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Readiness of the road network for connected and autonomous vehicles

Dr Charles Johnson

CAS

April 2017

The Royal Automobile Club Foundation for Motoring Ltd is a transport policy and research organisation which explores the economic, mobility, safety and environmental issues relating to roads and their users. The Foundation publishes independent and authoritative research with which it promotes informed debate and advocates policy in the interest of the responsible motorist.

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About the Author

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Acknowledgements

My thanks to my colleagues Chris Lloyd, for his editing and re-writing, Steven Sobolewski, for his literature searches, and Michael Corcoran for sorting out the formatting of my text and references.

Disclaimer

This report has been prepared for the RAC Foundation by Dr Charles Johnson (CAS). Any errors or omissions are the author's sole responsibility. The report content reflects the views of the author and not necessarily those of the RAC Foundation.

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Foreword

With autonomous vehicle technology attracting so much attention, and cars already being seen on London's roads in self-driving mode (albeit with a driver on hand ready to re-take control), we thought it timely to start thinking about the implications of this technology for drivers and for the roads we drive on.

This report focuses on the road infrastructure. One conclusion is unsurprising – that it is early days and, thus far, impossible to predict accurately how the roll-out of automation will happen. In countries which already have extensive road networks, like the UK, it is hard to see segregation for autonomous vehicles being a viable proposition in all but a few extremely limited applications (e.g. for shuttle services running on private premises). Similarly, any system requiring extensive roadside communications technology could prove prohibitively expensive, as well as raising issues of international interoperability.

Perhaps less obvious, though, is the conclusion that autonomy could require enhanced standards of road maintenance, to ensure that driverless vehicles are able to 'sense' the road environment accurately – the delineation of the carriageway, lane markings, traffic signs and signals etc. This conclusion sits awkwardly with the current state of our roads, with the government's own estimates for the maintenance backlog running into many billions. One thing is for certain – whatever trajectory emerges for the driverless car, we won't be travelling very far unless we have an adequately maintained network to drive on.

Steve Gooding

Steve Gooding

Director, RAC Foundation

Connected and Autonomous Vehicles (CAVs) appear to have reached – or be near – the **peak** of inflated expectations

Very little research has been done on the **difficult** questions relating to the **readiness** of the **road infrastructure**

Little attention has yet been paid to what **impact** different CAV strategies will have on the **condition of road infrastructure**, and its maintenance, renewal and configuration requirements

CAVS and road infrastructure exist in a **reciprocal** relationship. How this relationship will develop is **uncertain**

Governments need to decide on the level of automation that will be **supported** and how this will be **implemented**

CAVS are unlikely to develop to their **fullest** potential without **advanced planning** by transport policymakers, planners and engineers to ensure infrastructure change is **adequate**

Experience in **other sectors** – for example aviation and rail – suggests that as **greater** use is made of sophisticated technology, maintenance costs **increase** significantly

As local road condition continues to **deteriorate** there is need for significant **investment** in road maintenance

1. Introduction

How ready is the road network for connected and autonomous vehicles (CAVs)?

Research conducted by CAS investigated the answer to this question, guided by three further ones:

1. What are the implications of CAVs for road infrastructure?
2. How ready is the current road infrastructure for CAVs?
3. What challenges arise from the gaps identified between the current road infrastructure and the infrastructure required by CAVs?

By establishing what we mean by CAVs, providing a framework for conducting a structured analysis of the relevant evidence, and then using this framework to explore each of these questions in detail, this paper presents the findings and conclusions of that research.

Since CAVs are at a relatively early stage of development, more is unknown than known about how their widespread use might be brought about – and there is significant disagreement amongst their proponents about when a significant proportion of vehicles on the road network will be CAVs, ranging from a few years from now to 40 years or more. For example, Somers & Weeratunga(2015) suggest that significant penetration of the car market by autonomous vehicles will not happen till 2040. Bradley Stertz, corporate communications manager for Audi, has been reported as saying a fully automated vehicle with no driver will not be available for 30 years (Hill, 2016). Indeed, Gilbert Gagnaire, co-founder of autonomous shuttle company EasyMile, has stated that "If you ask me whether one day some will be level five (i.e. fully autonomous), I think it's not going to happen. Never" (Miller, 2016). This report does not attempt to go into detail about the timing of transition.

1.1 Connected and autonomous vehicles

At the outset, it is important to distinguish between *connected* vehicles and *autonomous* vehicles. The DfT's 2015 'The Pathway to Driverless Cars' report defines autonomous vehicles (AVs) as a vehicle that "is designed to be capable of safely completing journeys without the need for a driver in all normally encountered traffic, road and weather conditions" (DfT, 2015).

Connected Vehicles on the other hand, are those that are fitted with communications devices that provide information to either the driver or the vehicle, allowing them to collaborate with other road users and parts of the road infrastructure. Three types are typically identified as:

1. V2V (vehicle-to-vehicle)
2. V2I (vehicle-to-infrastructure or vice versa, I2V)
3. V2D (vehicle-to-device or vice versa, D2V). A device (for example, a mobile phone) may be operated by a driver, an employer or a transport authority (for example, Highways England). V2D includes such possibilities as V2P (vehicles to pedestrians' mobile devices and V2C (vehicles to the cloud)

Connectivity can be achieved through a number of technologies (wireless, the Internet, local area networks, GPS, etc.) and can provide information about many aspects of the road environment, aiding the vehicle in navigating and progressing through it.

Some proponents of AVs (for example, Google) are aiming to develop vehicles which are genuinely autonomous, but most are looking at combinations of connected and automated technologies, otherwise known as *connected and autonomous vehicles*, in order to produce safe and reliable vehicles.

For the most part, this paper refers to CAVs because connected and autonomous vehicles have similar implications for infrastructure change and design but where they have different implications they are treated separately.

1.2 Competing visions of the future

It would seem that two competing strategies are being pursued by both public- and private-sector champions of, and investors in, CAVs:

1. fully autonomous, independent, self-driving vehicles that can work with the existing infrastructure, or a simplified version thereof; and
2. CAVs which are only fully autonomous where the road infrastructure permits, and switch between levels of autonomy – for example, vehicles that travel in convoy but only on suitable roads.

There are many variants of these two basic approaches, for example: all CAVs being physically separated from other traffic and other road users; physical separation in some areas but not in others; and CAVs retaining non-CAV capability so the driver can take over in mixed traffic or urban areas. Neither of the two strategies appears to be taking fully into account either the condition, maintenance, renewal and configuration of road infrastructure, or the associated capital investment, operating costs, risks to other road users and time delays.

