Geospatial Commission

FINDING THE WAY FORWARD

Location data to enable connected and automated mobility

Contents

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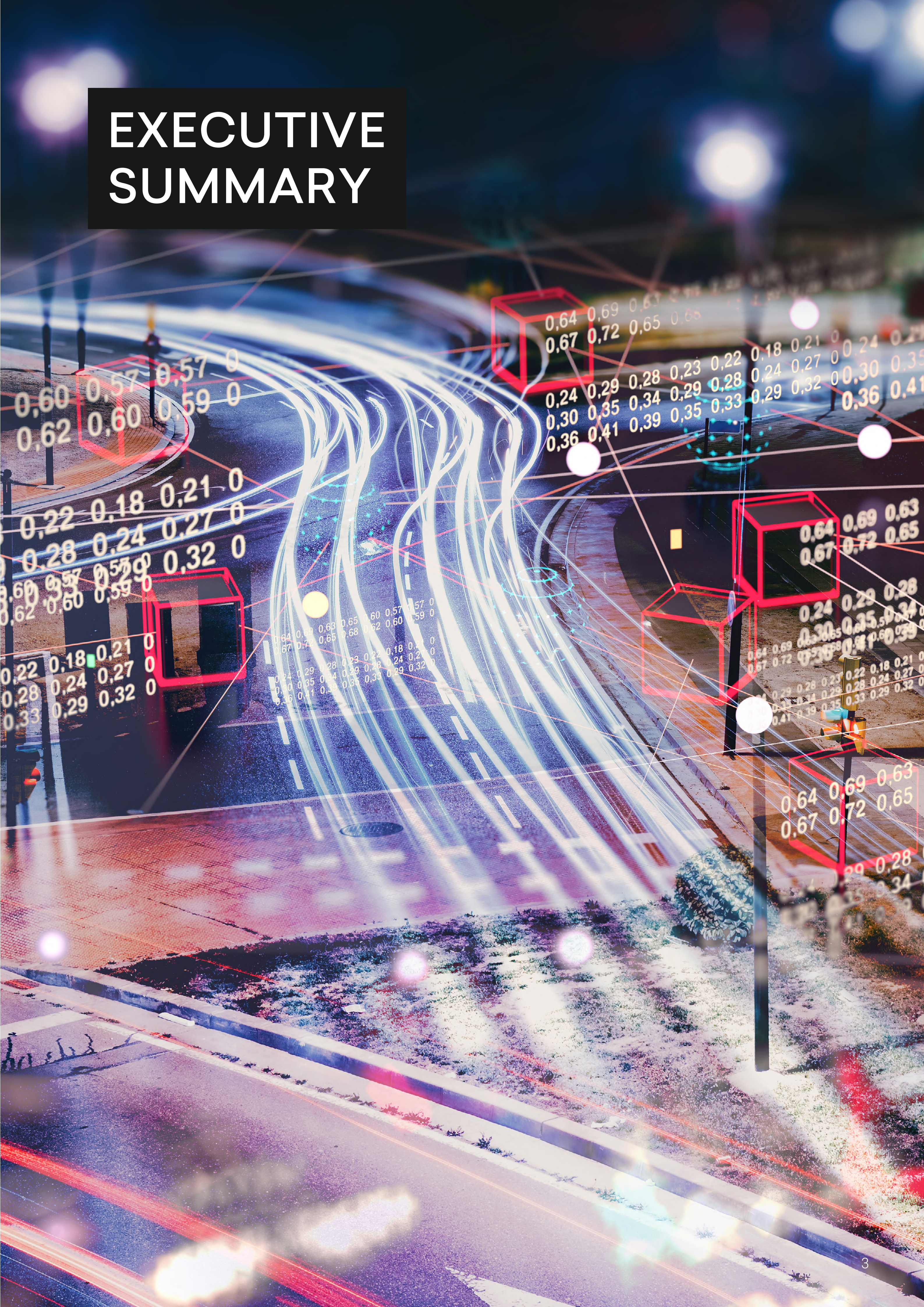
EXECUTIVE SUMMARY



Connected and automated vehicles (CAVs) are no longer within the realm of science fiction. Connected and automated functionality is becoming more widespread in our daily lives, from robot food and grocery delivery in Greater Manchester to driverless taxis in San Francisco.[1 2] Connected and automated mobility (CAM) is part of the future of transport and could reduce congestion, improve accessibility and make our journeys safer and more efficient. The impact of CAM will be felt on the road, in the air and at sea.

