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The UK private road transport system: how and why is it changing?

Future of Mobility: Evidence Review

Foresight, Government Office for Science

The UK private road transport system: how and why is it changing?

Dr Marc Stettler

**Centre for Transport Studies, Department of Civil and Environmental Engineering,
Imperial College London**

December 2018

This review has been commissioned as part of the UK government's Foresight Future of Mobility project. The views expressed are those of the author and do not represent those of any government or organisation.

This document is not a statement of government policy.

This report has an information cut-off date of April 2018.

Contents

1. Forecasts for the UK private road transport system

Main forecasts to 2040

There are a small number of forecasts for the future of private road transport activity up to 2040 in the public domain; these are summarised in Table 1. The most prominent forecasts are from the Department for Transport (DfT) using the National Transport Model (NTM), which was updated in 2015 to account for a wider set of uncertainties, including car ownership rates and trip rates in addition to income growth and fuel prices (Department for Transport, 2015a).

Table 1: Forecast changes for the private road transport system 2010–2040 (approximate figures)

Year	**Source**	**Vehicle km (billions)**	**Passenger km (billions)**	**Car fleet (millions)**	**Car ownership per person†**	**New car sales (millions)**
2010	DfT (2015a)	340		24	0.38–0.55‡	
	NISMOD (Hall et al., 2017)		630			
	UKTCM (Brand et al., 2017)			30		
	UKTCM (Brand et al., 2013)					2.4
	UKTCM (Brand et al., 2012)	408*				
2040	DfT (2015)	355–480‡		31–35‡	0.43–0.62‡	
	NISMOD (Hall et al., 2017)		650–950‡			
	UKTCM (Brand et al., 2017)			44**		
	UKTCM (Brand et al., 2013)					3.4***
	UKTCM (Brand et al., 2012)	490**				3.4**

† Lower and higher values represent London and South West regions respectively
‡ Range of values represents results from different scenarios
* Interpolated between 2007 and 2015
** Interpolated between 2030 and 2050 forecast
*** Interpolated between 2020 and 2050 forecast

Car traffic to increase in all scenarios

As Table 1 shows, the DfT forecasts that car traffic will increase in all scenarios to between 355 and 480 billion vehicle-km in 2040, an increase of between 4% and 40% relative to 2010 depending on scenario. The car fleet is also forecast to increase from 24 million to between 31 and 35 million. The **main driver** for the forecast increase in traffic levels is **projected population growth**. In addition to this, **rising incomes and falling costs** lead the DfT to predict an increase in the share of trips and distance per person travelled by car.

Other forecasts on the UK transport system shown in Table 1 include the UK Infrastructure Transitions Research Consortium's National Infrastructure Systems Model (NISMOD) (Hall et al., 2017), and the UK Transport Carbon Model (UKTCM) (Brand et al., 2012; Brand et al., 2013; Brand et al., 2017).

Unfortunately, reporting of the model outputs in these forecasts is not consistent with the DfT forecasts, which prevents comprehensive direct comparisons. The UKTCM forecasts of vehicle-km and fleet size in 2040 are above the range of forecasts for the DfT scenarios. An evaluation of differing methodologies and prediction of road traffic forecast models is a significant research gap.

Drivers for change in private road travel

Before publishing the 2015 forecasts, the DfT published a study into the drivers for change in road traffic (Department for Transport, 2015b), which are summarised in Table 2.

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Table 2: Drivers for change in road travel reviewed by Department for Transport*

