Department for Transport

Technology and RIS2

Moving Britain Ahead

October 2018

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Department for Transport
Great Minster House
33 Horseferry Road
London SW1P 4DR
Telephone 0300 330 3000
Website www.gov.uk/dft
General enquiries: https://forms.dft.gov.uk

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1. Introduction

For over fifty years roads policy has been developed against a stable background. Policymakers have sought to accommodate a rising number of motor vehicles within an existing road network. There have been debates about how far the wish to travel should be supported, and how the demands of mobility should be balanced against wider policy goals, but the choices have been stable and well-understood. The ways in which policymakers respond have therefore been broadly consistent.

But this consensus may be about to end. Technology companies and carmakers are investing billions of pounds in the expectation that we are at the dawn of a wholly new era in mobility. This will have fundamental implications for the general public, the freight and logistics industry, the automotive industry, insurers, highway managers, and a wide range of data and transport service providers. It could mean better journeys, safer travel and higher productivity for the nation as a whole.

Sales of electric-powered vehicles are increasing strongly and, by 2040, the Government does not expect new conventional petrol and diesel cars and vans to be available for sale in the UK. Last November, the Chancellor of the Exchequer set out our ambition to see fully self-driving cars on UK roads by 2021.

Implicit within this news is that the assumptions of the past may no longer apply in the relatively near future. Policies that worked well in the age of conventional mobility may no longer be effective in the era of autonomy. Policies necessary to tackle the problems of the internal combustion engine may no longer be needed in a world of ultra-low emission vehicles.[1] The working assumptions of a generation of transport experts may require a comprehensive update. This presents transport decision makers with a double challenge: It is highly plausible that the policies of the future will need to differ from the policies of the present. But there is not yet a consensus about what the policies of the future will need to become.

If there is growing agreement that change is coming, there is relatively little agreement about how quickly that change could emerge. Government has committed to bringing many of these benefits about rapidly, and has launched ambitious programmes to make their promise real. That notwithstanding, some elements of innovation will have a greater and longer-lasting impact than others, and some promising advances may ultimately be rejected. It is even possible that a roads revolution will not occur, and the existing paradigm will continue and evolve only incrementally.

There is also no consensus about what the overall effect of new technology is likely to be. Innovation is at an early stage which means a wide variety of futures are plausible and even the incredible does not seem wholly impossible. At one extreme, some predict that new technology will make it far easier for travellers to pick between

[1] An Ultra-Low Emission Vehicle (ULEV) emits extremely low levels of carbon dioxide (CO_2) compared to conventional vehicles fuelled by petrol/diesel. They typically also have much lower or virtually nil emissions of air pollutants and lower noise levels. Since 2009, the Office for Low Emission Vehicles has considered ULEVs as new cars or vans that emit less than 75 grams of CO_2 from the tailpipe per kilometre driven, based on the current European type approval test.

modes, and to select journeys that do not involve the car – resulting in a significant decrease in traffic. At another, a great improvement in the car could make private travel even more attractive and lure larger numbers onto the road for even more journeys – resulting in far worse congestion. And there are many possible 'futures' between these two scenarios that would result in better journeys for millions of people.

Government must plot a way through the uncertainty and seize the great opportunity, while managing the risks that could emerge. The developers of the next Road Investment Strategy (RIS2) will have to address this as part of their efforts to create a vision for the strategic road network (SRN) to 2050, and to inform the setting of an investment programme for the second Road Period (RP2), covering the years 2020-25. Highways England, as manager of England's SRN, will have to work in a changing and innovative environment for many years to come. This means encouraging innovation, attracting industry and providing leadership.

We have identified four principles for developing future-ready roads policy which will harness the power of technology:

- *Uncertainty is very large and will persist* – the current policy environment is more uncertain than at any point in living memory. This uncertainty is evident not only in attempts to predict the effects of technologies that do not yet exist, but also reflects the challenge of predicting how users will react to technologies they have not yet encountered. Change appears highly likely, but the exact nature of that change cannot yet be described with accuracy.
- *Research and development are key* – policy benefits from consciously working to reduce this uncertainty through research and through trials. It also benefits from an open discussion about the nature of the future.
- *Setting the vision and agenda* – we cannot control the future but government does hold several decisive levers. For example, in its role as champion of research and development, regulator, investor and road operator, government is able to shape the future vision for transport. It also has a powerful role in helping to forge industry consensus, and in converting a democratic mandate into a real-world policy that is acceptable to users.
- *Flexibility will be crucial* – in an uncertain environment, flexibility is likely to play an important part in successful policy. Some of the ways in which the road network needs to adapt will be easier to predict as time passes, and the next RIS will need to adjust to the developing technological position throughout its life.

It is with these points in mind that this paper aims to articulate our latest understanding of:

- The developing technologies and innovations that seem most likely to impact roads.
- What road users and wider society think about these developments.
- How policy makers are measuring the potential impacts.
- What this all may mean for roads policy and our vision for transport.

2. The Emerging Technology Landscape

Judging by most analysis, changes to road transport will be driven by innovation across the following five areas:

- Digital connectivity between vehicles and their surrounding environment.
- Increasing degrees of vehicle automation.
- Proliferation of electric vehicles.
- Emergence of new mobility models, such as 'mobility as a service'.
- Increased creation and utilisation of data.

Any attempt to predict emerging innovations will be speculative in nature and is therefore likely to change over time as our understanding improves. The effects of new roads technology will also be shaped by wider changes in society and broader currents of technological development across many other sectors, which add further complexity to the question of why and how we will travel in the future.

Connected Vehicles and Digital Infrastructure

Estimates suggest there are already around 3 million connected vehicles on UK roads using a range of applications, varying between transport notifications through to passenger entertainment.[2] Both the number and capability of connected vehicles is expected to grow rapidly, offering the potential to improve safety, efficiency, air quality, and the travelling experience, as well as helping to enable fully automated vehicles. But it is not yet clear which applications will prove successful and gain favour with users, nor which mix of enabling technologies and infrastructure will be necessary.

Fundamental to the success of connected vehicles will be access to telecommunications networks in order to receive and transmit data. A wide range of applications and services are being developed, with differing performance needs. For example, safety critical services such as 'collision ahead' warnings will have more challenging requirements than non-safety critical services.

At this stage, most roadmaps for the future suggest connected vehicles will be supported by a hybrid of networks providing the connectivity necessary for different purposes. This is likely to include:

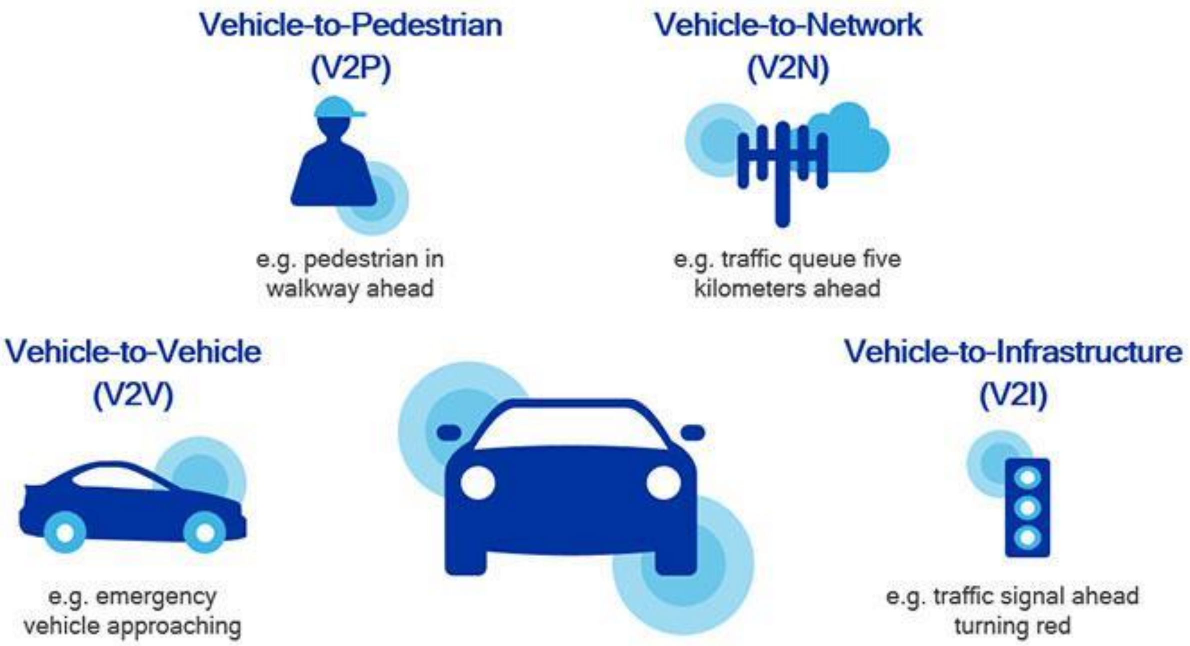
- *Vehicle to Vehicle (V2V)* – allowing for rapid exchange of information between vehicles in close proximity, enabling vehicle platoons, for example, as well as notifications and warnings. V2V does not require digital infrastructure because

[2] Analysis by Transport Technology Forum (TomTom plus INRIX plus Here); they estimate that 50% of all new vehicles will be connected by 2020.

information is transmitted directly between in-vehicle radios, though only over relatively short distances.