By 2035, 40 per cent of cars in the UK could have self-driving capabilities.[3] The self-driving market in the UK could be worth as much as £42 billion by 2035, creating up to 38,000 new jobs.[4] The UK government has set an ambitious vision to keep the UK at the forefront of development through funding, legislation and testing to enable the sector to thrive and deliver the associated economic and societal benefits.[5]

Authoritative and accurate location data and technologies will have an important role in the safe deployment of automated vehicles at scale.[6] Automated vehicles need to know where they are in relation to their surroundings, including the kerbside, other vehicles and pedestrians. They will need to understand which routes to take, where and when to change lanes and which obstacles to be aware of. Location data provides this critical information, generated by a range of technologies, including radar, cameras, high-definition (HD) mapping and positioning, navigation and timing technologies.

Many new vehicles are already connected to the internet, enabling navigation systems and smartphone integration. The connected vehicles of today can provide drivers with information about their route or the speed limit and collect data which, at an aggregate level, can be used by traffic authorities to monitor road conditions, identify accident hotspots and augment static roadside infrastructure. Future developments could enable connected vehicles to communicate with other road users and smart infrastructure, improving traffic flow and congestion as well as driver experience.

Three ways in which location data and technologies support safe deployment at scale

Location data and technologies are critical in enabling automated vehicles to monitor their environment

Sensors, including lidar, radar and cameras, and positioning, navigation and timing technologies, provide automated vehicles with detailed, real time information to help monitor their immediate environment to navigate safely.

Location data underpins the static and dynamic maps automated vehicles need to safely navigate the road network

Automated vehicles will likely operate on a converged solution of sensors and HD maps, which are highly accurate maps that enable precise localisation, in order to navigate safely. These maps will provide automated vehicles with critical beyond visual line of sight information and will augment data from sensor feeds.

Location data will power geospatial applications to make decisions for automated vehicles

High quality location data will power advanced geospatial applications and artificial intelligence (AI) to enable automated vehicles to make strategic decisions concerning the best route to take, tactical decisions related to expected behaviour along a planned route and reactive decisions, such as responding to an obstacle in the road.

This report highlights the role location data and location technologies will have in the safe deployment of CAM at scale on the UK's roads. It sets out the work that is underway using location data and some of the key steps needed to make the most of this opportunity. While this paper does not explore CAM in aviation and marine, some of the themes might be relevant to those sectors.

This report also considers areas where the CAM mobility sector can improve and make better use of location data that will enable the continued development and safe deployment of CAM. This report identifies that the sector should:

Improve the understanding of the road environment by addressing key location data gaps

To operate safely, automated vehicles will require authoritative location data - data that is trustworthy and precise - on the road network. Currently, some data about the road environment critical for widespread adoption is imprecise, not digitised or not collected. There is a need to improve the quality and granularity of this data, digitise it where it is not currently accessible digitally and close gaps, such as on lane markings, speed limits and street furniture.

