment necessary to support strategies for the growth of ports, airports or other major generators of travel demand in their areas. The primary function of roadside facilities for motorists should be to support the safety and welfare of the road user.* This might include communications infrastructure so that vehicles can realise the numerous potential benefits of connectivity services. It might also include safe harbour areas, so that vehicles can stop safely on high speed roads, which may become increasingly important for automated vehicles.
>
> *32. All developments that generate significant amounts of movement should be supported by a Transport Statement or Transport Assessment. Plans and decisions should take account of whether:*
>
> > *● the opportunities for sustainable transport modes have been taken up depending on the nature and location of the site, to reduce the need for major transport infrastructure;*

*● **<u>the potential of new technology has been considered;</u>***

● safe and suitable access to the site can be achieved for all people; and

● improvements can be undertaken within the transport network that cost effectively limit the significant impacts of the development. Development should only be prevented or refused on transport grounds where the residual cumulative impacts of development are severe.

33. When planning for ports, airports and airfields that are not subject to a separate national policy statement, plans should take account of their growth and role in serving business, leisure, training and emergency service needs. Plans should take account of this Framework as well as the principles set out in the relevant national policy statements and the Government Framework for UK Aviation.

34. Plans and decisions should ensure developments that generate significant movement are located where the need to travel will be minimised and the use of sustainable transport modes can be maximised. ***<u>This might include non-traditional solutions, such as the use of automated demand responsive public transport vehicles.</u>*** *However this needs to take account of policies set out elsewhere in this Framework, particularly in rural areas.*

35. Plans should protect and exploit opportunities for the use of sustainable transport modes for the movement of goods or people. Therefore, developments should be located and designed where practical to

● accommodate the efficient delivery of goods and supplies;

● give priority to pedestrian and cycle movements, and have access to high quality public transport facilities;

● create safe and secure layouts which minimise conflicts between traffic and cyclists or pedestrians, avoiding street clutter and where appropriate establishing home zones;

● incorporate facilities for charging plug-in and other ultra-low emission vehicles;

*● **<u>examine the potential needs of connected and automated vehicles; and</u>***

● consider the needs of people with disabilities by all modes of transport.

36. A key tool to facilitate this will be a Travel Plan. All developments which generate significant amounts of movement should be required to provide a Travel Plan.

37. Planning policies should aim for a balance of land uses within their area so that people can be encouraged to minimise journey lengths for employment, shopping, leisure, education and other activities.

38. For larger scale residential developments in particular, planning policies should promote a mix of uses in order to provide opportunities to undertake day-to-day activities including work on site. Where practical, particularly within large-scale developments, key facilities such as primary schools and local shops should be located within walking distance of most properties.

39. If setting local parking standards for residential and non-residential development, local planning authorities should take into account:

● the accessibility of the development;

● the type, mix and use of development;

● the availability of and opportunities for public transport;

● local car ownership levels;

● the changing nature of car ownership, and trend towards shared vehicle usage and automated vehicles; and

● an overall need to reduce the use of high-emission vehicles.

40. Local authorities should seek to improve the quality of parking in town centres so that it is convenient, safe and secure, including appropriate provision for motorcycles. They should set appropriate parking charges that do not undermine the vitality of town centres. Parking enforcement should be proportionate.

41. Local planning authorities should identify and protect, where there is robust evidence, sites and routes which could be critical in developing infrastructure to widen transport choice.

5. Supporting high quality communications infrastructure

42. Advanced, high quality communications infrastructure is essential for sustainable economic growth. The development of high speed broadband technology and other communications networks also plays a vital role in enhancing the provision of local community facilities and services.

Communications coverage is becoming increasingly important not just for populated areas, but also for highway corridors, as road users start to utilise vehicle connectivity benefits.

43. In preparing Local Plans, local planning authorities should support the expansion of electronic communications networks, including telecommunications and high speed broadband. They should aim to keep the numbers of radio and telecommunications masts and the sites for such installations to a minimum consistent with the efficient operation of the network. Existing masts, buildings and other structures should be used, unless the need for a new site has been justified. Where new sites are required, equipment should be sympathetically designed and camouflaged where appropriate.

44. Local planning authorities should not impose a ban on new telecommunications development in certain areas, impose blanket Article 4 directions over a wide area or a wide range of telecommunications development or insist on minimum distances between new telecommunications development and existing development. They should ensure that:

● they have evidence to demonstrate that telecommunications infrastructure will not cause significant and irremediable interference with other electrical equipment, air traffic services or instrumentation operated in the national interest; and

● they have considered the possibility of the construction of new buildings or other structures interfering with broadcast and telecommunications services.

