Connected and autonomous vehicles are expected to lead the next urban transport revolution – transforming urban mobility and the way roads are managed. Fraser Davidson and Elisabeth Selk of Arcadis examine how urban transport management could adapt for a new era of personal transportation.

INTRODUCTION
The UK’s first traffic lights were installed on Piccadilly Circus in 1926. As traffic volumes have grown and as a wider range of users – including pedestrians – compete for their share of access to road space, the challenge of maintaining traffic flow and minimising congestion has expanded. With traffic volume in the UK increasing by an average of 2% over the past three years, this is not a problem that will go away soon.

An urban transport revolution, enabled by connected and autonomous vehicles (CAV) and mobility as a service (MaaS) threatens to up-end many of the assumptions that underpin current traffic management practice – particularly with respect to traffic volumes and flows.

Congestion in London alone costs £4bn a year in lost productivity, so traffic management plays an essential role in regional competitiveness. However, the role of roads and the value derived from them extends far beyond their immediate purpose as traffic arteries.

The Mayor of London’s draft transport strategy, focused on promoting the role of public transport and healthy streets, aims to reduce the share of journeys undertaken by car to 20% by 2041 – highlighting the role of traffic management strategy in mediating between different road-users.

Ensuring that roads are people-friendly will continue to be a central pillar of traffic management strategy – whether or not autonomous vehicles take off.

Tools available to manage traffic flow are becoming much more sophisticated. Smart phones and connected vehicle technologies are already creating opportunities to get more out of existing road networks by increasing the ability of managers to secure marginal gains in traffic flows.

Enforcement will also have a greater role, not only to ensure that roads are safe, but also to generate the revenue to manage them.

In the future, the challenge of accommodating autonomous vehicles within the existing road system, and the wider adoption of MaaS offerings will require traffic management systems to balance the needs of an even more diverse pattern of road use within the constraints of the existing network.

THE ROLE OF ROAD TRAFFIC MANAGEMENT IN THE UK ECONOMY
The existing road network is the main artery for journeys and freight movement in the UK but is a scarce resource that needs to be used intelligently. Everyone relies on transport systems and everyone needs smooth, reliable and safe journeys. Despite London’s well-developed rail and tube network, 80% of journeys are on roads, including 6 million a year by bus and a further 6 million journeys on foot. The vast number of pedestrian journeys recorded in London highlights the fact that roads are social and economic spaces as well as transport arteries. Traffic management systems also have a significant health and safety role – associated both with air quality management and reducing the number of accidents using proven traffic calming technologies such as the variable speed controls seen on smart motorways. Given that 9,400 equivalent
changes such as the rapid growth in “white-van” deliveries, driven by internet-based shopping, requires an increasingly sophisticated approach to road network management. One of the big benefits of the introduction of the combined authorities, for example, will be that it will facilitate the central management of strategic arterial routes, the ones that suffer most congestion, on an area-wide rather than local authority basis. Manchester and Birmingham have both invested in a network-wide capability based on the integration of separate, legacy systems. The overall objective of a traffic management strategy is to facilitate free-flowing traffic with greater certainty. Additional capacity is not always a priority. Outcomes that traffic management systems are designed to deliver include:

- Network capability – accessibility, public transport capacity and reduction of casualties.
- Network operation – system capacity, traffic flow and road user satisfaction.
- Management of planned and unplanned events. Given that most of the causes of delay are related to external events – collisions, breakdowns and roadworks – the capability of an LTA to manage the network in real time is increasingly valuable. Now that MaaS – facilitated by Uber and car clubs – is established in the UK’s larger cities, the flexibility to manage changing traffic patterns can be expected to become a source of regional competitive advantage. Cities such as New York, for example, are already considering how autonomous vehicles could be integrated with the subway system. This thinking recognises the massive impact that CAVs could have in transforming the “final mile” of many urban journeys.

CONNECTED AND AUTONOMOUS VEHICLES

The development of CAV solutions and the availability of “always-on” digital services is expected fundamentally to reshape urban transport. With CAVs and their supporting infrastructure already being developed and tested on UK roads in Bristol, Coventry, Greenwich and Milton Keynes, some of these changes are taking shape.