Improve how location data and location technologies can work together by defining accuracy standards

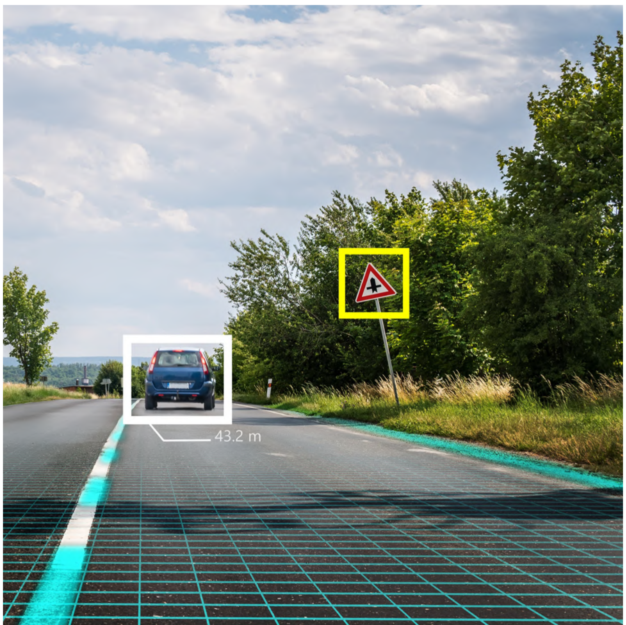
Data standards are critical to ensuring that the location data CAVs depend on for safe operation is appropriately accurate, interoperable and up-to-date. Standards are being established and there is a mutually beneficial opportunity for industry, regulators and government to work together to accelerate their adoption, especially on minimum accuracy for HD maps.

Improve data sharing practices to make connected vehicles data more accessible and reusable

The efficient sharing of location data will be fundamental to the safe operation of automated vehicles and to unlock new sources of location data gathered by connected vehicles. There is an opportunity to support and incentivise local authorities, who are responsible for the majority of the UK's national road network, and the vehicle manufacturers who are driving rollout, to share the data they hold.

Location data and technologies are and will be increasingly critical for the continued development and safe deployment of CAM at scale. Connected vehicles themselves will collect significant amounts of location data that could inform wider decisions about urban planning, traffic management and the rollout of electric vehicle chargepoints.

Achieving the safe rollout of CAM is not just dependent on improving the quality and use of location data. A robust regulatory framework will be required to support the development of the sector and maximise the public's confidence in automated vehicles. The UK has an opportunity to transform the transport sector and realise these benefits but doing so will require a whole sector approach.



Key definitions

Connected and Automated Mobility (CAM) refers to connected and/or autonomous ground-based vehicles and the technologies and infrastructure that supports them, e.g. personal cars / goods deliveries / taxis.

Connected and Automated Vehicles (CAVs) are vehicles, e.g. cars, lorries, that are both connected to other vehicles and the built environment and are partially or fully automated. Vehicles can be connected without being automated and some of this report's findings and insights relate just to connected vehicles and some to automated vehicles only. This distinction will be made throughout the report.

Connected Vehicles (CVs) are equipped with wireless communications technology that enables data transfer with other vehicles, infrastructure or other networks. Connected vehicles gather vast amounts of data, for example on driving patterns, traffic and road conditions. This data and the analysis and opportunities it offers are seen as valuable for improving transport and mobility.

Automated Vehicles (AVs) are vehicles fitted with an automated driving system that uses both hardware and software to perform dynamic driving tasks associated with moving the vehicle within a defined operational design domain and can operate without human intervention. The Automated and Electric Vehicles Act 2018 states that a vehicle is 'driving itself' if it is operating in a mode in which it is not being controlled, and does not need to be monitored, by an individual.[7] These vehicles are also referred to as self-driving vehicles. The Society of Automotive Engineers (SAE) defines six levels of driving automation ranging from zero (fully manual) to five (fully automated).

Location data, also known as geospatial data, refers to data that has a geographic element. It tells us where people and objects are in relation to a particular geographic location, whether in the air, on the ground, at sea or under our feet. These data can be static (such as a person's address or the location of a school) or dynamic (such as a bus travelling along its route).

Original Equipment Manufacturers (OEMs) are organisations that make devices from component parts bought from other organisations. In this context, they refer to the companies that design, develop and deploy the hardware and software systems that enable connected and automated vehicles to operate safely and efficiently on the roads. Examples include Ford, Tesla, Volvo and Waymo

Vehicle-to-everything (V2X) is the umbrella term for the unilateral or bidirectional sharing of data between vehicles and other vehicles, infrastructure, other road users or any other communications system. It includes vehicle-to-pedestrian (V2P), vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-network (V2N).