- *Vehicle to Infrastructure (V2I)* – connecting roadside infrastructure, such as traffic signals, signs and gantries with vehicles allowing, for example, roadside infrastructure to capture data and provide motorists with information such as the status of approaching traffic lights as well as general notifications and warnings.
- *Vehicle to Network (V2N)* – connecting vehicles to commercial mobile cellular networks can enable notifications, for example, about road conditions or disruption ahead, as well provide internet connectivity to passengers for entertainment and productivity. In the future, there is also potential for networks of 5G 'small cells' to be introduced in close proximity to certain roads in order to provide for more rapid, reliable communications.

Figure 1: Connected Vehicle Digital Infrastructure



All of these elements are likely to be required in some form, but the exact network architecture and merits of the potential telecoms technologies involved remain matters of debate. That debate will need to take full account of security and privacy risks and mitigations as well as public perceptions about networks and data. The final result will reflect a transnational compromise between emerging standards in the automotive and telecoms industries, as well as the choices of individual governments as infrastructure operators and, ultimately, users.

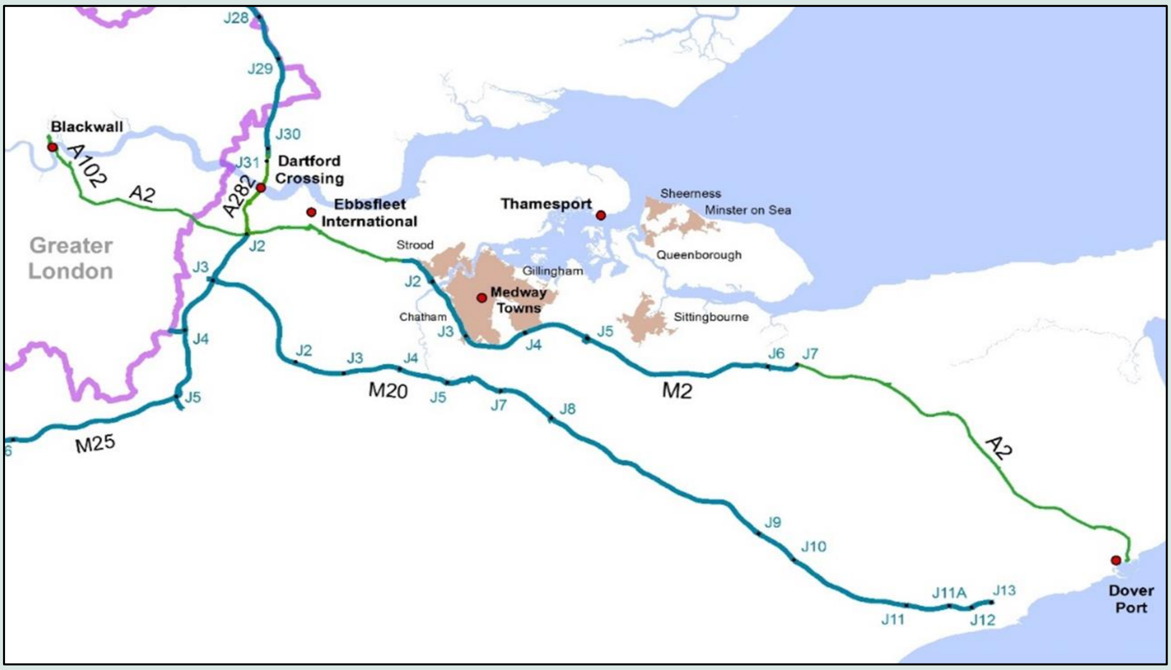
In this evolving environment, Highways England have responded with a combination of innovation and flexibility, with the potential need for future additional digital infrastructure accounted for within the newly awarded National Roads Telecommunications Service (NRTS) contract. They have also begun testing technologies and the services and applications enabled by those technologies through trials, such as the A2/M2 Connected Corridor.

NRTS 2

NRTS provides telecoms to meet the operational needs of Highways England (e.g. CCTV, phones, variable message signs), including the roadside cables required to make the network function. A new contract was recently awarded to Telent and includes a network upgrade that will enable Highways England to prepare for technologies such as 5G and connected cars. It has provision for any required transformation of existing network equipment to provide sufficient bandwidth to meet Highways England's forecast requirements during the contract term. NRTS was built with significant extra capacity, meaning that much of the SRN is able to absorb a large amount of future safety-critical data.

A2/M2 London to Dover Connected Corridor

Government is trialling an urban and interurban 'connected' road corridor on the A2 and M2 between London and Dover. It will provide a test facility for improved connectivity between the roadside and connected vehicles (and potentially between connected vehicles), helping establish how real-time data can be efficiently and securely exchanged.



The project aims to explore how connected technology will be used, and help demonstrate the viability, scalability of the wider deployment of connected vehicle technology. These technologies and services can then be rolled out across the wider network.

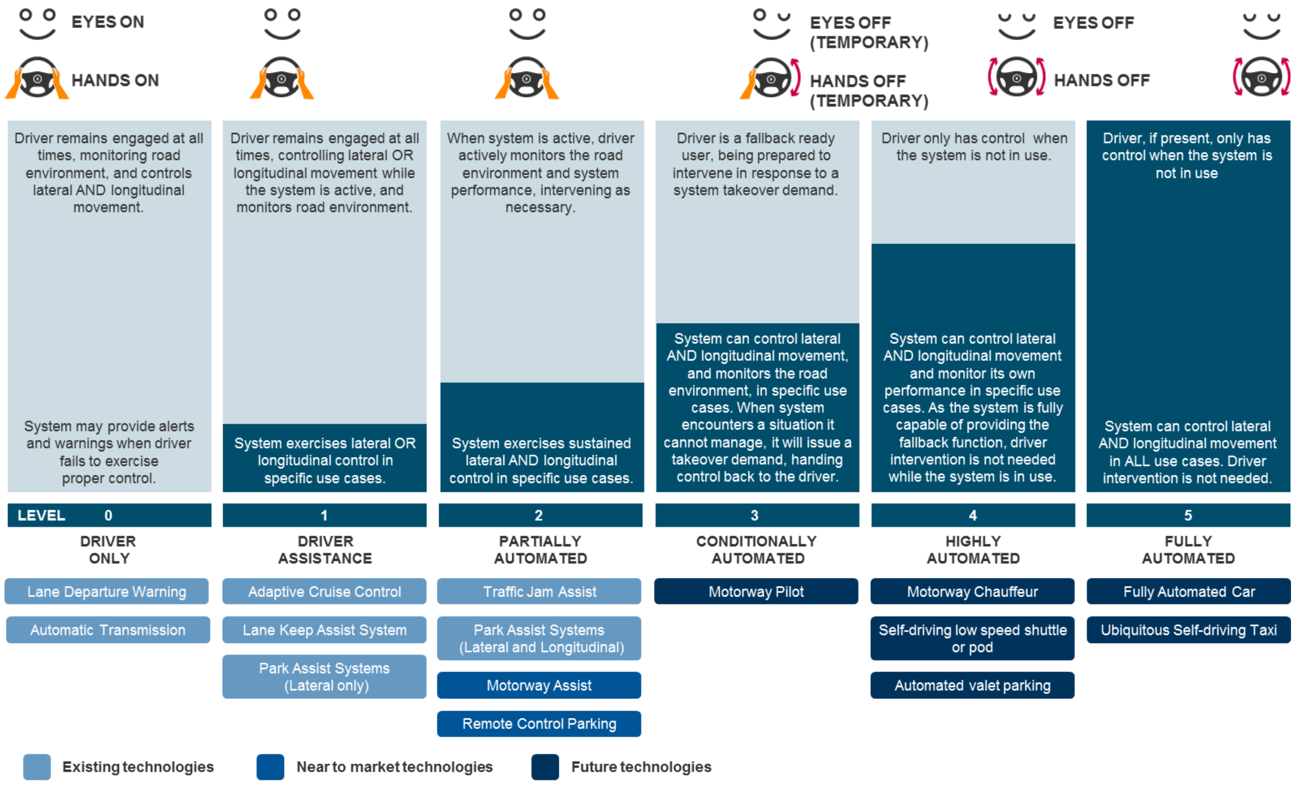
The development of connected vehicles is being driven globally by a combination of industry, academia and government. The UK is engaged in a number of trials and research projects which should show the likely scale of 'digital demand' created by connected vehicles over time across different road environments, as well as the optimal enabling technologies and likely quantum of enabling infrastructure.