Driver	Past trend(s)	Future trend(s)	Research needs
GDP, incomes and employment	Positive relationship between GDP and traffic. Correlation between fall in employment for young adults and driven km.	Some evidence for weakening relationship between GDP and traffic. Higher employment for females likely to increase traffic. Conversely, rise in part-time work likely to reduce traffic.	Evidence for causality, including how GDP translates to disposable income, updated fuel price and income elasticities.
Costs of driving	Costs have risen since the 1990s, especially in urban areas and for young adults, which could explain slow traffic growth in urban areas.	More efficient vehicles may reduce fuel costs, but it is unclear if this benefit will be more accessible to the wealthy. Long-term fuel prices will continue to affect costs and therefore traffic.	Effect of more fuel-efficient vehicles on costs of driving. Implication of low-emissions vehicles (e.g. electric vehicles) on total costs and car travel.
Company car taxation	Changes in company car use, and ownership has fallen since the 1990s, reducing total vehicle-km, especially for men.	Company car use cannot fall indefinitely, implying that the downward effect on car traffic will weaken (Le Vine & Jones, 2012).	Extent to which taxation scenarios will contribute to the cost of driving and therefore car travel.
Population growth	Increase in population of 3.8 million in decade up to 2012 was a primary driver of car travel. Population growth in urban areas does not drive traffic as strongly as growth in rural areas.	Car use per person has fallen in urban areas, likely due to the higher proportion of young people in urban areas and availability of other transport modes.	Effect of long-term trends of urbanisation on car travel with respect to different demographics.

Driver	Past trend(s)	Future trend(s)	Research needs
Migration	Migrants are more likely to live in urban areas and have tended to travel less by car. This is likely to have contributed to reduced car use in London and other urban areas in the last two decades.	Highly uncertain. It is not clear how migrants will travel in the future, and political decisions may affect the levels of migration.	Travel behaviour of migrants and their contribution to aggregate car travel is highly uncertain.
Technology	Some evidence that telecommuting can reduce the number of commuting trips; more likely among higher income groups.	Technological impacts are highly uncertain.	DfT evaluated evidence for effect of telecommuting but found very little evidence for effects of online shopping or social media. In addition, the effects of shared mobility, alternative vehicle powertrains and infrastructure are uncertain.
Household and family formation	The reduction in car ownership and car travel among younger people has coincided with people also delaying the age at which they have children and get married. Marriage or having a child is associated with a higher likelihood of owning a car.	There are a number of potential drivers for the delay of marriage or having children in young adults, which are not fully understood. Continuation of this trend would likely reduce car use.	Drivers for and quantification of the contribution of delayed life events on car use among younger people, and the effect of a delay in ownership on their future car use choices.

Driver	Past trend(s)	Future trend(s)	Research needs
Attitudes to driving and the environment	Cars are the most desirable mode choice due to advantages such as convenience, status. People who are pro-environment continue to travel by car unless they are young urbanites.	Some evidence younger cohorts are travelling less by car (Chatterjee, 2018). Environmental concerns may grow stronger after 'dieselgate'.	Continued assessment of any change in attitudes and affinities towards driving and owning a car. Evaluation of whether environmental concerns are changing and affect car use.
Market saturation	Market saturation refers to the ownership rates of cars, the trip rates by car, or the distance travelled by car. Household ownership of multiple cars has slowed.	Population growth would mean growth in the market, therefore alleviating any market saturation effects.	Market saturation and car travel patterns need to be evaluated across different segments of the population.
Network effects	Some evidence that limited road capacity increased congestion, potentially making driving less attractive and contributing to levelling off of car use.	If road capacity is constrained, congestion will make car travel less attractive. This is most likely in urban areas.	Quantification of the impact of capacity constraints in car travel. A study of US data suggests that increasing capacity leads to greater car use without alleviating congestion (Graham et al., 2014). How will future changes in capacity (e.g. AVs) affect car use?
Other factors	Weak evidence for other factors including: car clubs, location of new housing developments, education levels.	Highly uncertain; there has been rapid progress in shared mobility, albeit limited to urban areas and particularly London.	The impact of shared mobility options, e.g. car clubs, private hire vehicles (e.g. Uber) and ride sharing on car ownership and use.