A fundamental question for transport planners to resolve is the target level of vehicle automation. This will determine an implementation plan that will need to strike a balance between the medium term demands of mixed traffic and anticipating longer term requirements of a predominantly CAV fleet. The issues associated with this implementation are inevitably highly complex and could turn on whether the preferred autonomous technologies (e.g. autonomous concepts developed by Google and Tesla) can work within the existing infrastructure or whether a dedicated infrastructure will be needed to support CAV operation, such as dedicated lanes on selected roads.

CAV solutions are best viewed as part of a wider “system of systems”. The integration of CAV technology into new mobility services systems is expected to drive the biggest changes in multi-modal transport. Integrated booking and payment systems, for example, could start to bring together public and private transport networks including buses and metros, pay-as-you-go hire cars and ride hailing services such as those already offered by Uber. At current levels of evolution, the key systems are as follows:

- Connected vehicles are vehicles that use different communication technologies (wireless, internet, GPS) to communicate with the driver, as well as other vehicles (V2V), roadside infrastructure devices (V2I) and pedestrians (V2P), collectively referred to as V2X. Increased connectivity will create significant opportunities to improve performance and safety.
- Autonomous vehicles are those in which operation of the vehicle requires varying degrees of driver input to control steering, acceleration, and braking. Definitions for autonomy levels are summed up in Table 1 on the next page.
- New ownership and mobility models. The combination of MaaS and vehicle autonomy is creating real excitement with respect to the future of multi-modal travel. With users potentially moving away from car ownership to paying for multi-mode travel on demand, it is foreseeable that a completely new generation of digital transport providers will emerge in cities, in both the public and private sectors. Given the rapid adoption of “touch in and out” ticketing, car clubs and private car sharing, the potential for change is huge, and is expected to be influencing traffic systems within the next 15–20 years.
CAVS (CONTINUED)

Levels 1 to 3 are known as "something everywhere" solutions, providing many of the benefits of connectivity and autonomy, but capable of operating safely in all road environments where a supporting infrastructure is not available. Some technology development scenarios envisage a managed progression of technologies, anticipating for example that the predominance of conventional cars will limit the extent to which it is safe and acceptable from a regulatory and legal perspective to mix vehicles with different technologies. These scenarios envisage that, by driving in a smoother and more efficient way, CAVs are likely to have a positive effect on overall traffic flows. Some developers such as Google plan to move straight to fully self-driving vehicles (Level 5), on the assumption that the only reliable approach to ensuring CAV safety is to load the vehicle with its own independent technology. Which scenario will prevail will depend not only on the availability of suitable technologies and the speed of roll-out, but also on the preferences of drivers and other stakeholders. What can be certain is that, should CAV technologies be adopted at scale, the wider social and economic impacts will be extensive, as Table 2 (below) summarises.

### Table 1: Levels of vehicle autonomy

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Description</th>
<th>Example</th>
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<tbody>
<tr>
<td>0</td>
<td>No automation</td>
<td>Human driver completely controls the vehicle</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>Driver assistance</td>
<td>Individual activities that assist steering or acceleration/deceleration are partially automated</td>
<td>Park assist</td>
</tr>
<tr>
<td>2</td>
<td>Partial automation</td>
<td>Several, simultaneous activities that assist steering or acceleration/deceleration are partially automated</td>
<td>Traffic jam assist</td>
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<tr>
<td>3</td>
<td>Conditional automation</td>
<td>In certain driving scenarios, all dynamic, non-strategic, driving activities (e.g. vehicle control but not route choice) are automated but human is expected to intervene when requested</td>
<td>Automated motorway driving</td>
</tr>
<tr>
<td>4</td>
<td>High automation</td>
<td>In certain driving scenarios, all dynamic driving activities are automated and vehicle can cope without human intervention except when requested</td>
<td>Urban automated driving</td>
</tr>
<tr>
<td>5</td>
<td>Full automation</td>
<td>Always and everywhere, all dynamic driving activities are automated with no need for human intervention</td>
<td>Full end-to-end journey</td>
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### Table 2: Summary impacts of CAV technology