Plans announced at Budget 2017 for a trial to make our roads 5G-ready will also contribute to knowledge about this emerging technology as well as create new links between the telecoms industry and Highways England that are likely to be more important in the future. A feasibility study to determine its location began in 2018. Government is also increasingly working across departmental boundaries. For instance, by developing a greater level of coordination between the Department, Highways England, Department for Digital, Culture, Media and Sport, and Ofcom to ensure that the mobile phone industry improves coverage on transport networks.

Automated Vehicles

Fully automated vehicles are a key emerging technology that could fundamentally change our conceptions of mobility, accessibility, safety and congestion.[3] Most observers now accept that the technology required to deliver fully automated vehicles is achievable, and although there remains debate about when this will occur, we are already seeing the emergence of sophisticated features such as advanced driver assistance, automated braking and self-parking. A number of automotive manufacturers have committed to launching vehicles with high levels (i.e. level 4) of automated capability by the early 2020s.

Figure 2: Levels of vehicle automation[4]



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[3] www.gov.uk/government/uploads/system/uploads/attachment_data/file/463043/rrcgb2014-02.pdf

[4] This infographic is adapted from the Society of Automotive Engineers' Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (Standard J3016, standards.sae.org/j3016_201609/). While these are not formally recognised by the UK Government, or the United Nations World Forum for Harmonisation of Vehicle Standards, they are seen as a helpful guide to automated vehicle technology, describing what the system and driver can do at each level. In level 4 and 5 systems, the driver effectively becomes a passenger if they are inside the vehicle when the system is active. The driver may be outside the vehicle, in which case they are a remote driver (levels 0 to 3), or a dispatcher (level 5, and some level 4 systems) when the system is active. The graphic some shows example systems (a vehicle may have multiple systems of different levels) and a UK perspective of when the driver has responsibility.

However, there are a number of uncertainties that could affect the rate of change greatly:

- The speed at which the technology will develop and be adopted is not clear. This includes both the proof of concept and the move towards a mass-market technology in everyday use. This in turn affects the rate at which users take up automated travel.
- Industry is not yet able to articulate what it requires from existing infrastructure. New technology is likely to work best on purpose-built highways in good condition; and automated vehicles are also likely to benefit from the provision of high quality digital connectivity.[5]
- Legislation, insurance, driver training and many other aspects of driving are built on the principle of a human behind the wheel. These concepts need to be revisited and updated, a process already underway in the UK (see below).

Therefore, while it is plausible that autonomy may emerge through a ‘big bang’, there could equally be a more gradual process of adaptation where road infrastructure plays a significant role. But in either case the transition period will need to be handled carefully with implications for road management and the public given full and proper consideration.

On-road trials

Government is encouraging on-road trials of automated vehicles in the UK, and has made support for the autonomous sector a key part of one of the ‘grand challenges’ in its Industrial Strategy. Key examples include:

- The ‘world first’ Greenwich GATEway project in which the public have been encouraged to access a fleet of driverless pods providing shuttle services around the Greenwich Peninsula, which has increased understanding about public acceptance of, and attitudes towards, driverless vehicles.
- The MERIDIAN co-ordination hub for connected and autonomous vehicles (CAV), which is jointly funded by the Government’s £100m CAV investment programme and by industry, and creates a CAV testing cluster in the UK’s automotive and technology heartlands between Coventry and London.
- Truck platooning trials, backed by £8.1m in government funding and delivered by the Transport Research Laboratory, will assess the safety and benefits of Heavy Goods Vehicle (HGV) platooning on UK roads.
- The National Infrastructure Commission's innovation prize to assess how the road network could be adapted to support self-driving cars. The joint winners, City Science and Leeds City Council, were announced in September.

[5] RAC Foundation, *Readiness of the road network for connected and autonomous vehicles*, 7 April 2017, p26.

Automated and Electric Vehicles Act 2018

This Act, which received Royal Assent in July, provides a legal framework for insuring automated vehicles, removing one of the main barriers to their use by ordinary drivers. Under the provisions of the Act, motorists will need to get insurance that covers them when they are driving, and when they have legitimately handed control to their automated vehicle. This will ensure that victims of collisions caused by an automated vehicles will get quick and easy access to compensation.

Automated vehicles would have implications for road use and management. Fully autonomous vehicles could in theory travel closer together, or operate safely in narrower lanes, potentially facilitating additional road capacity on the existing road footprint. These sorts of improvements would rely on the willingness of passengers to be driven in this way – demonstrating the need to build public confidence in the efficacy and safety of these options – and would be affected by the existence of a 'mixed fleet' of legacy and fully automated vehicles for some time. Research carried out by the Department and Atkins suggests that a 15-40% increase in road capacity is plausible, but much of this would not materialise until autonomous vehicles comprise more than half the vehicle fleet. The research also emphasised the importance of public perception and acceptance in realising these gains.[6]

Automated travel could also have significant implications for the freight industry. Freight companies are constrained by the supply of trained drivers, and by the rules under which those drivers must work. New technology could allow drivers to work more efficiently, for example by allowing multiple lorries to drive in a 'platoon' of close-following vehicles. Fully-autonomous journeys would also have the potential to move more freight deliveries overnight – meaning less congestion for other users during the day.

The potential impact of automated vehicles will also be determined by the acceptance and level of demand from users. Automation could stimulate more road traffic demand in a variety of ways, for example, by making road travel easier for existing motorists and possible for those who currently do not, or cannot, drive. Automation could also reduce costs by enabling new shared-access mobility models, which could allow for cheap, responsive access to road travel. And types of journey not currently possible or necessary, such as empty vehicle running, may appear. Longer term, automation may also affect land use patterns: the growth of car travel in the twentieth century allowed for more dispersed patterns of living, and automated vehicles could encourage us to build more travel into our daily routines.

More than any other single roads technology, autonomy has the potential to present travellers with new options, which they could use in unpredictable ways that disrupt our existing assumptions about transport. Government is clear that the net impact of autonomy is likely to be positive: increased productivity, improved safety, better journeys, and more choice for travellers are all to be welcomed, particularly if coupled with wider improvements based on other technologies. None of the potential drawbacks would be relevant if autonomy was not providing a service that people found attractive – they are the costs of success. Maximising the benefits and

[6] Research on the Impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow.

planning for the consequences could be an important policy challenge for the decades ahead.

New forms of Mobility

New concepts of mobility have attracted much attention recently. The arrival of demand-responsive, digitally-hailed and paid for taxis and private hire vehicles (PHV) in cities worldwide have created new travel and economic opportunities, as well as disruption for existing transport providers. In London there has been rapid growth in PHV drivers and journeys, with the full impact on travel patterns and behaviours still being understood.

There has been a similar rise in the number of shared access bikes, with new digitally enabled arrivals challenging incumbent ‘Docked Bikes’ by undercutting on price and reducing barriers to use. We have also seen advances in payment mechanisms on modes such as light rail, bus and tram, with a shift in some areas away from the use of cash in favour of pre-paid cards and, more recently, contactless payment. Smart device-enabled applications such as Waze, Google maps and Citymapper allow for users to identify (and in some cases pay for) the most suitable form of transport and navigate to it.