* Information from Department for Transport (2015b)

Peak car: travel per person has plateaued

Car travel per person in the UK (and several other OECD countries) has plateaued in the last two decades and has not increased in line with forecasts, and is referred to as the ‘peak car’ phenomenon. Stapleton et al. (2017) summarised the proposed drivers for this trend, which include:

- Increasing income inequality and the worsening economic situation of young people (Klein & Smart, 2017).
- Increased uptake of higher education among young people, thereby delaying car ownership (Department for Transport, 2015b).
- Changing age structure of the population, with growing proportion of older people who drive less (Goodwin, 2012).
- Relative increases in non-fuel costs of car ownership (e.g. parking, insurance) (Le Vine & Jones, 2012; Department for Transport, 2015b).
- The approach of saturation levels of car ownership and driving licences (Delbosc, 2017).
- Changes in company car taxation reducing subsidised car travel (Le Vine et al., 2013).
- Replacement of car use by electronic communication combined with the growth of e-commerce, home working and online shopping (Metz, 2013).
- Changing preferences regarding ownership and use of cars relative to other goods and services (McDonald, 2015).
- Growing trends of urbanisation (Headicar, 2013).
- Increased congestion, especially on urban roads (Department for Transport, 2015b).
- Modal shifts encouraged by improvements to public transport, cycling and walking infrastructure (Department for Transport, 2015b; Goodwin, 2012).
- Declining marginal utility of increasing average trip length (Metz, 2013).
- Levelling off of door-to-door car speeds coupled with stable travel time budgets (Metz, 2013).
- The high rate of net immigration in the 2000s coupled with lower propensity to drive amongst immigrant communities (Headicar, 2013).

Using an econometric approach and aggregate data for car travel in Great Britain over the period 1970–2012, Stapleton et al. (2017) proposed that the most important factors affecting car travel are:

- Income: a 1% increase in income was associated with a 0.55% increase in vehicle kilometres.
- Urbanisation: a 1% increase in the proportion of the GB population living in the five largest cities was associated with a 1.7% decrease in the distance travelled.
- Fuel cost: a 1% increase in fuel cost per kilometre was associated with a 0.26% decrease in vehicle kilometres.

However, a limitation of this approach is the use of aggregate data that could obscure trends in different groups of the population and spatial variability. The authors suggest that further analysis using a wider spectrum of data is required, e.g. travel survey and consumer expenditure data.

Marsden & McDonald (2017) provide a detailed discussion of institutional issues in planning for uncertain futures, and discuss the failure of previous road transport forecasts to predict peak car.

The following sections review user engagement with private road transport and the technological drivers that may influence this in the next two decades or so.

2. How are users engaging with the private road transport system?

The private car enables people to determine their own physical movement to access to employment, services and goods that is necessary to achieve a desired quality of life. Car ownership is the primary way of accessing a car, but a range of alternative models are emerging and the private road transport system is thought to be in a state of flux (Morton et al., 2017).

Older drivers

By 2040, nearly one in seven people is projected to be over the age of 75 (Government Office for Science, 2016). Around the same time, one in 12 of the population will be over 80 (Office for National Statistics, 2015). The percentage of people over 70 who have a driving licence rose from 38% in 1995/97 to 58% in 2012, and this this is forecast to keep increasing, to ~70% in 2030 (Mitchell, 2013). As people who are 70 or over in 2040 will be used to driving and will be in work for longer, **there may be an increase in the activity of older drivers in the private road transport system** (Musselwhite et al., 2015; Shergold et al., 2015).

Ageing can impair sensory, psychomotor and cognitive abilities, which may affect driver performance and safety. Accident rates for older drivers (70+) are relatively low, but over-80s are more likely to be involved in accidents (Mitchell, 2013). Older drivers are most likely to suffer fatal injuries as a result of car accidents; of drivers aged 70+ involved in a killed or seriously injured (KSI) accident, 14% were killed (Road Safety Observatory, 2017).

Staying connected to communities and social networks is associated with positive mental and physical health (Musselwhite et al., 2015). Technologies, such as driver assistance and vehicle automation (discussed below), may help to improve the safety of the private road transport system for older drivers. A higher adoption of these technologies may further increase mobility by car of the growing number of older people, significantly increasing private road traffic in 2040. Further research is needed into the way older drivers accept, adopt and make choices regarding these technologies.

Young drivers

Since the mid-1990s **car use among young adults has declined**, both in terms of the proportion of young drivers holding a driving licence and the number of annual miles driven. This is clearly related to place of residence, with young adults living in London significantly less likely to hold a full UK drivers licence than those in other urban areas. Those living in rural areas are most likely to hold a driving licence. The main determining factor in annual mileage is whether the young adult drives themselves to work (Berrington & Mikolai, 2014). When surveyed, British young adults cite a number of reasons for not getting driving licences, including the financial costs (learning, insurance, car purchase), and higher personal income relates to a greater likelihood of holding a licence (Le Vine & Polak, 2014).