SECTION 1: A DEVELOPING SECTOR

Significant technological developments, including advancements in sensor technology and computing power, have brought the mass deployment of connected and automated vehicles (CAVs) on the UK's roads nearer. Many vehicles have built in wireless connectivity, enabling in-vehicle information and entertainment, and satellite navigation systems. Some vehicles already have automated driver-assist features, including lane assist, adaptive cruise control and guided parking. More advanced automated vehicles are currently being developed, with original equipment manufacturers (OEMs), including Ford, Tesla, Volvo and Waymo, all planning to rollout vehicles with a higher level of automation over the next decade.

The development of location data and technologies is underpinning growth in the connected and automated mobility (CAM) sector. Up-to-date HD maps have been developed specifically for automated vehicles by organisations like TomTom for research and development.[8] British company Oxford RF Solutions are developing the world's first solid-state 360-degree sensors to enable automated vehicles to operate in all-weather conditions.[9] Calyo, based in Bristol, is developing next generation deep-ultrasound sensor systems that will enable the environment to be perceived in 3-D in real time.[10] In 2022, a three-year project led by German engineering and technology company Bosch was launched to develop a holistic system architecture to enable the integration of sensors and communication between vehicles.[11]

The UK is home to a thriving CAM market that is primed to develop rapidly over the next decade. If automated vehicle development and uptake in the UK follows the predicted trend for Europe, road vehicles with automated systems ranging from hands-free to fully automated will account for 40 per cent of total UK annual vehicle sales - 1.36 million vehicles - by 2035.[12] By 2035 the UK CAM market is projected to be valued at £41.7 billion, of which £6.4 billion will be the underlying enabling technologies.
The global market size in the same year is projected to be £650 billion, of which the technologies market will make up £100 billion. Around 49,000 people will be employed in the manufacturing and assembling of CAVs in the UK while around 23,400 jobs will be created in the production of technologies.[13]

Automated vehicles could also improve the resilience of our supply chains, improve mobility options for those with additional accessibility needs and reduce road traffic collisions, 75-95 per cent of which are currently caused by human driver error.[14] Connected vehicles could be deployed as real-time roaming sensors that could improve road safety by monitoring the quality of the road surface and identifying accident hotspots, monitor changing air quality, provide an enhanced consumer experience through dynamic routing and navigation, improve the reliability of vehicles by providing OEMs and fleet operators with diagnostic information and drive cost efficiencies by reducing the need for expensive roadside static infrastructure.[15]

To deliver the widespread deployment required to realise these benefits, the UK must develop appropriate physical and digital infrastructure, establish the right legal and regulatory framework and build public confidence in the safety of the vehicles and use of drivers' data.

The Geospatial Commission's approach

The Geospatial Commission was established in 2018 by the government as an expert committee responsible for setting the UK's geospatial strategy and coordinating public sector geospatial activity. The Geospatial Commission is part of the Department for Science, Innovation and Technology. Our aim is to unlock the significant economic, social and environmental opportunities offered by location data, applications and services and to advance the UK's global geospatial expertise. The Geospatial Commission's 2021 report, 'Positioning the UK in the Fast Lane', found that the improved use of location data could improve the transport sector's development and support the UK's economic growth.[16] It identified the CAM sector as an area where location data would have an important role. In early 2023, the Geospatial Commission partnered with the Open Innovation Team to conduct a rapid review into the role of location data to enable road-based CAM. This review was supported by interviews with 22 experts and covered five themes: HD mapping for CAM; positioning, navigation and timing (PNT) technologies; the role of geofencing; public sector use cases for connected vehicle data; and the geospatial data requirements of CAM. Further information about the Open Innovation Team and the rapid review is set out in the annex to this report.