For policymakers, there is a more important conceptual choice to be made than is offered by these strategies, which will have significant implications for decisions about the required road infrastructure. The choice is between:

- the *vehicle* being in charge, with either no role for a human driver, or the driver only taking over control in limited circumstances; and
- the *human driver* being in charge, with automation there to aid performance in the event of emergency or in degraded situations.

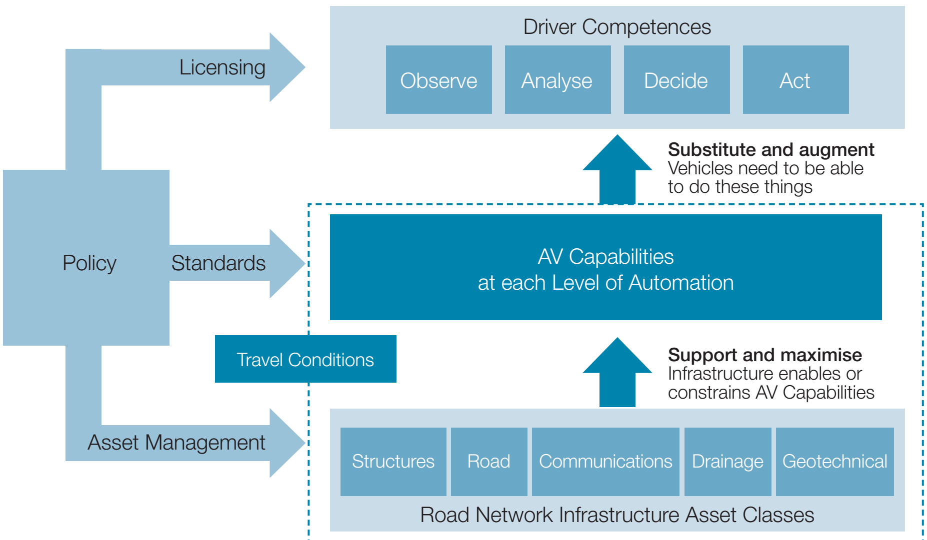
The Organisation for Economic Co-operation and Development and the International Transport Forum (OECD & ITF, 2015a) describe these two options as, respectively, the ‘everything somewhere’ and the ‘something everywhere’ options, because the first requires separation of CAVs from non-CAVs (so one has the ‘everything’ of automation, but in some places only) and the second requires a progression from where we are now to higher levels of automation but not necessarily fully autonomous vehicles (meaning that one has ‘something’ of automation in vehicles that are allowed to mix in with all traffic). The ‘something everywhere’ strategy is generally embraced by traditional car manufacturers and is well captured by the levels of automation.

Whether either, both, neither, or a compromise between these strategies is backed by government policy will have a significant bearing on the rate at which CAVs penetrate the UK market – and, correspondingly, on the scale of safety, social and economic benefits that this could secure.

2. An Analytical Framework

Faced with a large volume of research (including a wide range of online publications and blogs), the first task was to develop a framework suitable for identifying relevant evidence and structuring its subsequent analysis. This framework is presented in Figure 2.1.

Figure 2.1: Analytical framework



Source: Author's own

The framework is built around the notion of a reciprocal relationship between CAVs and the infrastructure of the road network, in which the following assumptions are made:

- To utilise roads safely in all conditions, CAVs must be able to substitute for (or augment) human driver competences and behaviours.
- Infrastructure must enable and support CAVs to make safe progress on the roads (i.e. controlling risks to other road users, especially vulnerable ones such as pedestrians and cyclists).
- The ability of CAVs to substitute wholly or in part for the competences of the driver is affected by (1) the level of automation, (2) the nature and condition of the infrastructure (e.g. the road type), and (3) the travel conditions (e.g. weather and traffic volumes).
- Policy needs to be co-ordinated across three areas: connected and autonomous technology, the licensing of drivers, and the provision of suitable infrastructure.

Though a number of slightly different definitions of levels of automation are in use, the six defined by the Society of Automotive Engineers (SAE) International in their *Automated Driving: levels of driving automation are defined in new SAE International Standard J3016* (summarised in SAE International, 2014) are the most commonly referenced, and it is these levels which are considered in the framework, and will be referred to hereafter.

The levels (along with simplified descriptions of each) are outlined in Table 2.1.

Table 2.1: Society of Automotive Engineers (SAE) levels of automation

Level	Name	Description
0	No automation	Human driver completely controls the vehicle.
1	Driver assistance	Individual activities which assist steering or acceleration/deceleration are partially automated.
2	Partial automation	Several, simultaneous activities which assist steering or acceleration/deceleration are partially automated.
3	Conditional automation	In certain driving scenarios, all dynamic, non-strategic, driving activities (e.g. vehicle control but not route choice) are automated but human is expected to intervene when requested.
4	High automation	In certain driving scenarios, all dynamic driving activities are automated and vehicle can cope with human not intervening if and when requested.
5	Full automation	Always and everywhere, all dynamic driving activities are automated with no need for human intervention.

Source: adapted from SAE International (2014), modified

3. Implications of CAVs for Road Infrastructure

3.1 Road sharing

The greatest demands on road infrastructure would arise from level 5 vehicles sharing the road with level 0–2 vehicles (i.e. fully autonomous vehicles sharing roads with vehicles with partial or no automation). This would require road networks capable of accommodating or restricting the full range of interactions between mixed traffic. Glancy et al. (2015: 99) argue that it “may make sense to designate portions of roadways (designated lanes) or entirely segregated roads” for CAVs, although they also note this would be very expensive and raise many planning issues.

The design of the road network would also need to take into account the increased risk to other road users arising from a more complex road environment. Unless CAVs are to operate on completely separate, dedicated infrastructure, other road users will need to be separated from or educated in and adapt to the behaviour of CAVs in different ways. As the ETSC notes (2016b), “the appearance of AVs in traffic may also change … mobility patterns to the extent of changing behaviour of vulnerable road users themselves – the simple act of crossing the road may also be transformed.” This is because changes to the infrastructure may result in vulnerable road users having to change their assumptions about how traffic systems work (Le Vine & Polak, 2014). Road systems enabled for CAVs may need to be simplified, for example by reducing the volume of visual cues given by traffic signs, road markings and so on to human drivers, so as to limit the interaction of CAVs (even low-speed electric pods) with other road users and to limit their access to the highways (see, for example, Shladover & Bishop, 2015: 3).

In general, there will be a need to define acceptable behaviour of CAVs in relation to other road users, for example in understanding their different braking characteristics and the fact that they may be able to drive with greatly reduced headways which cannot be copied by human drivers (Habibovic et al., 2014). Not only would this place increased demands on all road users, including both licensed and learner drivers who are driving level 0–2 vehicles, but it would also require that all the existing infrastructure necessary for such vehicles be retained alongside any new infrastructure required by level 4 and 5 vehicles (Glancy et al., 2015).