Factors affecting future car use

Implications for future private car activity are that **increases in educational enrolment**, **unemployment, the proportion of young adults living in the parental home, or stagnating incomes** for this demographic, may be associated with **declining car use** among young adults. Conversely, future increases in the level of education, female employment and young adult incomes may be associated with an increase in licence holding and car use (Berrington & Mikolai, 2014; Le Vine & Polak, 2014). Further research is required to understand the interaction of these potential trends, but the evidence also suggests there are many policy levers that could be used to promote or deter car use among young adults.

Furthermore, recent evidence also suggests that young adults (16–21) in the UK do not have a cultural affection for car ownership, but rather see it as another mode of transport that facilitates access to work and sociability (Green et al., 2017). This indicates that car use among young adults may be determined by a rational comparison against other modes of transport and is contrary to the assumption stated in a DfT report (Department for Transport, 2015b).

Car dependence

The term *car dependence* is generally used to describe the difficulty of moving away from the car system, despite the increasing awareness of the negative impacts. It has been examined at different scales; from individual attributes (micro), to trips and activities (meso) and to attributes of societies or local areas (macro) (Mattioli et al., 2016).

At the individual **micro-level**, there are numerous analyses about people’s preferences for car travel even if other modes are available, and in terms of reliance on cars due to a lack of alternative options. This second ‘structural’ argument is generally linked to **macro-scale** analyses of the role of urban form and population density in determining car use, and lack of public transport alternatives (Newman, 2014). Recent analyses of car use by activity (**meso-scale analysis**) suggests that there are certain activities for which a car is the only viable option, particularly where a car is useful for carrying cargo. For example, taking waste to recycling centres is highly dependent on cars. One implication of this meso-scale analysis is that transport policy needs to be joined up with other areas of public policy (such as waste disposal). The second implication is that owning a car to fulfil car-dependent activities may increase the likelihood of car travel for other activities, even if other modes are available (Mattioli et al., 2016).

Another example of car dependence is given by evidence from the RAC Foundation that one in six jobs advertised on the government’s employment database requires a driving licence or access to a vehicle (Makwana, 2016).

Further research is required to evaluate car dependence for particular activities paying greater attention to spatial dependence using spatially disaggregated data on car use, e.g. from MOT data (Chatterton et al., 2015). This also highlights that the future trends for private car use will be influenced by industrial strategy (e.g. availability and type of jobs) and other areas of public policy that affect activities that are currently car dependent.

Shared mobility

The average car in the UK spends 96% of the time parked (Bates & Leibling, 2012). Shared mobility is the shared use of a vehicle that gives users short-term access to car travel on an 'as-needed' basis and includes services such as car sharing, bike sharing, on-demand ride services, ride sharing, micro-transit and courier services (Stocker & Shaheen, 2017). This review focuses on the services that use cars, and are therefore more likely to compete with traditional ownership models. There are several shared mobility business models:

- **Car sharing**. Members of car sharing schemes (car clubs) have access to vehicles in return for a joining fee or annual membership fee in addition to usage fees, levied by time or distance. In some schemes (e.g. Zipcar), the car must be returned to a designated parking space, while in other schemes the car may be used for a one-way journey and parked at the customer's destination, as long as it remains within a designated service area (e.g. DriveNow). Fuel and insurance costs are typically included in the pricing scheme. One-way car sharing schemes tend to have a higher frequency of usage per customer than round-trip car sharing (Le Vine & Polak, 2017). In London, the number of car club members increased by 20% to 186,000 between 2014/15 and 2015/16 and 34.5 million miles were travelled in car club cars in 2015/16 (Bewick et al., 2016).

- **Ride sourcing**. Ride sourcing services provide pre-arranged or on-demand travel by connecting drivers with passengers, commonly through smartphone apps. While this is similar to minicabs, convenience and low costs have seen the use of private hire vehicles (PHVs, e.g. Uber, Addison Lee) increase significantly; the number of PHVs (87,409) and PHV drivers (117,712) in London have increased by 39% and 50% respectively since 2015, while the number of taxi drivers has remained stable (24,487) (Transport for London, 2017b).