<table>
<thead>
<tr>
<th>Potential Benefits</th>
<th>Possible downsides</th>
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<tbody>
<tr>
<td>Safer driving resulting in better health outcomes, improved traffic flow and reduced driver stress</td>
<td>Limited improvements in safety due to continuing mix of conventional and autonomous vehicles</td>
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<tr>
<td>Accelerated adoption of MaaS at scale, reducing overall number of vehicles in cities</td>
<td>Vehicle ownership remains persistent, holding back the achievement of scale of MaaS offerings</td>
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<tr>
<td>Reduced accident risk drives lighter and more fuel-efficient vehicle specification (towards EV)</td>
<td>Focus on increased user comfort drives preferences for larger vehicles</td>
</tr>
<tr>
<td>Increased mobility for non-drivers (young, old, disabled), reducing potential social exclusion</td>
<td>Continuing need for investment across a wide range of transport modes with risk that MaaS will crowd out other investments</td>
</tr>
<tr>
<td>Creates demand at scale for centrally provided transit vehicles</td>
<td>Replaces demand for mass transit solutions and creates more road congestion</td>
</tr>
<tr>
<td>Decreases up-front costs for the owner (driver, energy use, physical traffic systems)</td>
<td>Increases system costs (complex technology, maintenance of infrastructure, system operation)</td>
</tr>
<tr>
<td>Lower levels of vehicle ownership reduce requirements for parking and congestion</td>
<td>Car use increases, fostering congestion</td>
</tr>
<tr>
<td>More efficient traffic management reduces congestion</td>
<td>Partial adoption of CAV solutions reduces some road capacity</td>
</tr>
<tr>
<td>Land dedicated to urban parking freed up for redevelopment by continuous operation of AVs</td>
<td>Self-driving taxis and self-parking cars increase empty car travel and congestion</td>
</tr>
<tr>
<td>More effective demand management sharing of road space</td>
<td>Crowding out of pedestrians and cyclists</td>
</tr>
<tr>
<td>New opportunities: vehicle ownership, transport derived revenues, urban regeneration</td>
<td>New risks: system failure, security, privacy (e.g. all aspects of vehicle activity will be tracked and will be linked to the user/licence holder) and ethics</td>
</tr>
</tbody>
</table>
Evolving Traffic Management Solutions

The evolution of traffic management systems in the UK is a case study in how the availability and application of data has enabled cost effective increases in road network capacity.

This has been achieved alongside building capability to manage new, traffic-related policy outcomes such as pollution levels.

The challenge of CAV and MaaS is that it will promote modal shifts – changing patterns of usage and demand that will need to be accommodated in a reconfigured transport network. This will be managed using different assumptions and algorithms. Technology providers are already anticipating this challenge by investing in vehicle-to-infrastructure (V2I) communication and data exchange, so that systems and vehicles can interact directly.

As with most systems, there is a close relationship between the detail, accuracy and timeliness of the data and the ability to manage system outcomes. The promise of the smart phone and connected vehicle revolutions is that system management could become more automated and more responsive to conditions on the ground. However, to achieve this outcome, the level of complexity in network analysis, modelling and management will increase significantly. Furthermore, significant investment in the safety integrity of systems in line with safety integrity levels (SIL) standards will be needed if automated operation is to take place.

Network operation is becoming a key feature of transport management networks. Traditionally, traffic signal sets – the bedrock of traffic management – have operated in isolation.

Use of network technologies to manage traffic signals as a system typically delivers big benefits, reducing delayed journeys on corridor routes by 12% to 20%. The fact that major cities such as London and Manchester continue actively to extend the use of smart technologies such as Scoot (split cycle offset optimisation technique) highlights the potential for incremental gains in network performance. However, at present, not all controls can be operated in a system and alternative technologies are available.