The sharing of roads between level 5 vehicles and level 3–4 vehicles would represent a less demanding scenario, because there is less diversity between them, but it nevertheless introduces additional complexities. Whether vehicles leapfrog the lower levels and go straight to level 5 (as Google predicts), or there is a slower, phased process of integration (as seems more likely in the UK), the change management challenges to standards setters, driver licensing authorities, asset owners and managers will be intense although the former, more sudden, scenario will be more demanding; clearly, policymakers will need to decide early which of these two strategies to support. For example:

- Fully autonomous, self-driving vehicles may be allowed to operate in this mode only on certain roads, may be separated from other traffic, or may be partially integrated and have to be returned to level 0–2 driving when not on dedicated roads or in dedicated lanes (OECD & ITF, 2015b). This could also, as the European Road Transport Research Advisory Council (ERTRAC) suggests, include having to switch to level 0–2 if the road conditions demanded it – for example, if heavy snow is lying, or if there is flooding or resurfacing works, or to avoid situations with frequent stops, such as road intersections (ERTRAC, 2015).
- Convoys, or platoons as a string of vehicles travelling nose-to-tail are sometimes known, may share the same road with non-convoy vehicles, or they may have separate lanes or roads dedicated to them, which raises the question of whether all vehicles in a dedicated lane or road have to be in convoy, or if independent vehicles can share the road – or indeed use other lanes on the same road.
- Road maintenance would have a significant bearing on the ability to deliver the surface, connectivity, drainage and signage quality needed to support the introduction of level 4 or 5 CAV, whether through integration with level 0–2 vehicles, separation or both (EuroRAP & Euro NCAP, 2011). Prioritisation methods used by Highways England (and by its counterparts in Wales, Scotland and Northern Ireland) and by county councils to select between and schedule maintenance, repair, renewal and enhancement schemes would need to align with government policy on CAVs. These organisations would need to create and consolidate long-term asset management strategies, and amend decision criteria and performance objectives to suit the new world of CAV-populated roads.

- Careful thought will need to be given to the issue of driving in degraded conditions – including those arising from severe weather, road accidents, and emergency situations caused by accidents, breakdowns or trespass. One problematic situation would be the case of roadworks in which lane markings may disappear or be replaced by cones, or where traffic is guided through the roadworks by staff using hand signals (Ng & Lin, 2016).

The crucial issue is whether there is going to be a staged, managed progression through these levels, or whether the Google vision of skipping the intermediate levels (3 and 4) and moving straight to fully self-driving vehicles is possible, desirable and likely to happen. This will depend not only on the availability of suitable technology but also on whether or not drivers, communities and voters are willing to accept the implications of this transition. Yeomans (2014: 8) has noted a preference in the UK population for persisting with 'normal' non-autonomous cars, partly because a high percentage of car owners (up to 65%) enjoy driving – as demonstrated, for example, by the fact that there are about half a million vintage cars using the UK's roads. A number of other reasons have been identified, including concerns about the safety and security of autonomous vehicles and the desire to remain in control of the vehicle (Clark, Parkhurst and Ricci, 2016).

3.2 Road infrastructure asset classes

The UK Office of Rail and Road (ORR) views the road network as being made up of five main classes of assets (ORR, 2016). These are indicated in Figure 2.1 and summarised in Table 3.1. The reliability and availability of each of these could have implications for each level of automation.

Table 3.1: Road infrastructure asset classes

Asset class	Description examples
Structures	This includes buildings, bridges, lighting, crash barriers, underpasses and tunnels.
Roads	This includes anything relating directly to the road, such as the surface, the condition of the surface, road markings, width of the lanes, road layout, pavements, speed bumps, curbs, parking areas and cycle paths.
Communications	This refers to any assets that support communication to the driver and/or the vehicle. Included are both static communications (such as, road signs, traffic lights, road markings and other signage) and electronic communications (such as wireless or mobile networks, and all forms of connectivity and data transfer). There is some overlap here, with road markings being part of both the road surface and communication.
Drainage	This comprises culverts, channels and gullies needed for keeping roads clear of surface water and minimising flooding.
Geotechnical features	This includes road geometry, embankments and cuttings.

Source: Adapted from ORR (2016)

Decisions about the infrastructure implications of introducing CAVs are, of course, informed by what vehicles need to be able to do to substitute for drivers. The research literature is clear that communication is the most important aspect of CAV capability, and thus the most important asset class, because it is associated with all forms of connectivity, the big data management requirements of connectivity, and cyber security. Communications are where new development is most needed.

CAVs will become more reliant on having the correct communication channels in place the further they advance through the levels of automation.

For example, the One-North CAV test bed in Singapore is a set of public roads that have been assigned as a CAV trial area. In preparation for the trial, Dedicated Short-Range Communication (DSRC) beacons have been installed at several junctions to provide information including traffic conditions, traffic light signals and the positions and locations of traffic incidents or roadworks (Land Transport Authority of Singapore, 2016). These beacons have been installed to enhance the capabilities of CAVs in the trial.

There are a myriad of other implications for road infrastructure, some requiring detailed highways engineering expertise to articulate. For example:

- A fully automated transport system can be expected to reduce the need for sharp braking and could be operated on a surface with only a modest level of friction. Potentially this could allow current Polished Stone Values and texture depth requirements to be relaxed (Dunford et al., 2014).
- Lamb (2015) notes that because CAVs will run consistently in the same lane positions there will be greater wear and tear in the wheel tracks, and that either the road area beneath the tracks will need to be strengthened, or maintenance repairs will need to be more frequent.
- The lane-keeping assist systems which are now a feature of certain cars are reliant on road markings to accurately determine the boundaries of lanes, implying that these markings therefore need to be maintained in good condition for the system to work.

With regard to the latter, as levels of automation increase, the need for the maintenance of these kinds of markings may become less important, as communication networks start to provide all the information required for the CAV to know where it is. However, contrary arguments have been put forward by a number of commentators. For example, Weeratunga and Somers (2015) argue that static communications will need to be maintained to a much higher standard than currently. In any case, until level 5 CAVs are commonplace, maintenance standards will need to be updated and aligned as systems evolve.

Experience in other transport sectors, such as aviation, suggests that the approach to maintenance has to change as automation increases, and maintenance costs typically increase – partly because the infrastructure has to be better maintained for safety reasons, and partly because it becomes more sophisticated, meaning that the maintenance workforce has to be more skilled and, therefore, charges more for its services (Bernhardt & Erbe, 2002).