Taken together, these trends could be seen as the early manifestation of ‘mobility as a service’ – a new approach to transport that provides travellers with mobility across many different modes through an integrated system. Several European cities are pioneering this approach: the Whim app was developed in Helsinki and promoted as a cheaper, more flexible alternative to car ownership. Small trials are ongoing in the West Midlands, offering unlimited or discounted access to several modes for a monthly subscription and fee.

West Midlands is the UK’s first Future Mobility Area

In October, Transport for the West Midlands was awarded £20m by the Government to support work with companies to trial and demonstrate new transport technologies and services. This will encompass both new modes of transport and better integration of existing modes, the supply of real time data, and seamless payment methods. The ambition is to provide people with greater transport choices that are easier, quicker and cheaper to use.

The potential for seamless, on demand travel across multiple modes has been underpinned by the proliferation of smart mobile devices coupled with innovation in digital connectivity and data utilisation. In the future, a step change away from previous patterns of travel could be enabled and accelerated by other technological advances: operators such as Uber and Lyft are investing heavily in the development of automated vehicles, and longstanding vehicle manufacturers increasingly speak of their industry evolving towards a ‘service provision’ model that operates as well as manufactures vehicles.

Nonetheless there remains uncertainty about how such trends will evolve and what the impact will be. The potential for new mobility models to take off initially appears to be greatest in urban areas, where a relatively dense mass of users exists across various times of the day and can be catered to by a fleet or fleets. Today, journeys by all forms of PHV represent only around 1% of London’s daily journeys, as opposed to

31% by private car. But, over time and with the emergence of automation, on demand transit could become an increasingly important part of urban travel.

How innovative mobility models are changing travel behaviours

Data shows that Londoners increasingly use Uber to link to railway stations for onward commutes. Figure 3 shows where the lines indicate Uber trips which began in outer London on weekdays between 5am and 10am, and ended at a railway station. These are early stages and we are still understanding the ways in which travel behaviours can be influenced by the arrival of on-demand, digitally enabled mobility. But this example shows that these services can form part of wider trip chains, potentially supporting other forms of transport.

Figure 3: Railway station Uber trips in London Zones 1 and 2

In Centennial, Colorado, the authority worked with Lyft and ‘Go Colorado’ to offer residents free journeys to and from a local light rail station, encouraging mass transit use and decreasing reliance on cars. Ridership from the small catchment area grew steadily over the trial period, with each journey costing an average of US$4.97. Integration of public mass transit and private ride-sharing options in this way could extend and improve public transport networks, and potentially do so at a lower cost than conventional modes. It is also possible that, by doing so, it could reduce journeys made on strategic roads.

A shift from private vehicles to shared transport could have implications for road layout and utilisation and planners are beginning to envision the possibilities of freeing up roads and parking spaces in urban and residential areas if shared, on demand mobility takes off. The Department has commissioned work to understand better “the street of the future”; the outputs from this work will contribute to the development of a Future of Urban Mobility Strategy.

Future of Urban Mobility Strategy

In parallel with the development of RIS2, we are developing a Future of Urban Mobility Strategy, which will set out the principles that will guide government's approach to emerging mobility technologies and services in cities. It will recognise the freedom of cities to shape their own place-based visions for the future, while equipping them with the right tools to realise these visions in a context of change and uncertainty.

On the SRN, there may be scope to reimagine intercity travel. Highways England recently highlighted that changes in mobility could lead to a focus on concepts like 'Connecting Hubs' (such as strategic park and rides) which would support more integrated travel and "improve boundaries between different modes of transport and enabling smooth onward journeys".[7] The greater the role played by shared models of mobility, the more important it will be to ensure major transport hubs are well-connected to other modes, including roads.

Data and Smart Infrastructure

In recent years there has been huge growth in digital data, driven by the proliferation of mobile devices, development of low cost sensors, and growth of the wider 'internet of things'. The impact is being felt across all sectors, and data is now considered so essential that the National Infrastructure Commission have urged for it to be regarded as infrastructure in its own right.[8]

In road transport, increasing amounts of data are created by modern vehicles and their occupants as well as networks of sensors providing an unprecedentedly rich, real-time picture of the transport network and allowing for improvements in how infrastructure is built, managed, maintained and operated. Sensors and traffic data have for decades been used to assess and optimise performance on the SRN and to inform motorists using variable message signs. Innovation is increasing opportunities to alert motorists and operators directly, in real time, about road incidents and performance, and it is possible to use predictive analysis to assess how networks are likely to perform in the hours and minutes ahead.

[7] www.gov.uk/government/uploads/system/uploads/attachment_data/file/666876/Connecting_the_country_Planning_for_the_long_term.pdf

[8] *Data for the public good*, NIC, 2017, www.nic.org.uk/wp-content/uploads/Data-for-the-Public-Good-NIC-Report.pdf

New Sources of Data

Most of Highways England's self-generated traffic data comes from an extensive network of detectors including magnetic 'loops' under the road surface, which detect when vehicles pass above, and radar. This information is used to assess traffic flow and average speeds and, on smart motorways, set variable message signs and speed limits with little human intervention. This data is publicly available, and companies such as RAC, TomTom and Google use it as the basis for their forecasts, and is supported using commercially-available data from monitoring boxes placed in participating vehicles. Trials of innovative sensor technologies are ongoing and Highways England are funding more trials through their Innovation Fund.

Smart phones have powerful sensors (e.g. Advanced-GPS, vision, audio, temperature, direction, and acceleration) which have created vast opportunities for data mining and application development. It is now possible, for instance, to identify potholes and other road surface anomalies from mobile device accelerometer data, which can be accurately located through network cell and GPS data. And 'floating car' data which sends location/speed data from any car from which GPS positions are continually recorded (via on-board units, smart phones, etc.) is an increasingly important tool for traffic management.

Modern vehicles now record data relating to vehicle functions and status and increasingly utilise in-built 4G SIMS. From April 2018, all new vehicles will be fitted with E-Call, which automatically calls emergency services in the event of an accident, and similar types of connectivity are likely to be integral to future vehicles. Soon, vehicle sensors will commonly gather data relating to the environment around the vehicle (e.g. road conditions) and within the vehicle (e.g. vehicle occupancy). Data about aspects of the journey itself can also be collected, and this is being used by the insurance and freight industries.

New traffic management systems

CHARM is an Anglo-Dutch project to modernise Highways England and Dutch traffic management centres and introduce innovative traffic and incident management. The new system will be capable of managing current and planned network capacity and be able to interface with emerging technologies. CHARM will allow control centres to adjust operational capability at busy times or during incidents. This includes applying Artificial Intelligence (AI) techniques to loop detector data and floating car data to predict/detect congestion and incidents.

Emerging sources of transport data are expected to catalyse new business models and services, both by themselves and when fused with data from other sources. It will also change the role played by highways authorities. The collection of data and its provision to vehicles may become essential to road operation – particularly for automated vehicles. Users are likely to compare this information to other sources, so it is essential that it is accurate in order to remain credible. Highways England has a long history of dealing with traffic data, but this part of their role is likely to become more prominent and more important to their relationship with users.

Data also has the potential to transform basic activities, such as road maintenance. The current cycle of observing, assessing and intervening can be greatly refined by sensors embedded in the infrastructure itself, or by information gathered by passing vehicles. As part of this, Highways England are exploring the benefits of Building Information Modelling and the concept of 'digital twinning' – the use of digital representations of an asset or system, to support construction, modelling, and ongoing asset management.[9]

However, while the volume and diversity of data is increasing, many challenges have been identified across the transport sector in terms of using that data effectively. Common standards for the exchange of certain data have not yet been established, and many of the connections between organisations that are necessary to maximise its use – for example local highways authorities and commercial organisations – are immature or have yet to be made. It is also essential that any use of data respects the privacy of users, and that data systems are secure. We also need to consider whether users should be able to opt out and what the implications of this would be for how the network functions. There is also significant variation in the quality of data available, both from existing roadside sensors, and from some commercial providers. This is an area of future activity which Highways England has identified as important.