The ways in which smart systems can improve network performance include:

- Optimising signal timings on a transport corridor to eliminate hot-spots and pinch points. The aim is to create “green waves” of traffic that pass through a number of junctions without stopping. Avoiding stop-start traffic flow improves the reliability of journey times, and reduces pollution.
- Responding to local traffic volumes to optimise cycle-times – particularly where traffic volume is low. This reduces the frustration of unnecessarily long signal cycles.
- Supporting civil enforcement of traffic related offences as part of a wider mobility strategy.
- Implementing pre-planned system-wide traffic management scenarios to mitigate the impact of planned events.
- Reducing the impact of unplanned events such as vehicle collisions by managing traffic in real time to stabilise the operation of the road network.
- Enabling signal prioritisation for buses and other public vehicles. This improves the speed and punctuality of public transport journeys, typically reducing delays by 5% to 15%.
While much of this functionality can be automated, systems operation continues to rely on human intervention. The technology has become much more sophisticated and user friendly, but effective traffic management continues to rely on experienced traffic managers with the skills to be able to interpret and act on real-time data and modelled traffic scenarios.

**TRAFFIC MANAGEMENT INNOVATION**

Current innovation is focused in part on making traffic networks even more responsive to real-time road conditions – either eliminating waits at junctions and pedestrian crossings in low traffic conditions, or by automatically detecting and implementing planned responses to road traffic accidents. A new system being trialled in France, GLOSA (green light optimised speed advice), tells drivers what speed they need to use on a road to avoid being held at a red light. Unfortunately, some of the benefits of smart management systems could get eroded over time if traffic volumes continue to increase. However, as the biggest causes of traffic delay will always be interruptions such as accidents and roadworks, the investment in network resilience will continue to provide long-term benefit. Investment in smart traffic management systems typically has a pay-back of under one year with respect to measurable benefits such as reduced delays to journeys.

In addition to traffic signals – increasingly linked to a wider range of traffic management strategies including the facilitation of tidal-flow lanes and reduction of air pollution – other elements of traffic management systems include:

- ANPR (automatic number plate recognition) systems for real-time traffic flow monitoring as well as civil enforcement
- Lane occupation, ramp access and variable lane speed control.
- Beacon-based data harvesting from smart phones and GPS.
- Dynamic messaging systems linked to real-time data as well as pre-planned scenarios.
- Over-height vehicle detection.
- E-call systems providing emergency notification or connected vehicles.
- Direct data acquisition and exchange through application programming interfaces (APIs) with applications and navigation systems.

The growing focus on live data is important, as the acquisition of “floating” data direct from vehicles is cheaper and more efficient than investment in conventional systems such as induction loops buried into road surfaces.

Social media is becoming a key means of measuring network performance as well as communicating to users. The development of large data sets also improves the ability of network operators to predict how road systems will respond to changes in traffic patterns. This data will be increasingly valuable as the operation of road networks is disrupted by new transport modes and technologies.
INTEGRATING CAVS INTO EXISTING NETWORKS

In the long-run the adoption of CAVs at scale is expected to increase capacity of existing roads, which in turn should reduce the need for new road infrastructure.

However, CAV adoption is likely to have substantial implications for the maintenance, renewal and configuration of road infrastructure. Table 3 (below) outlines some of the main changes that may be required in road infrastructure. Initially, roads will be shared by vehicles at various levels of automation regardless of the technological evolution path. The adoption of this mixed-mode approach may be limited initially to specific spaces such as trunk roads or city centres. The greatest demands on road infrastructure would arise from fully autonomous vehicles (Level 5) sharing roads with vehicles with partial or no automation (Levels 0-2). Any situation where vehicles are using different control systems will require additional infrastructure such as the beacons and smart controllers that are already being incorporated into traffic management systems.

Capex requirements will differ significantly according to the scenarios envisaged, for example:

- Fewer changes in infrastructure are expected to be required for the Level 5 self-driving vehicles being designed by Google, Tesla and others to run safely and effectively on existing infrastructure, using existing static communications like road signs, traffic signals and message screens. Adopting such an approach is highly dependent on the adoption of common approaches to governance and regulation across the main CAV markets.

- Traffic segregation may be needed to capture the main benefits of CAVs. Vehicles that are at different levels of automation might need to be physically separated through the provision of dedicated lanes. Such an approach will have a significant impact on the rate of adoption. As part of the planning for this eventuality and to accelerate adoption, it has been suggested by some advisors that city centres such as London could be considered as possible CAV-only areas.