3.3 Driver competences

One of the main concerns about vehicle automation is that although it is possible to develop automated systems which can deal with predictable situations much more effectively than humans can, they are not necessarily as good at dealing with what Ng (2016) terms 'corner cases', in other words "all the strange things that happen once per 10,000 or 100,000 miles of driving" (Ng, 2016).

It follows that a key consideration in the introduction of CAVs is determining what core competences of safe and responsible drivers CAVs need to substitute.

As indicated in Figure 2.1, research points towards four main areas of human driver competence:

1. **observation**: this includes detection, examination, recognition, and attending to and monitoring of both moving and stationary objects both on and around the road;
2. **analysis** and the development of situational awareness: this includes understanding the significance of detected objects, and interpreting and anticipating their actions;
3. **decision-making**: this includes identifying options, determining the risks and benefits associated with these options, and choosing amongst the options; and
4. **taking effective physical actions**: this includes the basic actions that can be taken in vehicles: starting and stopping (including parking), accelerating, decelerating and changing direction.

All four levels of 'cognitive performance' required by AVs (observation, analysis, decision-making and action-taking) will have implications for infrastructure, since the last three will all be dependent on the accuracy of the first, and the possibility of reducing the need for safety features will need to be balanced with the necessity of retaining sufficient redundancy in systems to reduce safety risk as much as possible (Litman, 2017).However, the precise implications for infrastructure will be determined by the policy decisions that are made.

It is important to note that most current trials of CAVs are being carried out in constrained scenarios, including:

1. Highly mapped test areas or constrained environments such as:

   - GATEway (Greenwich Automated Transport Environment), London – a small, highly mapped area, testing automated shuttles and other vehicles (gateway-project.org.uk). To allow the GATEway shuttle trials to take place, Olympian Way will undergo changes including new markings to explain where shuttles will operate. From November 2016, shuttles will run in a dedicated lane, alongside a separate shared pedestrian and cycle lane.
   - Lutz Pathfinder, Milton Keynes – a small area of pedestrianised streets, with low-speed automated pods (ts.catapult.org.uk/current-projects/self-driving-pods).
   - Google car, California – testing on freeways only between 2009 and 2012 (https://waymo.com/ontheroad/)

2. Simulated driving environments, separate from live traffic:

    - Horiba Mira City Circuit, Nuneaton (www.horiba-mira.com/our-services/intelligent-mobility)
    - Mcity, Ann Arbor Michigan, USA (www.mtc.umich.edu/test-facility)

3. Environments with a focus on connectivity of infrastructure, not automation:

    - UK CITE (Connected Intelligent Transport Environment) – 40 miles of connected road in Coventry and Warwickshire (http://www2.warwick.ac.uk/newsandevents/pressreleases/wmg_part_of_1637_million_uk_cite_project_to_create_one_of_the_world146s_most_advanced_environments_for_connected_and_autonomous_driving1/)

3.4 Additional influences

3.4.1 Travel conditions

There are four main types of travel condition – optimal, normal, degraded and emergency. Either fully autonomous vehicles will be able to operate safely in all of these, or the human driver will need to take over some level of control in certain circumstances. Which of these travel conditions applies depends on various factors, including:

- road surface condition;
- road type (rural, urban, etc.);
- weather;
- time of day;
- availability of infrastructure (especially communications assets); and
- congestion.

3.4.2 Available level of automation

The extent to which traffic comprises mixed levels of CAVs is a key issue. Depending on the rate of market penetration of CAVs, there is a possibility of roads being shared by vehicles at all levels of automation – a situation which would lead to the retention of all current safety infrastructure and the possible addition of new infrastructure required by automated systems.

Furthermore, several commentators have envisaged situations where vehicles and drivers will swap regularly between different levels of automation depending on the circumstances, for example type of road, road conditions (Shladover & Bishop, 2015: 4).

3.5 Vehicle capabilities

It follows from what has already been discussed that CAV capabilities need to be understood as a set of requirements derived from: (1) an understanding of the current availability and reliability of road infrastructure assets; (2) the human driver competences that need to be substituted given the infrastructure; and (3) an understanding of prevailing travel conditions.

3.6 Policy options arising

From the previous sections (3.1 to 3.5), a number of policy options arise, namely:

- whether or not to separate CAV from non-CAV traffic;
- whether to regulate the minimum level of automation that a vehicle must have, and the speed of transition to the minimum level;
- the degree of personal choice which should be allowed to drivers regarding whether to turn off some or all of the automated features on their vehicle; and
- the degree to which CAV systems are standardised or harmonised across countries.

Policy implications are revisited in more detail in section 5.1.

4. Readiness of the Current Infrastructure

Now that the infrastructure changes that might result from the introduction of CAVs have been explored, the readiness of current infrastructure can be examined. This examination draws upon the research literature, expert interviews, and a review of changes that have already been made as part of the various trials of CAV worldwide.

The information has been organised by the five main classes of road infrastructure assets, as outlined in the Analytical Framework in Figure 2.1, followed by a series of examples considering these assets together, and the impacts of CAV technology in practice.

4.1 Communications

4.1.1 Roadside communication

A range of roadside communication devices are being considered to supplement vehicle-based devices, sensors and vehicle-to-vehicle communications. These include communication beacons located at strategic positions which may replace traffic signals, provide vehicle position information and serve a range of other functions (for example siting emissions sensors). Desouza (2016) notes that there is likely to be a problem with the loss of certain sorts of communication signals (for connectivity) in urban side streets, which could increase the need for a variety of devices and also raise the corresponding cost. As noted in section 3.1, communication is largely regarded as the single most important challenge for introducing CAVs.

4.1.2 Fibre optic networks

Much of the literature on communications deals with radio and wireless communications (Gill et al., 2015) including apps which may, for example, be used to convey information about traffic and road conditions en route. By way of contrast, the trial being run at Mcity in Ann Arbor, Michigan, is using fibre optic cable to connect many of the roadside communication devices. However, they note that this is an expensive option which may be limited to certain urban environments, since even the trial involves hundreds of miles of cable (Vock, 2016). A recently installed fibre optic network of 30 kilometres in Reading cost £4.94 million (Jackson, 2016).

4.1.3 Construction plans

One of the most important features of current CAVs is that they require very detailed maps of the routes being travelled. Filing construction plans which will affect the road network well in advance will be crucial for planning and mapping activities (Rodoulis, 2014; SWOV, 2015), even though infrastructure planning may be working on 30-year horizons (Gill et al., 2015).

Transport and urban planners need to be thinking now about the implications of introducing CAVs, and should work with system developers to decide on finding practicable solutions (Houses of Parliament POST, 2013; Vock, 2016). It is interesting to note that Main Roads Western Australia has been considering deploying digital communication units only at critical points with a poor safety record in order to reduce costs (Weeratunga & Somers, 2015). The cost to Western Australia is estimated at A$16.5 million–A$22 million (approximately £10 million–£14 million) for installing 550 units at key intersections, plus A$1 million (approximately £0.6 million) in annual maintenance costs.