Electric vehicles and supporting infrastructure

Transport has been powered by fossil fuels since the age of steam. It is now clear that advances in battery technology are enabling a major shift towards Electric Vehicles (EVs). The decarbonisation that this will facilitate is critical to helping the UK achieve its climate change obligations and to improving air quality. Lower fuel costs coupled with the likelihood of reduced EV maintenance costs mean this shift also has the potential to greatly reduce the costs of travelling by road.

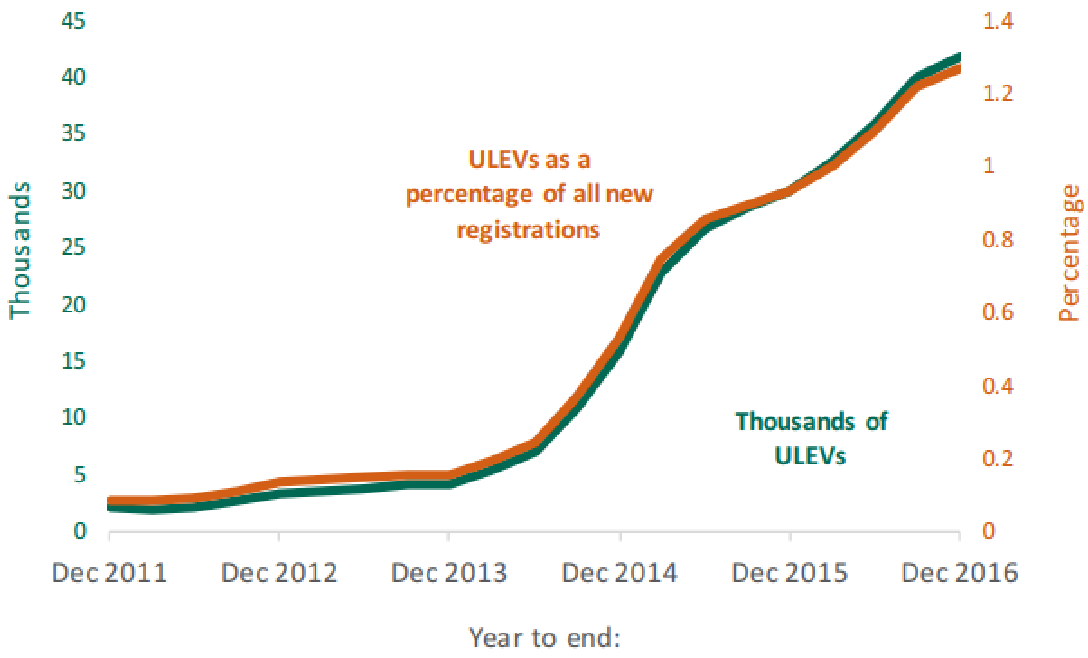
There are already several categories of EVs on the market, including all-electric (where the battery is the only power source) and plug-in Hybrids (which switch between running on electricity and fossil fuels). Both plug-in hybrid and all-electric vehicles are recharged by connecting to the electricity grid. Hybrid vehicles, such as the Toyota Prius, do not plug in and have a much smaller battery which is recharged while driving, but their range under electric power is more limited. Fuel Cell vehicles generate their own electricity on-board from a fuel such as hydrogen, and do not need to plug in to the electricity grid to recharge, but uptake in the UK so far has been limited.

There remains debate about which EV technologies will prove to be most effective or popular with consumers, and different manufacturers are backing different mixes of technology. In 2017 plug-in hybrid vehicles accounted for over 70% of electric cars

[9] www.costain.com/news/news-releases/highways-england-launches-bim-component-library/

registered in the UK. Over 130,000 are registered in the UK and this number is rising rapidly with sales increasing year on year. During 2017, over 47,000 new electric cars were registered for the first time, up 27% from around 37,000 during 2016. This amounted to 1.8% of all new vehicle registrations – up from 1.3% one year previously and 0.9% two years before.

Figure 4: New Ultra Low Emission Vehicle registrations, UK, 2011-2016



Government has set out the objective to end sales of new conventional petrol and diesel cars and vans by 2040, with funding being provided for a range of measures aimed at increasing the uptake of EVs. This includes the Plug-in Car Grant which offers up to £4,500 to help offset the extra cost of purchasing an EV and grants for the installation of charging infrastructure at peoples' homes, at the workplace and in on-street locations. Government is also investing to stimulate ultra-low emission vehicle research and development through a number of competitions to support uptake, including the Office of Low Emission Vehicles' Go Ultra Low city scheme providing £40m to eight cities.

It is anticipated that the majority of people will charge vehicles at home where possible, and that increasing battery ranges will reduce the need for on-the-move charging. Nonetheless, home charging "is not always going to be the best or only solution available"[10], particularly as many people do not have a dedicated parking space close to home, and given uncertainties around future vehicle ownership trends.[11] As such, the future roll-out of sufficient public charging infrastructure will be key to meeting the Government's 2040 commitment, with charging infrastructure on the SRN likely to continue to hold particular importance because of 'range anxiety' – a concern that the range of an electric battery will not be sufficient to complete a journey. This can be addressed through appropriate provision of reliable rapid charge points: 50kW rapid charge points can provide an 80% battery charge in as little as 20

[10] National Grid, *Our Energy Insights*, 2017

[11] A 2008 DfT survey concluded that "48% of all households had access to a garage and 57% to other off-street parking". http://webarchive.nationalarchives.gov.uk/20111005202126/http://www2.dft.gov.uk//pgr/statistics/datatablespublications/trsnstatsatt/parking.html

minutes and there are currently some 460 such charge points in close proximity to the SRN. RIS1 has committed to ensure there is at least one rapid charge point within 20 miles along 95% of the SRN by the end of 2020.

Innovation is leading to the development of increasingly rapid 'Superchargers' and 'Higher Powered Chargers' (up to 350kW) in order to respond to increased battery size and capacity. As these improved batteries enter the market, provision of more rapid charge points is likely to have an important role to play in facilitating longer journeys along the SRN as well as densely populated urban areas. However, many of today's EVs are limited by the maximum charging power they can accept, as a result, continued access to slow (3kW) and fast (7-22 kW) chargers will still be important for vehicles such as plug-in hybrid EVs.

Recent analysis by the Committee on Climate Change suggests that a further 700 rapid charge points will be required close to the SRN by 2030, and it is likely that there will be a need for upgrades to electricity distribution in many areas.[12] The private sector already plays a crucial role in supporting rollout of charging infrastructure and has been responsible for a substantial number of the rapid charging points already installed. This role is set to continue and grow.

It will be necessary to ensure this technology is delivered ahead of anticipated demand in order to incentivise and then accommodate it. Collaboration between a range of public and private stakeholders, including Highways England, will therefore be necessary in order to ensure infrastructure deployment is as rapid and efficient as possible.

There will be other considerations for Highways England and government in the years ahead, including opportunities to use the SRN to trial and showcase new technologies. This could include electricity storage models, and vehicle-to-grid technologies.

Other innovations

Policy makers will need to be both open-minded about, and mindful of, the potential impact of emerging innovation from non-road based modes. Radical technological change may enable new modes of transport, such as Hyperloop, freight drones, and passenger drones, all of which are at various stages of trialling. We also need to accept that the impact of technological development will not be limited to transport – it will affect all sectors, and in ways that could profoundly alter travel patterns.

[12] www.theccc.org.uk/publication/plugging-gap-assessment-future-demand-britains-electric-vehicle-public-charging-network/

3. User reactions

Assessing emerging technologies makes it possible to illustrate the potential implications ahead for road travel, but an equally critical question is whether those technologies will change the way people behave. Our intellectual framework for considering how transport works depends on successfully modelling how people behave, and a fundamental shift in behaviour could put policies and forecasts into question. While there are limits to how far these questions can be answered before people are faced with new choices in the real world, early research allows us to gauge how likely disruptive change will be. We have therefore sought to understand whether there are any early indications of the extent to which travel behaviour could change in response to the emergence of new technology.

Ultimately, if large scale changes occur, they are likely to be brought about by shifts in user behaviour, rather than by the inherent capability of technology itself. In the twentieth century some changes to travel patterns did come about as vehicles became more reliable and sophisticated; but the greatest transformations came when people began adapting the way they lived and worked to take advantage of the car.