This report builds on the findings of the rapid review, setting out the role location data plays in enabling the safe deployment of road-based CAM at scale and three opportunities to support the better use of geospatial applications across the CAM ecosystem.

Government action to support the CAM sector

The government has committed to supporting the safe scaling up and growth of the CAM sector by identifying and making required improvements to public sector data, funding innovative projects, developing a new legislative and regulatory framework and supporting the UK's testing environment. The Centre for Connected and Autonomous Vehicles (CCAV) is an expert policy unit within the Department for Transport and the Department for Business and Trade tasked with shaping the safe and secure introduction of self-driving vehicles and services on UK roads and leading the government's wider Future of Transport programme.[17] CCAV is overseeing a £100 million funding package for CAVs safety and commercialisation. This includes £42 million of funding awarded to seven projects through the 'Commercialising Connected and Automated Mobility Deployments' competition to develop new automated passenger or goods services to the point of commercial deployment by 2025.[18] Alongside this funding, the government's vision for CAM is for the market to be enabled by a comprehensive regulatory, legislative and safety framework.[19] Figure 1 sets out the developments in recent years for the legislative and regulatory framework.

Figure 1: Recent developments to the legislative and regulatory framework

July 2018 - the government passed the Automated and Electric Vehicle Act 2018 (AEVA), to support innovation in the sector and ensure future automated technology is invented, designed and operated safely in the UK.[20]

January 2022 - the Law Commission of England and Wales and the Scottish Law Commission published a far-reaching review to enable the safe and responsible introduction of automated vehicles on roads and public places in Great Britain.[22]

July 2022 - The Highway Code was updated to clarify driver responsibilities and rules on the use of self-driving vehicles, in advance of their introduction.[21]

August 2022 - the Centre for Data Ethics and Innovation published a report that sets out proposals for a trustworthy approach to the regulation and governance of self-driving vehicles.[23]

March 2023 - the Government Chief Scientific Advisor published their Pro-innovation Regulation of Technologies Review, which recommended that the government bring forward the Future of Transport Bill to unlock innovation across automated transport applications.[24] The government committed in its response to bringing forward legislation on the Future of Transport when parliamentary time allows.

The government has also helped establish a testing environment to enable the development of CAM from concept to deployment in both virtual and physical road environments. The CAM Testbed UK, coordinated by Zenzic, a government-industry partnership, is a comprehensive and coordinated set of six world-leading facilities which enables the modelling, simulation, testing and trial deployment of CAM solutions.

To date, the Testbed has invested over £120 million in grant funding to more than 80 collaborative research and development projects, involving over 200 organisations.[25] Convex, part of the CAM Testbed, is exploring how data exchange and data sharing services can be improved between connected and autonomous vehicles, transport network operators and mobility service providers, to deliver more innovative and integrated mobility solutions.[26]

In 2020, the Department for Transport produced a 'Connected Vehicle Data Strategy' that examined strengths and weaknesses in data preparedness for connected vehicles and identified a series of key service areas that data would impact on and action plans to drive progress towards better use of data.[27]

In 2020, Ordnance Survey, working with stakeholders, identified that additional and improved data was needed to meet the requirements of CAM. In 2023, the Public Sector Geospatial Agreement (PSGA) included new data which would be important for the operation of automated vehicles including on indicative speed limits, average speed and road widths. In 2023, the Department for Transport launched a project to support the development of digital traffic regulation orders in line with the 'Future of Mobility: Urban Strategy', which proposes the creation of a regulatory framework that evolves with transport technology and advocates data sharing to improve the transport system.[28]