4.1.4 Multiple traffic signals

One of the claims made for CAVs is that traffic signals could be replaced by other communication devices. However, vehicles which are running on existing infrastructure will need to be able to perceive and correctly interpret traffic signals.

One of the problems already encountered is that poor weather conditions interfere with many sensors that require line of sight (Glancy et al., 2015). For example, strong sunlight at low angles can severely disrupt the ability of CAVs to perceive traffic signal information (Ng & Lin, 2016). The suggestion has been made that multiple signals may be required to overcome this problem but in some circumstances even redundant arrays of multiple sensors may fail to provide adequate roadway data for CAVs (Levin, 2015).

4.1.5 Clarity of road markings, signals and signage

In a similar vein, a case has been made for static communication devices like road markings and road signs to be either of better quality than they are now or at least maintained in better condition (EuroRAP & Euro NCAP, 2011; Smith, 2016; Vock, 2016). There are already documented examples in the USA of trial CAVs coming to a standstill because of poor road markings (Louw, 2016).

4.1.6 Level of standardisation of signals and signage

Closely related to the need for better quality static communications is the need for standardisation. A recent study in the USA (Vock, 2016) found that there was little standardisation even of signals and signs which the researchers had supposed were common across states. Indeed, they found that there was little standardisation within states. The same is true across Europe (EuroRAP & Euro NCAP, 2011; Houses of Parliament POST, 2013) and is likely to cause significant problems for the perceptual abilities of CAVs.

4.1.7 Handling tolls

Many highways, bridges and tunnels around the world have tolls, and there has been a marked increase in the use of automatic tolls (Gill et al., 2015). They also raise the question, however, about how tolls will cope with platoons.

Automatic tolls usually register individual vehicles, but will they be able to register every vehicle in a long nose-to-tail platoon, and will they be able to detect whether there is a responsible human driver in the vehicle? It may prove necessary to change the equipment in both the tolls and in vehicles to cope with this (ASECAP, 2015).

4.2 Structures

4.2.1 Parking facilities

The size, use and distribution of parking facilities may need to change considerably as CAVs become common. Several authors have predicted that there might be a significant decrease in the need for some types of parking, such as residential parking, park-and-ride sites and shopping centre parking, because of a reduction in car ownership (Gill et al., 2015; Rodoulis, 2014). However, there may be an increased need for other sorts of parking, such as parking facilities for CAVs which are for hire. In the latter case it is anticipated that such parking facilities will be focused on certain areas such as transit hubs, like train stations. All this depends on another prediction coming to pass, namely that ownership of vehicles will decrease significantly and be replaced by the hiring of CAVs (Yeomans, 2014).

4.2.2 Fuelling and power distribution

In addition to parking facilities, CAVs for hire will also need to be able to refuel. One prediction is that fuelling stations will usually be co-located with parking facilities (Gill et al., 2015). This also raises the question as to whether driverless cars will be able to refuel themselves. One assumption is that eventually most CAVs will be electric vehicles (Gill et al., 2015). Where fuelling stations are co-located with parking facilities, this will mean providing the necessary power distribution infrastructure to deliver this solution.

4.2.3 Segregated infrastructure

Several of these scenarios suggest a need for the segregation of CAV from non-CAV traffic. This, in turn, suggests a need for the separation of CAV from non-CAV roads. One consequence of this separation might be an increased need for underpasses and bridges for at least two reasons. Firstly, separation of CAV roads from non-CAV roads might necessitate this in order to maintain separation. Secondly, ensuring the safety of other, vulnerable road users if existing static communications were to be removed might also necessitate the construction of additional underpasses and bridges to separate different kinds of road users. In a country like the UK, the expense of building such structures and the limited availability of land for separated infrastructure would almost certainly bring a halt to any schemes dependent on fully segregated infrastructure.

4.2.4 Street lighting

Ensuring that the visibility of road markings, signals and signs is suitable for CAVs to perform effectively may require improved street lighting, either through better illumination or more closely spaced lights (Shladover & Bishop, 2015: 31).

4.2.5 Roundabouts

It has been suggested that better communications, such as vehicle connectivity, will remove the need for many traditional static communication devices by allowing vehicles to track each other. This is expected to greatly increase traffic flow speeds at junctions. However, some control may still be advisable, and it has been suggested that roundabouts would be much better suited to CAVs and the integration of CAV and non-CAV and much more efficient than systems that work on the same principles as current traffic signals (Gill et al., 2015).

4.3 Roads

4.3.1 Maintenance

It has already been noted that AVs are likely to require road markings, signs and signals to be maintained to a much higher level than is currently the case. It is also possible that road surfaces, too, will need to be maintained to a higher standard. For example, a pothole in a traffic lane carrying vehicles in a platoon, where vehicles follow each other very closely, could be extremely dangerous, particularly at high speed.

4.3.2 Autonomy-enabled roads

A range of options has already been identified for autonomy-enabled roads. These include completely separated roads, dedicated lanes on existing lanes, and areas being designated as CAV-only. City centres are already being identified as possible CAV-only areas (Houses of Parliament POST, 2013). Indeed, O'Sullivan (2016) suggests that the Congestion Charging zone in London should become a CAV-only zone.

4.3.3 Road geometry

A number of suggestions have been made as to how use of space and costs could be minimised in the design of roads in the longer term (Rodoulis, 2014). For example, it might be possible to have narrower streets (possibly with wider kerbs and more cycle space) and tighter corner radii. Implementing this would be relatively straightforward with new roads, for example in new housing estates, but more problematic if it were to involve changes to existing roads.

However, it should be noted that such ‘road improvements’ would make such roads unsuitable for non-CAV traffic, as drivers of non-CAV vehicles would be unable cope with the reduced space and increased driving performance required. The risk of accidents and collisions would thus be greatly increased for non-CAV drivers. Making these kinds of changes to the infrastructure could add further weight to the argument for the need for the separation of CAV from non-CAV traffic. The alteration of existing urban landscapes to make way for CAV-enabled infrastructure may be too expensive and too unpopular (Lamb, 2015).

4.4 Geotechnical features

The introduction of platooning and convoys raises issues about traffic travelling at different speeds and how that might be handled (ETSC, 2016a). One option might be to reduce road gradients, for example by having more cuttings, embankments and tunnels. However, although this might be plausible – if unlikely – in the longer term when new roads are being designed and built, it is implausible that gradient reduction could be undertaken on a meaningful scale on the existing road network. There are, however, other ways in which differential speeds could be managed – for example by having additional, reserved overtaking lanes; by dissolving platoons at critical locations such as on steep gradients or at busy junctions (Bergenhem et al., 2010); or by putting in place rules governing how platoons are formed and what sorts of vehicles can form a particular platoon.