If transport innovations are adopted and revolutionise our roads, we should be open to the possibility of similarly profound changes in the years ahead. We can be relatively confident that new technology will make possible some journeys which are not feasible today. New market models and vehicle technology are also likely to mean that more people will have access to cars than at present. However, very little is currently known about how people might change their travel, lifestyle and work choices.

These choices are a combination of many different factors. In addition to reflecting what new technology makes possible, they also reflect what people want to achieve through transport, and what the public are willing to accept. This not only covers technical questions, but also how far people feel confident and able to place trust in the safety, reliability and usefulness of new technology. This can be challenging for people whose experience of road travel is firmly grounded in today's experience, who are unlikely to have tried the newest modes of travel, and who are often deeply invested in the transport choices they have already made.

We have therefore prioritised increasing our understanding of these social and behavioural dimensions, in particular exploring:

- public attitudes towards the adoption of new road transport technologies;
- how adoption of these new technologies might impact travel, lifestyle and work choices; and,
- how the public might react to new mobility services.

Research snapshot – Road User Perspectives on Emerging Vehicle Technologies and Shared Services

To explore how people might use new technologies, and in particular how they could respond to electric and automated vehicles and new mobility models, the Department commissioned a programme of social research involving drivers and non-drivers in London, Birmingham and Newcastle upon Tyne.

This research found a strong emotional connection to driving, with drivers associating it with choice, freedom and control. Car owners said they enjoy the freedom and independence they get from owning a car, and often saw their car as an extension of their personality and private space. They also saw ownership of a car as an unavoidable part of their lifestyle. While there was recognition that driving, particularly in urban areas, could be frustrating (due to congestion and the behaviour of other road users), there was nevertheless a strong attachment to travel in one's own car.

When participants were presented with emerging vehicle technologies they were comfortable with some technologies, such as EVs, which they saw as enabling them to make the same journeys more effectively and with less of an environmental impact. Their reactions to CAVs were more complex. In general, they were excited about the possibilities that the technology could open. They saw the technology as opening up mobility to groups who are currently excluded, especially older people or disabled people who are unable to drive. They also thought that the technology, if safe and reliable, could be a way to make journeys with less effort, especially if the roads are congested.

The implications for journey choices aren't clear, but some participants felt they would travel the same amount or more often by car if they had access to an automated vehicle. Participants did, however, have a number of reservations about the technology. Some felt uncomfortable with the idea of relinquishing personal control over driving. The research suggested that the public may not be fully aware of the potential benefits of CAV technology. They seemed more aware of potential disadvantages of the technology, such as potential safety or cyber security issues.

Participants were more sceptical about the potential for journey sharing, citing concerns over safety and personal space, although those who were currently making less frequent use of their car or who were travelling more via public transport were open to sharing with others in new service models. This represented a minority, but was more common in London where, for some, public transport options were already seen as more convenient than car travel for many journeys. However, many participants felt that shared-usage would represent a compromise on comfort and convenience. Drivers and passengers alike valued their own cars as a space in which they could control who they were in close contact with. Some participants also could not easily envisage how sharing would fit into their lives and schedules, especially for complex trips or trip-chains.

Based on our research, there is not yet evidence of an immediate change in the choices users make as soon as new technology becomes available. Many drivers are psychologically attached to their existing choices, and our wider analytical framework is likely to remain accurate while this continues to be the case. However the implications of this, against a backdrop of decreasing journey costs and more access to vehicles, is that road use could well increase. Traditional patterns of vehicle ownership could endure and still allow for people to frequently access mobility services on demand when required. And there is also a possibility that new technologies will facilitate increases in travel. Scepticism about sharing suggests that this may not automatically be counterbalanced by an increase in vehicle occupancy.

In the longer term, there is still potential for a significant shift in user attitudes, resulting in a paradigm shift in how transport is used. This will be harder to predict, although we are able to consider potential scenarios. We will continue talking to road users to see if, how and when new attitudes to transport emerge.

4. What this means for road demand

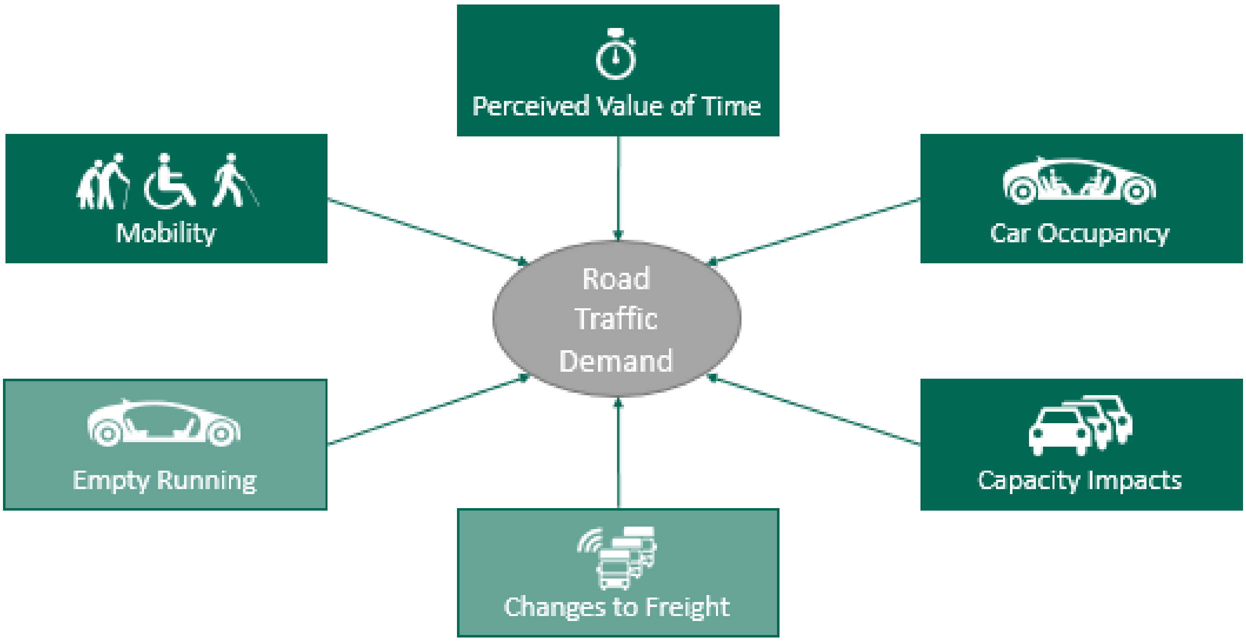
Road investment and policy decisions are informed by established transport modelling and appraisal practices, underpinned by forecasts of future road demand. Our current transport models and forecasts are based on evidence of historic and current drivers of demand and their relationship to individual and aggregate travel choices. Key drivers of demand include population, the cost of travel and economic growth. Forecasting future demand is complex and there is significant uncertainty about both future trends in drivers of demand and how they interact with demand. Uncertainty in inputs is dealt with in the Department's *Road Traffic Forecasts 2018* (RTF18)[13] by using a scenarios approach, constructing a number of different plausible future scenarios, for example, considering the impact of higher economic growth and lower fuel costs.

New technology adds to the uncertainty about the future trajectory of travel demand. If there is a 'roads revolution' ahead, it is unclear how far our existing understanding of the drivers of demand will continue to apply. To begin to address this, we have started to test how the introduction of CAVs may impact on demand through examining the levers in existing models. The purpose of this analysis is not to make forecasts about how emerging or potential technologies will impact on demand, but to better understand what aspects of these new technologies traffic levels might be most sensitive to. This will be used to inform the priorities for our future research. The following information is an excerpt from RTF18; more information on the narrative and underlying assumptions can be found in this publication.

We have considered a range of possible impacts on road traffic demand from CAVs shown in Figure 5 below. These were identified by reviewing emerging research in this area and consulting with both internal and external experts. These are first-order effects and there could be knock-on impacts which generate higher-order effects, for example decisions about where people live and work, which are not considered here. We have focussed particularly on the potential impact of CAVs on road demand; it is also possible for new technology and business models to change the nature of the public transport offer, thereby impacting road demand.