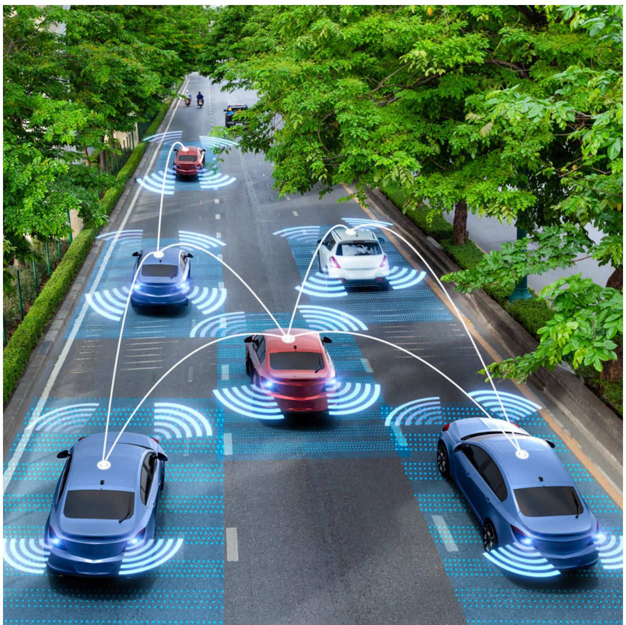
SECTION 2: ENABLING SAFER DEPLOYMENT WITH LOCATION DATA

Location data underpins modern navigation systems from knowing where your end destination is to accurately depicting the road network for reaching your destination. This data is used by drivers to interpret and navigate the road network, from determining when to change lanes, moderate speed and respond to road turns. For connected and automated vehicles, this data will need to be authoritative and accurate. All vehicles will need to have a common understanding of their vehicle in relation to others and the road environment.

There is currently no widely accepted definition of what constitutes the 'safe' operation of an automated vehicle. To maximise the benefits and reduce risk, rolling out CAM will require legislation to clarify the responsibilities of key actors, such as vehicle manufacturers and the human 'driver' when an accident occurs, as well as rigorous safety standards, test processes and cyber security guidance to prepare vehicles for real-world conditions and maximise public confidence.[29]

Location data and location technology is required to enable automated vehicles to monitor their environment

Sensor technologies enable automated vehicles to perceive and react to their environment. On-board camera, ultrasonic, radar and lidar sensors are the primary means through which an automated vehicle monitors its environment and are typically cross-referenced with HD maps.[30] Sensors automatically detect the location of objects, such as other vehicles, pedestrians and traffic lights, categorise them and determine their distance from the vehicle.



Different sensor technologies meet different requirements. Radar sensors monitor the position of nearby vehicles and cameras detect the location of other vehicles, pedestrians and road signs, as well as detect lane markings. Lidar detects lane markings and identifies the edges of roads and ultrasonic sensors in the wheel detect the position of kerbs and other vehicles to assist with parking.

Positioning, navigation and timing technology (PNT) provides a further geospatial data source for CAVs which is used in positioning and localisation. PNT services encompass Global Navigation Satellite Systems (GNSS), but can also include positioning via computer vision, HD maps and telecommunications networks. The level of positioning accuracy needed from PNT by automated vehicles is higher than most other non-automated use cases, however there is no sector wide consensus on the degree of accuracy required across multiple operating environments.

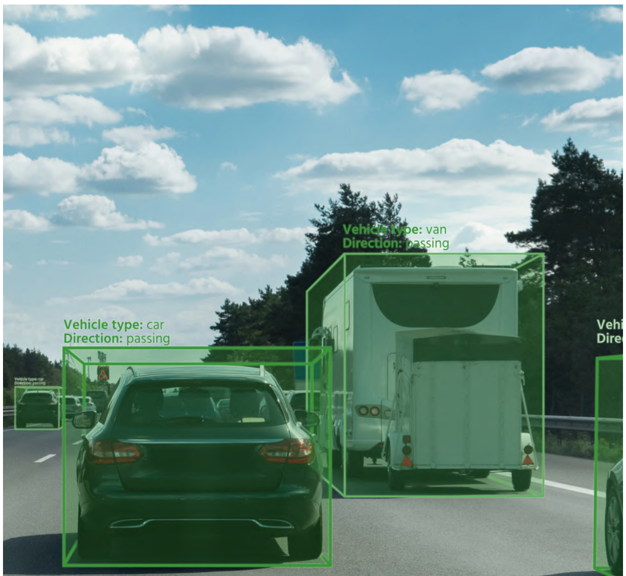
The European Union Agency for the Space Programme estimated that automated vehicles will require horizontal position accuracy to be less than 20 centimetres, vertical position accuracy to less than two metres, timing accuracy at less than one microsecond and availability better than 99.9 per cent.[31] We found that the CAM sector will likely adopt a multisource approach, whereby satellite-based PNT services could be complemented by a range of existing and emergent localisation from ground-based radio antennas (providing 4G network) to roadside cameras and laser scanners. This could help increase resilience in the event of failure from PNT.