Road verges might also need to be better designed and better managed to ensure that sensory systems which depend on line of sight can work effectively. Poor management of verges could diminish both the observation of other vehicles and the identification of road verges where these are being used for vehicle positioning. So, for example, there may be need to better control of vegetation to ensure good visibility (although effective vehicle-to-vehicle connectivity would significantly mitigate this issue).

4.5 Drainage

It is uncertain how CAVs will perceive such things as surface water and flooding, even though the reactions of CAVs to such events as skidding and aquaplaning may be better than those of human drivers. Better design and improved maintenance of drainage is likely to be crucial. It is worth noting in this respect that the condition of 73% of the drainage assets (e.g. pipes and gullies) on the English strategic road network – which is the responsibility of the government-owned company Highways England – is currently unknown or uncertain (ORR, 2016).

4.6 Driving scenarios

The following are examples of how specific applications of CAV technology could have an impact on infrastructure changes, giving an idea of the level of analysis and planning that will be required to make them work in practice.

4.6.1 Platooning

Driving scenario

Cargo trucks hauling over a long distance, with platooning technology allowing more than one truck to be controlled in a convoy (level 3).

In this scenario we are only examining the vehicles on the motorway. The current motorway infrastructure is the initial setup. The lead vehicle could be controlled by a human driver or by an automated highway pilot system (level 3 or 4).

Implications

Policy decisions, particularly on the segregation of lanes for platoons, will have a great influence on what infrastructure is needed.

If a segregated lane policy were to be decided upon, then an additional lane would need to be created. This, of course, could be an existing lane which is reserved for platooned vehicles. Litman (2017: 10) argues that “Co-ordinated platooning is now technically feasible but not operational because many benefits require dedicated lanes.” Platoons will be limited by the slowest vehicle in the convoy, which raises more questions as to what happens if one platoon needs to overtake another, slower-moving platoon? Several other problems arise related to the speed of platoons. “How will vehicles with speed management systems operate in a fleet with unequipped vehicles – will the unequipped vehicles travel faster and continually overtake so that the speed management system is finally switched off by a dissatisfied driver?” (ETSC, 2016a).

Will a segregated lane need an additional overtaking lane? Alternatively, if the platoons are to operate in mixed traffic, how will other single vehicles be able to navigate around them?

In the USA and Australia, it is feasible to consider having platoons of ten or more trucks, as there are long stretches of flat and straight roads. However, as Edmund King, President of the Automobile Association, has noted (Quirke, 2016), British motorways have a high frequency of exits, and this may make platooning very difficult; how would other drivers exit safely if the platoon is in their way? A number of suggestions have been made for how this might be managed. Bergenhem et al. (2010) have suggested that this could be achieved by the ‘dissolving’ of platoons at critical locations such as busy junctions. Another approach is to limit the size of platoons. In the SARTRE project (Safe Road Trains for the Environment), the maximum length of platoons has been set at ten vehicles, but current research designs limit it to five vehicles (Chan et al., 2012). In the recent European Truck Platooning Challenge trial, the platoons were limited to three vehicles, all of the same vehicle type and capable of driving at the same speed.

Many media reports of this trial assume that platoons will consist of just three vehicles, but there arises the interesting issue of how such platoons could be kept separate on busy roads in the event that different platoons are travelling at different speeds. What road markings or communications systems are required by the trucks to stay in formation and safely follow the lead vehicle? Questions also arise about how platoons of mixed vehicles will assemble. Will there be a need for lorry parks where platoons can congregate (McKinnon, 2016) or would they assemble actively on the road (Bergenhem et al., 2010)? It is reported that platoons comprising a larger number of vehicles are going to be trialled on a quiet section of the M6 in Cumbria, which may test some of these concerns (BBC, 2016; Quirke, 2016).

4.6.2 Advanced emergency braking system – collision avoidance

Driving scenario

Two vehicles are travelling along a single-lane A-road at a safe distance from one another. The vehicle in front sees an obstruction in the road and stops suddenly. The vehicle behind needs to perform an emergency stop and is fitted with a collision avoidance braking and steering system, a level 2 autonomous system.

Implications

In this example the collision avoidance system should be able to function without any additional changes to the infrastructure.

A wide range of car manufacturers (e.g. Audi, BMW, Chrysler, Honda, Kia, Land Rover, Mercedes-Benz, Subaru, Toyota and Volvo) have made collision avoidance systems available on most of their models, and they are in use today. Even so it is still worthwhile considering what additional infrastructure could improve the performance and safety of these systems.

For example, assuming the vehicle needs to steer to avoid collision, is there sufficient space on the side of the road for a vehicle to make an emergency manoeuvre or to stop, and how will the vehicle recognise that this space is available and also safe to use? Similarly, will roads have ‘safe harbours’ for malfunctioning vehicles (Shladover & Bishop, 2015: 11) such as are being incorporated in the Drive Me project in Gothenburg? One of the potential advantages claimed for level 5 vehicles (for example, Sisson, 2016a, b) is that carriageways and roads could be made narrower, but how might that affect the scope for possible manoeuvres? Will any kerbs or barriers at the side of the road be visible to the system’s sensors?

There are also issues to do with blind spots in observation systems, and correct reading of lane markings and other signals, which may lead to decision conflict (ETSC, 2016a). What happens in a situation where the CAV is certain to crash if it does not change lane, but cannot change lane because this will endanger other vehicles or road users? Researchers, carmakers and automotive engineers are already working on algorithms to solve such ethical dilemmas, for example by minimising human injury or loss of life even if that means injuring or killing the driver of the vehicle (Knight, 2015).

4.6.3 Valet parking assist

Driving scenario

Parking, in a public parking area, a vehicle equipped with a valet parking system which allows it to automatically search a parking area for a free space and park in it without the driver being present.

In a current public parking area, a vehicle with a valet parking assist system can safely drive itself to a parking spot provided that it has a detailed map of the area.

Implications

The system is dependent on highly detailed maps of the parking area, but is it possible that all parking facilities will be accurately mapped and that these maps will be kept up to date – for example what happens if there is construction work going on in a car park? So, in areas where coverage is not possible this would need to be addressed with an appropriate communication system that can pass building details to the vehicle.