[13] At: www.gov.uk/government/publications/road-traffic-forecasts-2018

Figure 5: Potential Traffic Impacts of CAVs



a. Mobility

- People previously unable to travel by car may become able to do so, including those who do not currently hold driving licences and those who are physically unable.[14]
- Existing motorists may be encouraged to make more road journeys as new services and technologies make it easier to access a car.[15]

b. Perceived Values of Time

- The cost of driving, in terms of the value of time spent travelling, could change in the context of highly automated vehicles, as the vehicle could allow occupants to use their in-vehicle time more productively.[16]

c. Car Occupancy

- With the introduction of CAVs into the fleet alongside the adoption of new business models, ridesharing could become increasingly popular, potentially resulting in an increase in car occupancy rates, though early research suggests an existing reluctance to share journeys with strangers and that these sorts of service may be more likely to materialise in urban areas, for shorter journeys, rather than on the SRN.[17]
- Alternatively, CAVs could lead to a reduction in car occupancy. For example, lower vehicle running from more efficient driving and/or journey transaction costs could make private travel more viable and escort trips could be reduced. Empty running could also lower the average car occupancy rate.

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[14] Wadud, Z., MacKenzie, D. and Leiby, P (2016), *Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles*
[15] Institution of Mechanical Engineers, Low Carbon Vehicle Partnership and University of Leeds and Institution for Transport Studies (2016), *Automated Vehicles: Automatically Low Carbon?*
[16] Wardman, M. and Lyons, G. (2016), *The digital revolution and worthwhile use of travel time: Implications for appraisal and forecasting*
[17] Kantar Public, Department for Transport, *Future Roads: Public Dialogue*

d. Capacity

- Improved traffic management – vehicle-to-vehicle and vehicle-to-infrastructure connectivity could combine to improve traffic flow and reliability. These technologies could allow for safer and more efficient lane closures, and dynamic routing.
- Increased road space utilisation – road capacity may increase as vehicles could make more efficient use of the road, for example, by travelling with shorter headway.
- Research indicates the potential for disruption to traffic flow and capacity. Accounting for user preferences, comfort and safety it is plausible that CAVs could be more cautious than the current fleet.[18]

e. Freight

- CAV technologies could facilitate HGV platooning during off-peak periods, which could change operating models and journey times.

f. Empty Running

- At higher levels of autonomy, empty-running becomes a possibility, where cars travel on the road with no passengers. For example, if on demand access to CAVs emerges this would be a requirement for the system to function. This could increase pressure on the road network. There is significant uncertainty about when empty-running might occur, how it might work, and what business model might apply.

We have completed a number of sensitivity tests designed to help us better understand uncertainty and what assumptions about the consequences of future technology have the largest impact on demand. Of the six potential impacts discussed above we have conducted tests on four:

- *Mobility* – increased licence holding to 100% of adults by 2050 (as proxy for licences being potentially unnecessary with the emergence of fully automated vehicles) and increased trips rates for over 75s.
- *Perceived values of time* – lowered the value of time for car users by 25% by 2050.[19]
- *Car occupancy* – increased and decreased the average car occupancy rate by 0.2 from an average of 1.5 people per car.
- *Increased capacity* – increased road capacity between 20-40% depending on the road type, for example higher capacity benefits are assumed on motorways and dual carriageways.

Although these tests are informed by emerging research in this area, the evidence is of low maturity and as such these tests should be considered as a 'what if' analysis. More details on the methodology can be found in RTF18. Due to modelling capability it was not possible to conduct sensitivity tests on freight or the details of empty running.

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[18]Informed by Atkins (2016), *Research on the Impacts of Connected and Autonomous Vehicles on Traffic Flows*
[19]Informed by De Looff, E., Correia G., Van Cranenburgh S., Snelder, M. and Van Arem, B. (2018), *Potential changes in value of travel time as a result of vehicle automation: a case study in the Netherlands*

Quantified Technology Tests in the National Transport Model

We have looked to conduct a number of quantified tests within our modelling suite, whilst acknowledging the limited and uncertain nature of the evidence base. The outputs are sensitive to the input assumptions, which are based on evidence that is speculative due to the early nature of this research. We have only considered a limited number of tests and the range of uncertainty could be substantiality larger.

We also acknowledge the fact that the modelling suite is calibrated to the 'current state of the world' – one which could be very different to that proposed in the quantified tests. As a result, any modelling in this publication has used 'current state of the world' elasticities, which would be subject to change in a world where CAVs make up a significant proportion of the fleet.

The technology tests we have done have focused on transport technology and are unlikely to capture the full extent of uncertainty associated with future technologies. This includes the impacts of currently unforeseen technological innovations which may significantly impact upon road demand.

Although there is uncertainty around uptake rates of CAVs, we have only modelled one CAV uptake rate within these tests. This allows us to describe the impacts of CAVs on the network, independently from uptake levels.

Table 1 below shows traffic growth from 2015 to 2050, under the individual demand tests. These tests are pivoted off the reference scenario in RTF18 to allow comparability between scenarios and past publications.[20] Of the three demand tests, car occupancy rates have the largest impact on road demand. Comparing a test of increased and decreased car occupancy (behavioural shift towards ride sharing vs a shift towards increased private travel) traffic growth by 2050 ranges from 5% to 55%. The tests on values of time and mobility have a smaller effect, increasing traffic growth by 2050 by 5% and 7% above that of scenario 1 respectively.

Table 1: Results of Sensitivity Tests

Tests	Traffic Growth from 2015 to 2050
Reference Scenario	35%
Increased Mobility	42%
Decreased Perceived Value of Time	40%
Decreased Car Occupancy (Private Travel)	55%
Increased Car Occupancy	5%

The demand sensitivity tests have been split into two narratives, 'private, productive and mobile' and 'ride sharing'. Table 2 shows the assumptions for these.[21]

[20]The reference scenario in RTF18, is based on the central demographic and economic forecasts of the Office for National Statistics and the Office for Budget Responsibility. There are seven scenarios in RTF18 that represent different plausible future outcomes; these are considered equally likely.

[21] Standard refers to the standard assumptions made on these parameters in scenario 1-7 of RTF18.

Table 2: Assumptions in Narratives

Narrative	Mobility	Value of Time	Car Occupancy
Private, Productive & Mobile	Increase	Decrease	Decrease
Ride-Sharing	Scenario 1-7	Scenario 1-7	Increase

Traffic growth from 2015 to 2050, under the combined tests, ranges between 5% and 71% or from 300 to 500 billion vehicle miles per year, clearly demonstrating the wide range of uncertainty. The ride sharing test suggests the impact of this on demand would not be large enough to counteract the growth that would take place as a result of economic growth and demographic change in the reference scenario.

Figure 6: Technology Narratives – Traffic Growth from 2015 to 2050.