Location data underpins the static and dynamic maps automated vehicles need to navigate the road network

In order to provide valuable information on the surrounding environment, most automated vehicles will use precise, up-to-date, location data rich HD machine-readable maps which will augment sensor data. Information on maps can provide the vehicle with a means of path awareness and foresight that sensors alone cannot deliver to help a self-driving vehicle understand its environment. This includes environmental, geographical and time-of-day restrictions and the presence or absence of certain road characteristics. For example, there are objects, such as road signs, that sensors may not be able to see at all times, such as if a sensor fails or if the sensor's view is temporarily obstructed by another road user or adverse weather conditions.

Location data is critical for the static and dynamic maps that make up the HD maps used by automated vehicles to navigate the road network. Static maps provide detail on attributes and objects that do not change regularly, for instance road speed limit, street furniture and road geometry. They are fixed images that show the data as it is at a certain geographic and temporal point. These maps are typically generated using lidar cameras, satellite and aerial imagery.

Dynamic maps and interactive maps layer real-time information onto static maps. This can include information on weather conditions, the location of flooding and traffic incidents. Static and dynamic maps typically rely on three types of location data: base mapping, contextual information and real-time information. Base mapping provides a high-resolution machine-readable version of a set of static assets, such as road geometry.



Automated vehicles use contextual information, such as new road markings or cycle lanes, to understand their surrounding environment to make appropriate navigation decisions. Real-time, dynamic information provides automated vehicles with live information on the location of real-time hazards including traffic congestion, road accidents and weather conditions.

Location data will power geospatial applications to make decisions for automated vehicles

Automated vehicles will need to make several decisions based on their location and the location of static and dynamic objects in their immediate environment and beyond their visual line of sight. Automated vehicles will depend on data, including location data, to make these decisions quickly and safely. Location data derived through sensors, PNT and HD maps will enable efficient routing and navigation decisions from when and where to change lanes to finding the fastest or most environmentally friendly route via an electric vehicle charging station.

CAVForth buses use artificial intelligence to make decisions based on various sources of information including sensors, GPS and its in-built map. The automated system uses this information to find a safe path to its destination within its environment and travels the route through a set of low level instructions to control the vehicle's steering, throttle and brakes.[32]

To plan the shortest and safest path, automated vehicles make strategic, tactical and reactive decisions, all of which are enabled by location data. These different decisions, categorised by the Danish Ministry of Climate, Energy and Utilities in Figure 2, correlate to different stages of a typical journey and each uses different data.[33]

Strategic decisions are generally at a journey-level with a timeframe of more than 60 seconds and relate to route planning from origin to destination. These decisions can include temporal considerations, such as the weather or the traffic flow conditions, during the planned journey time. They can also relate to decisions associated with the amenities available along a journey, including rest stops, parking and EV chargepoints. These types of decisions are typically made prior to a journey commencing and use geospatial data derived from HD maps and V2X communication.

Tactical decisions are generally at a lane-level with a timeframe of between three and 60 seconds and require more detailed and precise data, for example on lane positioning. These decisions are related to expected behaviour along a planned route and include decisions, such as which lane to be in when turning at an intersection. This tactical decision making can use geospatial data captured by sensors, such as the perception of road markings, as well as data provided by HD maps such as the location and extent of bus lanes.