Parking crops up regularly as an issue in the envisaged world of level 5 fully autonomous vehicles (Adams, 2016). The need for garages and parking lots could be greatly reduced as CAVs become more common. It is estimated that in some US cities, up to one third of the land is devoted to parking (Rodoulis, 2014). If vehicle ownership were to reduce, and vehicle hire increase, where will all these hire vehicles be parked, even allowing for the prospect of greater vehicle utilisation? Will special parking facilities have to be built, perhaps on the outside of urban centres, or will AVs cruise around towns and cities waiting to be hired? Adams (2016) refers to this latter possibility as performing the ‘infinite-Uber-loop’. It is difficult to predict which way this might go. Much will depend on public attitudes to car ownership, changes in land use, and the appetite (or lack thereof) of local planning authorities for making such changes.

5. The Challenges Ahead

Having identified the types of infrastructure change that might result from the introduction of CAVs, and the readiness of the current infrastructure for CAVs, some key challenges arising from the gaps between these changes and current capabilities are now addressed.

5.1 Policy decisions

The most important influence on the need (or absence of need) for infrastructure change is the nature of the policy decisions that will be made, both nationally and internationally, on how CAVs will be accommodated and what form of vehicle autonomy will be supported. Many governments (e.g. USA, UK, China, Germany and Australia) are busy developing plans and guidelines for how the introduction of CAVs should take place, although much of this is concerned at the moment with the testing of CAV systems (ETSC, 2016b).

At one end of the spectrum, developers like Google and Tesla are talking about developing self-driving vehicles that can run safely and effectively on existing infrastructure, using existing static communications like road signs, traffic signals and message screens – a scenario which would, in principle, reduce the need for a significant amount of infrastructure change.

At the opposite end of the spectrum, other stakeholders have proposed that self-driving vehicles could cause all sorts of operational problems, such as simply coming to a grinding halt on the highway if anything were to go wrong with them. They are arguing for better vehicle connectivity, and supporting the concepts of platooning and convoys.

At both ends of the spectrum, the case is being made for separating vehicles that are at different levels of automation, either through creating separate, dedicated lanes or even by building separate, dedicated roads. This might work in the USA or Canada, where there is space aplenty, but not in the UK, meaning that this course of action is a non-starter here. Moreover, although convoys would work on major highways, which are the safest roads in any case, they would not on the typical urban and rural roads found in the UK. One option could be to formally require drivers and vehicles to switch back and forth between driving modes and automation levels (Shladover & Bishop, 2015). This would entail having effective and reliable infrastructure cues or communications to alert drivers and vehicles to the need to so switch.

5.2 Cost considerations

Many potential benefits which could result from the introduction of CAVs have been identified. These include safety, social, environmental, economic and health benefits. As noted, in some visions of the future of CAVs, these benefits might be achieved with little or no change to road infrastructure. However, other commentators disagree markedly with this. For instance, Williams (2013: 2) concluded that "the costs of both the necessary infrastructure enhancements and vehicles are presently well beyond government or consumer reach". Lamb (2015) also argues that separate infrastructure is unlikely because of both the cost involved and the time it would take to implement.

Two types of infrastructure costs need to be considered:

1. Infrastructure costs to support the initial phases of CAV adoption and pump-prime its anticipated benefits.

   One of the most important requirements for creating CAV-friendly road systems is achieving maximum predictability in the traffic environment (Ng & Lin, 2016). Early development of CAV-enabled infrastructure is likely to involve the retrofitting of communication beacons, antennae and roadside data processing and communications units to existing signs and signals, which will need to be retained to support non-CAV traffic – at least at first (Glancy et al., 2015). The hope is that upfront investments of this sort will enable the adoption of CAVs to achieve a critical mass – that is, to reach the point where falls in the price of CAVs and the increasing ability to use them conveniently, safely and reliably trigger a step change in demand for them.

2. Infrastructure costs that make the widespread use of CAVs possible.

   It is argued that infrastructure change will need a 30-year planning horizon, and that, given the huge costs involved in altering all infrastructure, it is more plausible to focus on sections of roadways than attempting a wholesale transformation; moreover, that the extension of connectivity to large volumes of vehicles would make significant demands on the capacity of some communications systems, for example very large increases in data transfer on the Internet, with which they might not be able to cope safely and effectively (Gill et al., 2015). Inadequate maintenance and differences in road markings and traffic signs are another major obstacle to the effective use of technology in vehicles (EuroRAP & Euro NCAP, 2011).

   This assumes that widespread use of CAVs is a good thing, but there are warnings of potentially negative consequences that need to be managed carefully. Although CAVs may eventually reduce the need for new infrastructure and free up urban space, their adoption may also result in increased urban sprawl if travel proves to be faster or to suffer less congestion (Rodoulis, 2014).

Litman (2017) notes that:

a. highly safety-critical vehicle systems are likely to remain expensive, as has been the case with similar systems in the aviation industry, because of the demanding manufacturing specifications and the need for the systems to be robust, incorporate redundancy, and be resistant to abuse such as cyberattack; and
b. it is unclear what the effects of the introduction of CAVs will be on the increase or decrease in vehicle use and vehicle miles, roadway costs and residential parking.

It is difficult to judge the costs of adapting existing infrastructure for CAV use because so little information on costs is available, but, for reference, Highways England spent £3.0bn in 2015/16, including £1.9bn on its capital programme (ORR, 2016). As an indication of the potential scale of costs, it cost Highways England £90 million to adapt a 7-mile stretch of motorway for hard shoulder running at the M4/M5 interchange, and the 27 miles of the M6 toll road cost £900 million to construct. Also, as has been noted already (in sections 3.2, 4.1 and 4.3.1), roads will need to be maintained to a higher standard for use by CAVs. Incidentally, this has implications for the performance measures and targets used to assess the performance of Highways England (ORR, 2016).

Highways England is responsible for only 2% of the English road network, but the highways for which they are responsible carry approximately a third of all traffic. In recent years, less (£1.2 billion in 2015) has been spent on the remaining 98% than by Highways England and its predecessor the Highways Agency. This raises obvious questions of where the money would be found to fund infrastructure changes to enable the use of CAVs on urban or rural roads. The Asphalt Industry Alliance's 2016 Annual Local Authority Road Maintenance survey (Asphalt Industry Alliance, 2016) reports that local roads in the UK are deteriorating at a faster rate than they can be repaired, and that the one-off cost of getting the local road network in England and Wales back into reasonable condition is £11.8 billion, and, moreover, that it would take 14 years to clear the backlog of repairs in England and 16 years in the case of London.