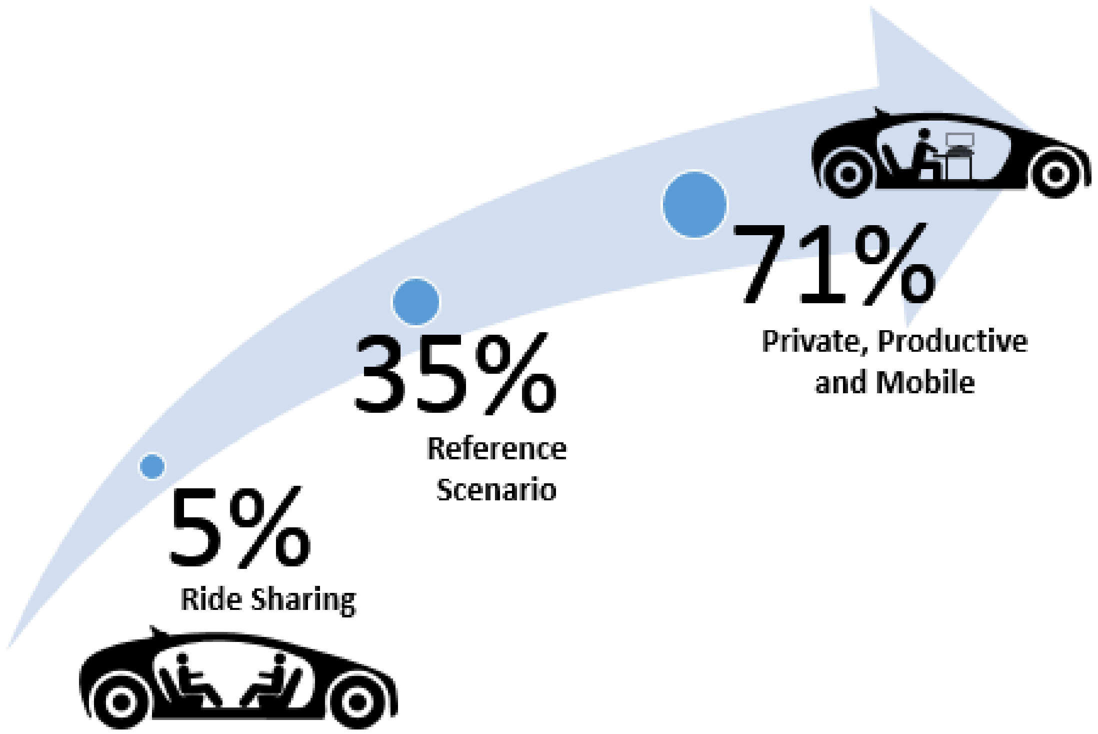

Table 3 show congestion results for increased capacity. To show two possible extremes on congestion we have coupled the ride sharing narrative with capacity improvements, while assumed standard road capacity on the private, productive and mobile narrative. The ride sharing and increased capacity test shows a positive picture for congestion, with traffic in congested conditions falling to a lower level by 2050 than 2015. This contrasts against the private, productive and increasing travel narrative with 24% of traffic in congested conditions by 2050.

Table 3: Results of Capacity Tests

Tests	Percentage of traffic in more than 80% congested conditions
Reference Scenario	11%
Private, Productive and Mobile - Standard Road Capacity in 2050	24%
Ride Sharing - Increased Road Capacity in 2050	5%

Ultimately, it is too early to say definitively whether new technology will increase or decrease aggregate road travel demand and congestion relative to our existing forecasts. Changes such as ride sharing could reduce road demand while reduced car occupancy (for example from empty running) could do the opposite. Although CAVs have potential to improve road capacity, there is also the possibility of disruptions to traffic flow and capacity. Given the range of uncertainty, technological developments cannot be relied upon to reduce future levels of congestion.

Whilst we believe the technology-focused sensitivity tests have explored some of the key elements related to CAVs that may impact road traffic demand, it is clear, given the level of uncertainty, that we should look to update our capability to model the impacts of such a significant shock to the transport system. These sensitivity tests have shown that any significant behavioural change related to car occupancy levels could impact road traffic demand considerably. We will continue to approach this area as a key focus of research in the near future.

5. What this has meant for policy

Despite the uncertainties, there are great possibilities if we embrace the potential of new technology. Cleaner, cheaper, safer, more available transport is in the interests of all. Britain could become a world-leader in a burgeoning new industry, with a transport network that marks it out as a global leader. A policy of 'wait and see' would miss these opportunities, and would lose the chance to shape the arrival of new technology to suit our country best.

Existing government policies already make important steps in this direction. We have:

- Created the Office of Low Emission Vehicles and the Centre for Connected and Autonomous Vehicles to establish the UK as a pioneer in new automotive technology. We are leading the world in terms of automated vehicle regulation and insurance.
- Committed that new conventional petrol and diesel cars will no longer be available for sale by 2040. To achieve this we have begun investing nearly £1.5bn to establish the UK as a leader in development, manufacture and use of EVs. This includes support for a range of vehicle and charging infrastructure grants and research into ultra-low emission vehicles, to drive continued uptake.
- Started testing roads technology of the future, with initiatives like the A2/M2 connected corridor; a HGV platooning trial on the SRN, and the suite of CAV trials we are backing in the West Midlands.
- Funded research into areas like the impacts of technology, public perceptions and digital infrastructure requirements.
- Worked across government departments to ensure a joined-up approach to issues like spectrum policy, mobile coverage on transport networks, and data security.
- Enhanced our analysis and policy development by incorporating scenario analysis to aid thinking about longer term possibilities and trend breaking directions.

Ultimately, future roads technology and mobility trends are well integrated into government policy, as demonstrated by ongoing investment in innovation through government as well as the recently announced Future of Mobility 'grand challenge' identified in the Government's Industrial Strategy. The potential for a roads revolution is one of the key considerations of the National Infrastructure Commission's assessment of future infrastructure needs.

These initiatives mean the UK has one of the most active and forward-looking policies in the world for advancing roads technology. However we are only beginning to understand the benefits, needs and consequences of emerging innovation and policy must adapt continuously if it is to stay up to date. We also recognise the difficulties and inherent risks in trying to predict the future: it is not government's role to select winning technologies, but instead to create the conditions in which innovation can prosper.

Alongside the development of the Future of Urban Mobility Strategy focusing on city roads mentioned earlier, there is also a need to ensure policy for the SRN is at the cutting edge. While there is not yet a consensus on the speed and scale with which new technologies will be taken up, we know that a number of innovations could be focused first on the SRN. Technologies such as 5G connectivity are likely to be justified best on our busiest roads; developing automated vehicle technology is able to operate most effectively on purpose-built highways; advances in data and AI can be more rapidly deployed into existing Highways England traffic control centres and utilise extensive existing infrastructure such as gantries and variable message signs The next RIS therefore needs to pioneer the adoption of new technology.

We therefore propose that RIS2 develops an approach based on three pillars in preparing for new technology:

- Continued research and trials;
- Key structural commitments supporting technology
- Allowing for flexible decision making in the future

We intend to continue with a world-leading programme of **research and trials**, involving both the Department and Highways England. This will aim to explore areas where our knowledge is limited, and where the capabilities of new technologies have not yet been tested, so that the uncertainties around future roads can be better understood. We intend to continue with existing efforts to test the latest technology along our roads, and to be at the forefront of new infrastructure standards. We also intend to support innovation by others, allowing the SRN to be a testbed for the latest new technology once it is safe for the open road.

We propose to make **key structural commitments** that make it easier for new technology to thrive:

- RIS2 expects to continue encouraging the spread of charging infrastructure across the SRN, to ensure that range is no barrier to EVs.
- We will remain committed to the open sharing of transport data collected by Highways England, so that third parties can use it to provide users with new services.
- Highways England remains the most authoritative voice on road standards in the UK. We intend to ask them to provide similarly authoritative guidance to other highways authorities on future-proofing roads.
- The system for assessing Highways England’s performance should encourage the use of new technology to deliver better outcomes to users.

A decisive commitment by government can help focus and accelerate positive technological shifts. As future trends become more certain, we expect to keep developing policies that help disparate technologies come together to improve road conditions for the user.

The Draft RIS

In addition to measures identified in other strategies and plans, the Draft RIS proposes key actions that Highways England will be expected to take in 2020-25 to ensure that it can lead the way in adapting the road network to future technology. Specifically it proposes that Highways England should:

- Be empowered to develop the infrastructure standards of the connected and autonomous era, by identifying how new technology can be effectively rolled-out across the network in a way that is both safe and speedy. This is likely to include:
  - Supporting vehicle manufacturers as they work to create the right flows of data and information to and from CAVs.
  - Making smart motorways suitable for regular use by automated vehicles as soon as possible in RP2, to meet the Government's ambition to see fully self-driving cars, without a human operator, on UK roads by 2021.
  - Making all-purpose trunk roads suitable for regular use by automated vehicles without the need for major upgrades to their physical infrastructure.
  - Creating guidance or standards that local authorities can use to bring autonomy to their network.
- Continue with existing provision of data, and ensure an open architecture that allows software developers to provide users with new services.

Where there is not yet certainty, we will aim to set policy in a way that allows for **flexible decision-making** in the future. For example, relatively little is yet known about the effects of automated vehicles on the freight sector. By the time RIS2 concludes in 2025, it is possible that some form of automated freight traffic could already be operating on our network. Highways England has a ring-fenced innovation fund within the current RIS, and we expect this to continue into RIS2. This will allow Highways England to continue installing cutting-edge technology throughout the period and to respond to trends that have yet to manifest themselves. We will also create provisions to allow more funding to be mobilised from other parts of the RIS, if the needs of technological adaptation prove greater than currently anticipated.

RIS2 will be finalised in late 2019, following advice from Highways England and the Office for Rail and Road. In the meantime, we intend to develop and deepen our policy for ensuring that England's strategic roads are at the forefront of this roads revolution. We therefore intend to engage with experts to best understand emerging technology, and to incorporate the latest thinking into our vision for the future.