- **Ride sharing**. Ride sharing includes peer-to-peer carpooling, where drivers can offer rides to other members of the ride-sharing service, typically for long-distance planned trips (e.g. BlaBlaCar). Ride sharing can also take place through ride sourcing apps, for instance uberPOOL, which matches passengers travelling in the same direction, so that they can share the vehicle and cost of the trip.

Impact of shared mobility schemes

The evidence for the impact of these shared mobility schemes is still limited, but there is emerging evidence of highly diverse effects on car use. A US study has found that the availability of **car sharing schemes** can reduce car ownership, by suppressing vehicle purchases among some members, and overall distance travelled by car (reduction of 6–16%). However, the scale of the impact depends on the user, the city and other environmental factors (e.g. availability of other modes of transport) (Shaheen et al., 2016). Evidence for London also suggests that car club membership leads to lower levels of car ownership and reduced distance travelled by car (reduction of 730–840 miles per year per member) and also that the vehicle occupancy is higher for car club trips (around 2.5), compared to the national average (1.6) (Berwick et al., 2016). More early evidence from London suggests that income level is a large factor in determining the effects of car clubs; people on moderate incomes are more likely to reduce car ownership than those on high incomes. There is evidence that non-car-owning households use the car club for the cargo capability – one of the aforementioned drivers for car dependence (Le Vine & Polak, 2017). Further research is required to understand how car clubs affect behaviour through life-course events (e.g. marriage, children) and as the services evolve (e.g. price levels, service coverage) in different environments (e.g. parking availability, public transport provision), and across different users and trip activities (Le Vine & Polak, 2017).

Evidence for the impact of **ride sourcing** and **ride sharing** on travel behaviour is very limited. One US study of ride sourcing users in San Francisco found that if ride sourcing were unavailable, 39% would have taken a taxi, 33% would use bus or rail, and 6% would drive their own car. In other words, ride sourcing was taking trips away from both taxis and public transport. However, there is little evidence for the effect of ride sourcing on generating trips that otherwise would not have happened, or on overall car use, even though ride sourcing allows users to drive less themselves (Rayle et al. 2016).

The impact of shared mobility on future car use is highly uncertain. However, it is an area where policymakers can have significant impacts given that car sharing schemes require public sector agreements for parking spaces, and ride sourcing of PHVs requires approval from a licensing authority (Le Vine & Polak, 2017).

Road pricing

Fuel duty generated £27.9 billion, or 1.4% of UK GDP, for the Treasury in 2016–17. The Office for Budgetary Responsibility has identified that improvements in fuel efficiency of vehicles (discussed below) pose a risk to tax revenues and forecasts that income from fuel duty will reduce to 1.00–1.12% of GDP by 2030 (Office for Budget Responsibility, 2017). Recently, the idea of **road user charging** (a.k.a. road pricing) has been raised, after government proposals for a road pricing scheme were abandoned in 2007 due to public opposition (Tetlow & Campbell, 2017). A number of studies have evaluated the effectiveness of road pricing in reducing congestion and other externalities of road transport (Glaister & Graham, 2003; Johnson et al., 2012). The likelihood is that road pricing would make the cost of car travel more transparent and raise the cost of driving electric vehicles, which do not currently pay fuel duty. There are limited applied cases, but there is evidence for significant effects on car travel behaviour (Gibson & Carnovale 2015).

Road pricing is a significant uncertainty to 2040, not in terms of the science but because there is uncertainty in government and public attitudes. However, the reduction in government income, through fall in fuel duty as electric vehicles become more widespread, is likely to require the motoring tax system to be revised, and therefore this uncertainty should be built into forecasts. In some possible future transport models, such as transport as a service, pricing may be easier to factor in to the overall provider costs; however, how and if pricing will manifest remains a key uncertainty.