Although adaptations to the road infrastructure might be required to accommodate CAVs, communications are the most important aspect of CAV capability, associated with all forms of connectivity, data management, data analytics and cyber security.

CAVs will become more reliant on this communication infrastructure as they advance through the levels of automation. Connected vehicles, for example, will support the co-operation between vehicles and infrastructure (V2V and V2I), sharing location and speed data with other vehicles and sourcing congestion and signal phase data from infrastructure. At present, the channels required to support this extended communication need to be reinforced using two technologies:

- Mobile data communications, either using existing solutions (4G / long term evolution, LTE) or next-generation 5G mobile data services, which will be able to use devices akin to mobile phones with little dedicated investment. The main question is whether 5G will have enough capacity and be quick enough to send large volumes of data in areas of peak data traffic, such as traffic jams.

- New Wi-Fi based standards tailored for connected vehicles. ITS G5 is a proposal for a dedicated channel giving a very fast service and high-speed delivery which will address the latency problems of current Wi-Fi technology which will require a new network of dedicated roadside beacons.

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Changes</th>
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<tbody>
<tr>
<td>Static communications</td>
<td>Standardisation of road markings and signage at a minimum quality level</td>
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<tr>
<td>Multiple traffic signals</td>
<td>Integration of CAV and non-CAV in roundabouts</td>
</tr>
<tr>
<td>Changes in demand for</td>
<td>Changes in the location and scale of parking provision in response to</td>
</tr>
<tr>
<td>parking spaces</td>
<td>modal shift. Increased road capacity resulting from a reduction in on-street parking</td>
</tr>
<tr>
<td>Energy distribution</td>
<td>New energy infrastructure in line with demand driven by modal shift – e.g. transition to electrical propulsion and realignment of power infrastructure to parking</td>
</tr>
<tr>
<td>Segregated infrastructure</td>
<td>Progressive adoption of measures to encourage technology transition – e.g. CAV-only areas in City Centres and partial segregation on highways</td>
</tr>
<tr>
<td>Increased maintenance</td>
<td>Sophisticated technology requires higher operations and maintenance expendi-</td>
</tr>
<tr>
<td></td>
<td>ture. Potential requirement to maintain road surfaces to a higher standard for safety case. Requirement for new revenue streams if road tax and petrol tax revenues fall</td>
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</table>
The ownership model for the DSRC and LTE technologies is a key point of difference. With DSRC, it is expected that cities will be responsible for procurement of a dedicated infrastructure and service. By contrast, LTE access is likely to be provided as a service using infrastructure owned by the mobile network providers.

**PROSPECTS FOR CONNECTED AND AUTONOMOUS VEHICLES IN THE UK**

Although the hype around CAVs is probably at its peak, there is no doubt that transport modes are changing fast, evidenced by the accelerating roll-out of charging facilities for electric vehicles.

Even if adoption is slower than envisaged, there is little doubt that new mobility modes, whether autonomous or not, will be a big challenge for the operation of conventional road traffic networks.

Vital work to develop open standards and system interfaces will help to ensure that further integration is built into traffic management systems as car capability evolves.

The installation of an additional roadside communications grid will require a big investment and must be well-timed to avoid the risk of a “Betamax” moment. Accordingly, the Department for Transport recommends a twin time scale approach. The use of existing connected vehicle, smart phones and current mobile communications by the public sector provides a “quick win”. This leaves preparations for modern technologies for the longer-term, once market-ready solutions are in place and benefits have become clearer. Trials on open roads of CAV technologies have begun and are addressing the real-world issues of how CAVs, pedestrians and other road users interact. Vehicle segregation may work in some instances, as could the clustering of platoons of AVs on open highways. The likelihood, however, is that wider AV adoption will need to be encouraged to secure wider network benefits. Such a scenario highlights the importance on the ongoing adaptation of the UK’s traffic management infrastructure. LTAs can facilitate this process by:

- Aligning all new investment to systems that are based on open, interoperable data standards.
- Maintaining traffic modelling and traffic planning capability to be able to plan and prepare for anticipated changes in traffic modes.
- Considering the impact of future changes in transport mode in the design and procurement of new traffic management services.