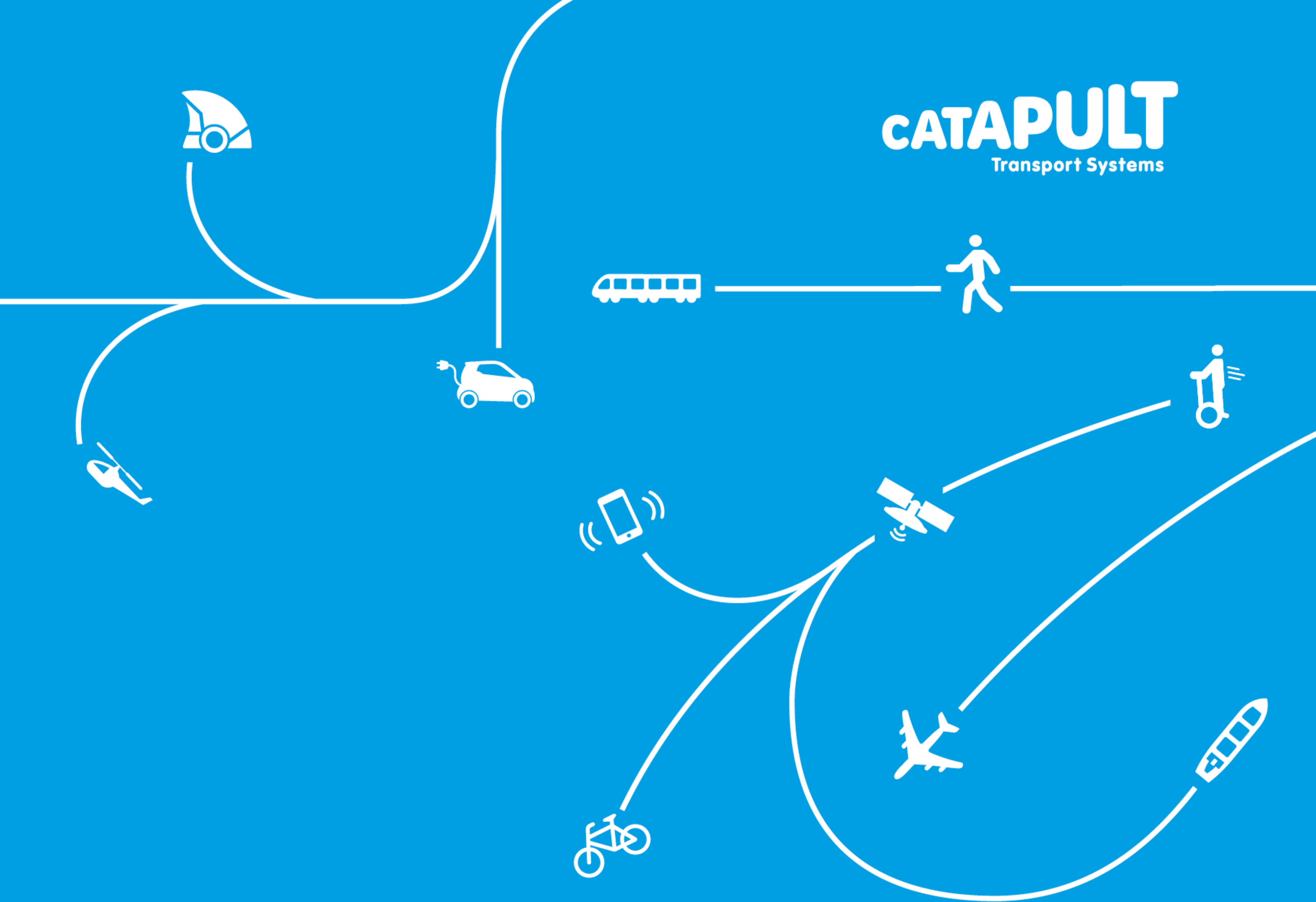
45. Applications for telecommunications development (including for prior approval under Part 24 of the General Permitted Development Order) should be supported by the necessary evidence to justify the proposed development. This should include:

● the outcome of consultations with organisations with an interest in the proposed development, in particular with the relevant body where a mast is to be installed near a school or college or within a statutory safeguarding zone surrounding an aerodrome or technical site; and

● for an addition to an existing mast or base station, a statement that self certifies that the cumulative exposure, when operational, will not exceed International Commission on non-ionising radiation protection guidelines; or

● for a new mast or base station, evidence that the applicant has explored the possibility of erecting antennas on an existing building, mast or other structure and a statement that self-certifies that, when operational, International Commission guidelines will be met.

46. Local planning authorities must determine applications on planning grounds. They should not seek to prevent competition between different operators, question the need for the telecommunications system, or determine health safeguards if the proposal meets International Commission guidelines for public exposure."



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