3. The effect of technology on the private road transport system

Forecasts for the effect of technology on the road transport system have tended to focus on the potential of new vehicle technologies to **reduce transport carbon dioxide (CO_2) emissions** (Martin et al., 2017; Brand et al., 2017; Brand et al., 2013). However, a research gap exists in evaluating potential interactions between new technologies and car travel demand. This section summarises **environmental drivers of technology** and then the highly uncertain **effects of autonomous vehicle technologies**. The time lag for penetration of new technologies has been studied for the case of low-emission vehicles in Norway (Fridstrøm, 2017), but this appears to be a research gap for the UK.

Environmental drivers of technology

Climate change and air quality are the two main environmental drivers that are affecting the development of vehicle powertrains. Recent evidence has found that vehicle emissions of CO_2 and noxious pollutants, specifically nitrogen oxides, are significantly higher in real-world driving compared to regulatory lab testing (O'Driscoll et al., 2016). The European Commission has a target to reduce fleet average CO_2 emissions by about 20% compared to today (95 gCO_2/km) (European Commission, 2017b). From September 2017, the European Commission introduced more effective emissions testing that will address real-world emissions and force manufacturers to invest in low-emissions technologies (European Commission, 2017a).

Moves to achieve compliance with clean air standards

Air quality in cities is improving in general; however, at the time of writing (April, 2018) concentrations of nitrogen dioxide **(NO_2) were higher than European air quality standards at many roadside locations** (DEFRA, 2017a and 2017b). The 2017 Air Quality Plan from Defra predicted that 29 out of 43 zones in the UK would remain non-compliant with NO_2 regulation in 2020 and that 2 out of 43 zones would still be non-compliant in 2025 with current policies [1] (DEFRA, 2017b).

The plan states that **Clean Air Zones** which impose a financial penalty on older vehicles (older than Euro 6 diesel and Euro 4 petrol) are likely to be the only way to achieve compliance with NO_2 concentrations in the most polluted zones (Defra, 2017). From 23 October 2017, a **toxicity charge** (T-charge) of £10 per day was levied on vehicles that did not meet the required emissions standard (Euro 4 for both petrol and diesel cars). Furthermore, an ultra-low emissions zone (ULEZ) will be introduced as early as April 2019, which will impose a daily charge of £12.50 on cars that do not meet required emissions standards (Euro 4 for petrol and Euro 6 for diesel cars) (Transport for London, 2017a).

These charges incentivise people to switch to cleaner vehicles by increasing the cost of car travel in non-compliant vehicles, and potentially make other transport modes more attractive to those that cannot afford to upgrade their vehicle. There is evidence that the bad publicity surrounding diesel cars is depressing diesel sales at a national level; UK diesel car sales fell by

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[1] These numbers are taken from Table 6.2 in DEFRA (2017b)

21% for August 2017 compared to August 2016, while sales of alternative vehicles grew by 58% in the same period (SMMT, 2017).

Implications of low-emission vehicles for future private road transport

1. **Internal combustion engine vehicles with lower emissions may be more expensive** due to higher costs of emissions control technologies. Until economies of scale reduce costs, then alternative fuelled vehicles (e.g. electric vehicles) will also be more expensive in terms of the upfront purchase cost (Bishop et al., 2014). This could incentivise shared mobility by allowing the higher capital cost to be spread across more trips.

2. **Lower-emissions vehicles will likely be more fuel efficient** and reduce the cost of each vehicle-kilometre travelled in a car. A ‘rebound effect’ can occur when a price drop induces more activity, and high-level econometric studies show that a 1% reduction in fuel costs is associated with an approximate 0.2% (0.09–0.36%) increase in vehicle kilometres travelled (Stapleton et al., 2016; Stapleton et al., 2017).

The **relative costs of different vehicle technologies** will have a large impact on the adoption of different powertrains, and forecasts for adoption should account for the complexity in the passenger car market, and differences in driving behaviour (Contestabile et al., 2011; Tran et al., 2012).

Automation: connected and autonomous vehicles (CAVs)

Connected and autonomous vehicles (CAVs) are vehicles used to move passengers or freight with some level of connectivity to other vehicles and to infrastructure, and with automation that assists or replaces human control. CAVs are already used in controlled environments (e.g. London’s Docklands Light Railway), and many in the automotive industry predict a **revolution in passenger transport** that will be unlocked by automation. **CAVs are expected to bring benefits in terms of**:

- productive time
- safety
- increased road capacity
- accessibility
- reduced environmental impact of road transport (KPMG, 2015).