5.3 Perceptual accuracy

There are many concerns being expressed about the perceptual accuracy of the autonomous systems currently in use, including concerns about blind spots in existing systems. Current sensor technology cannot 'see' as far as humans and has a 150-metre limit, which is close to the braking distance at motorway speeds (Michal Aeberhard – BMW engineer quoted in Bowles, 2016). Moreover, one Google car crash resulted from avoiding sand bags on the edge of the roadway (Bowles, 2016)

Standard GPS is only accurate to within 3.5 metres, so using GPS to guide road positioning of vehicles will need augmented systems such as differential GPS or space-based optical clocks (Messner, 2014; Somers & Weeratunga, 2015).

As with any safety-critical communications system, there is a need for triangulation (usually achieved through having built-in redundancy i.e. the ability to prevent or recover from the failure of a specific component or system) so that vehicles 'know' precisely where they are. There are thousands of examples in Google car trials of the human driver having to resume control, and instances of vehicle systems disengaging because of poor road markings (Louw, 2016). US Department of Transportation is reported to be producing guidelines emphasising the need for standards in this area, especially concerning how CAVs should react if the technology were to fail (Kang, 2016).

Implementing roadside communications – for instance incorporating communication devices in street lights – may be desirable on all roads, and actually essential on urban roads for both precision and as backup to other systems.

5.4 Level of automation

The level of automation possible, and policy decisions about automation levels in mixed traffic, will also be crucial. Is it a good idea, as Google, Tesla and others are suggesting, to skip the intermediate levels entirely and jump from assistive technologies straight to fully self-driving vehicles? Might they be allowed only on certain roads? In which case, would there be a need for geographically defined 'wake-up calls' when control has to be handed back to the driver? However, a Houses of Parliament research briefing (Houses of Parliament POST, 2013: 1, 3) identifies two problems with separating vehicles at different levels of automation in this way. It points out that there is currently no UK legislation and there are no EU standards covering how CAVs might operate in mixed traffic, and also that "many of Britain's roads are close to capacity, so there is not space to dedicate separate lanes to autonomous vehicles". If traffic is mixed, all the existing infrastructure will need to be retained and possibly supplemented (if the Google, Tesla and other strategies are not supported) by additional infrastructure such as roadside communications systems. There are also questions about the extent to which communications systems will need to be standardised, either worldwide or across continents.

As demonstrated by the Analytical Framework (Figure 2.1), all four levels of 'cognitive performance' required by AVs (observation, analysis, decision-making and action-taking) will have implications for infrastructure, since the last three will all be dependent on the accuracy of the first. However, the precise implications for infrastructure will be determined by the policy decisions that are made.

5.5 Managing safety risks

The introduction of CAVs brings with it a range of possible safety risks. Table 5.1 identifies some of the main ones. As CAVs are introduced, policy decisions will need to address these risks and consider what effect the existence and condition of the road infrastructure will have on controlling and mitigating these risks. Until now, policymakers have been focusing on how to test the safety of CAVs, particularly once they are allowed to drive on public roads; but current trials are only examining CAV performance in controlled and constrained circumstances (see section 3.3). In addition to this, trials need to be considering how the type of risks and infrastructure mitigations identified in Table 5.1 should be implemented and managed.

Table 5.1: Infrastructure options for mitigating safety risks

Examples of safety risks			
CAVs *	Driver	Infrastructure	Other road users
At any CAV level: does not substitute adequately for the competences and behaviours of the driver Misreads the driving environment, leading to faulty analysis, incorrect decisions and inappropriate actions	At higher CAV levels: loss of driver-accessible information from the driving environment Driver can't retake control safely due to insufficient environmental cues In mixed traffic, not enough information for non-/low-CAV drivers to interact safely with other road users	Varying availability of, and variations in, infrastructure to accommodate AVs across territories Road safety benefits held back by non- standard infrastructure UK CAV industry held back by slow growth in domestic market	Loss of traditional signs, signals and road markings puts other road users at risk Pedestrians cannot tell how to interact with traffic safely
Road infrastructure mitigations			
Fully self-driving level 5 vehicles are not accepted except on segregated routes.	Non-CAVs or partial CAVs must be separated from CAV traffic.	Retaining the 'supervising' driver is essential, therefore infrastructure cues to drivers and vehicles are needed.	New infrastructure needed to accommodate CAVs, alongside existing infrastructure which continues to require maintenance repair, renewal and enhancement.

Source: Author's own

* CAV: connected and autonomous vehicle

5.6 Conclusions

This paper set out to assess the readiness of the road network for connected and autonomous vehicles (CAVs), and began by asking three questions:

1. What are the implications of CAVs for road infrastructure?
2. How ready is the current road infrastructure for CAVs?
3. What challenges arise from the gaps identified between the current road infrastructure and the infrastructure required by CAVs?

The evidence is not yet there to support definitive answers to these questions. CAVs could be said to have reached – or be near – the peak of inflated expectations. Much of the research and opinion on CAVs is concerned with current and emerging CAV technologies, and contains a great deal of speculation.

Very little research has been done on difficult questions relating to the readiness of the road infrastructure, the training and testing of new drivers, interactions between CAVs and other road users, the safety of vulnerable road users, and CAV parking and breakdowns.

What is clear from the research that has been done is that CAVs and the road infrastructure exist in a reciprocal relationship. How this relationship will develop is uncertain.

CAVs are unlikely to develop to their fullest potential without advanced planning by transport policymakers, planners and engineers (Litman, 2017) to ensure that infrastructure change is adequate (Lamb, 2015). Governments need to decide on the level of automation that will be supported, and how this will be implemented. Policy options – such as prioritising the platooning of heavy goods vehicles, or accelerating the phasing in of CAVs by leapfrogging levels 2 and 3 and going straight to levels 4 and 5 (see Table 2.1) – have significant implications for infrastructure change and cost. The speed with which change can take place relies heavily on the appetites and ability of governments and local authorities to plan and pay for it, and the willingness of the general public to accept it.

Without clear policy direction, change in road infrastructure will, in all likelihood, be slow and piecemeal. The problem for policymakers at the moment is that research on the infrastructure requirements of CAVs is in its infancy, and evidence for the implications of the various automation options largely lacking. Little attention has yet been paid to what impact different CAV strategies will have on the condition of road infrastructure, and its maintenance, renewal and configuration requirements, and in particular, the extent to which key features of the infrastructure, such as road signs and markings, will need to be maintained to a higher standard. Experience in other sectors – for example, aviation and rail – suggests that as greater use is made of sophisticated technology, maintenance costs increase significantly. This will need to be taken into account in any planning, but also needs to be considered in the light of the Asphalt Industry Alliance's finding that local road condition continues to deteriorate, with the recognition that there will be a need for significant investment.

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Designed and printed by
The Javelin Partnership Ltd
Tel: 0118 907 3494

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sustainable source which is FSC certified
as containing 50% recycled waste.

Main proofreader:
Beneficial Proofreading Services
Tel: 07979 763116