Advanced CAV technology development began in 1977 in Japan and today over 30 companies around the world are developing CAV technology, including most vehicle manufacturers. Most vehicle manufacturers that have announced plans for CAVs already offer or plan to release vehicles with some automated features in 2017. By 2017, eleven companies had claimed that they would have highly automated vehicles (Level 4 or higher, see Table 3 for definitions) by 2020. Companies claiming to be at the forefront of deploying CAV technology include NuTonomy, who plan to deploy fully automated taxis by 2018, and Tesla Motors, which announced that their new vehicles will be equipped with the hardware necessary for full autonomy by the end of 2017 (Stocker & Shaheen, 2017). Separate agencies are predicting that all cars will be CAVs by 2035, others that CAVs will make up 75% of car sales by 2035, while another is predicting that CAVS will account for 9% of sales in 2035 and 90% of sales in 2055. Experts believe that fully automated vehicles are 20–30 years away (Stocker & Shaheen, 2017; Flaig, 2017). KPMG has produced forecasts for production of CAVs to 2030 (KPMG, 2015).

CAVs and traveller behaviour

Historically, improvements in road capacity have not improved average vehicle speeds or congestion as more road space attracts more drivers (Graham et al., 2014). The impact of CAVs on traveller behaviour is also highly uncertain and complex. Increases in road capacity as a result of CAVs may induce car travel, as with previous efforts to increase road capacity. Furthermore, since CAVs enable their occupants to do something with their time, people may be willing to spend more time travelling (Van den Berg & Verhoef, 2016). Both of these aspects reduce the cost of car travel, which could in turn induce more people to travel, and travel significantly further by car (Wadud et al., 2016; Harper et al., 2016).

A synergy may exist between **vehicle automation, shared mobility** and **electrification**; higher vehicle utilisation through automation of shared vehicles would make electric vehicles more cost competitive and mitigate the environmental consequences of more car travel (Offer, 2015).

Uncertainties over CAVs

A report for the RAC Foundation (Johnson, 2017) highlighted that there are still a number of significant uncertainties over CAVs, relating to:

- the readiness of the road infrastructure
- training and testing of new drivers
- interactions between CAVs and other road users
- the safety of vulnerable road users
- CAV parking and breakdowns

There is also little evidence for the impact of different CAV strategies on the condition of road infrastructure, its maintenance, renewal and configuration requirements, and road signage/marking requirements. Examples from the aviation and rail sectors indicate that more advance infrastructure requires higher costs of maintenance.

The majority of studies conclude that governments' planning decisions will affect the speed at which CAVs are adopted, whether they interact with shared mobility and electrification, and the infrastructure cost.

Table 3: Society of Automotive Engineers (SAE) vehicle automation level definitions (SAE 2014).

Automation level	**Description**
Level 0	No automation
Level 1	Automation of one primary control function, e.g. adaptive cruise control, self-parking, lane-keep assist or autonomous braking
Level 2	Automation of two or more primary control functions which can work together to relieve the driver of control of those functions
Level 3	Limited self-driving; vehicle can control all safety critical functions under certain traffic or environmental conditions. Driver needed for occasional control with adequate warning
Level 4	Full self-driving without human controls within a well-defined operational design domain, with operations capability even if a human driver doe not respond appropriately to a request to intervene
Level 5	Full self-driving without human controls in all driving environments that can be managed by a human driver

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5. Appendix: Methodology

A literature search was conducted for this review using combinations of the keywords shown in Table 4. Relevant references were compiled and reviewed. Citing articles were also searched.

Table 4: Keywords for literature search

Infrastructure	Activity	Agent	Engagement	Technology	Time
Road	Mobility	Private	Availability	Autonomous	Trend
	Car	Shared	Tax	Electric	Current
	Vehicle		License	Fuel	Future
			Insurance	Powertrain	Forecast
			Maintenance	Intelligent	Projected
			Parking	Smart	
			Infrastructure		

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