Reactive or operational decisions are generally at a lane-level with a timing of less than three seconds. These typically low-level instructions utilise on-board sensors that calculate the distance between the vehicle and other objects. They realise the strategic and tactical decisions and include responses to immediate changes in a CAV's nearby environment, for example braking to avoid a collision.

Figure 2: Examples of geospatial data used in automated vehicle decision-making[34]

Geospatial data used in strategic decision making	Geospatial data used in tactical decision making	Geospatial data used in reactive decision making
• Network data and associated routing information, e.g. turn restrictions / speed limits • Traffic flow and congestion • Weather conditions along route • Other hazard warnings • EV services • Parking and type (car park, on-street, off-street) • Address data / points of interest • Location and time of special events - for example parades • Road construction data	• Road carriageways and lanes • Traffic signals • Signage • Road markings • Curvature of road (sinuosity) • Slope of road • Speed limits • Junctions and their types • Road width • Road shoulders • Road dividers • Road and turn restrictions • Presence of bus and/or bike lanes	• Location of obstacles in close vicinity - for example obstacles in the road

The CAM environment and the role of location data

Connected and automated vehicles will depend on a multitude of location data derived from different sources to perceive and react to their environment. These sources include HD maps, sensors positioned on the built environment and on-board sensor technology.

1

Location data derived from HD maps, PNT and V2X communication is used in positioning and localisation. This data can inform navigation and routing decisions, based on variables including the weather or traffic flow conditions and amenities available along a journey, including rest stops, parking and EV chargepoints.

2

Location data derived from on-board sensors is used to calculate the distance between the vehicle and other objects, such as other vehicles, pedestrians and traffic lights. This data informs decisions related to immediate changes in the nearby environment, for example braking to avoid a collision.

The location data these sensors collect mean that CAVs could be deployed as real-time roaming sensors to inform infrastructure maintenance and improve road safety.

3

Location data derived from sensors fixed in the built environment, for example on street lights or traffic lights, can be used to provide vehicles with useful beyond visual line of sight information. This data can inform decisions such as when to change lanes. Sensors on street furniture can be used to monitor the deployment of CAVs, as well as real-time traffic and environmental conditions.

SECTION 3: OPPORTUNITIES TO IMPROVE LOCATION DATA FOR CONNECTED AND AUTOMATED MOBILITY

We have identified three opportunities to support the better use of geospatial applications across the complex CAM ecosystem and support safe rollout at scale:

Improve the understanding of the road environment by addressing key location data gaps

Improve how location data and location technologies can work together by defining accuracy standards

Improve data sharing practices to make connected vehicle data more accessible and reusable

Realising these opportunities will require consensus building in a constantly evolving sector and finding the resource to improve public sector-held datasets in a challenging economic environment.

As the sector develops a better understanding of the location data requirements needed for safe deployment and operation. Improving existing location data and creating new sources will require a whole- sector approach across a wide range of private and public sector organisations.

For example, local authorities are responsible for 97 per cent of the national road networks and therefore at present hold data that is important for safe navigation. The development of connected and automated vehicles (CAVs) is being driven by original equipment manufacturers (OEMs) who hold data their vehicles collect.[35]

Opportunity 1

Improve the understanding of the road environment by addressing key location data gaps

Automated vehicles cannot continue to develop and deploy at scale safely without authoritative and appropriately accurate location data. Authoritative data is recognised as data of appropriate quality provided by trustworthy organisations. In this case, authoritative data is needed to enable the vehicle to understand its environment and make decisions about safe navigation.

It can be used by industry regulators to confidently and fairly allocate risk by underpinning liability regimes and insurers to independently determine whether and which parties are at fault in the case of an accident. However, what constitutes authoritative data can change over time depending on its application or use. The same data that is deemed accurate, valid and trusted for one specific use might not be for another.

Private sector data, for example from OEMs, may be recognised by members of a community of interest to be authoritative because its provenance is considered highly reliable or accurate. When there needs to be general acceptance of the definitive single source or independent accuracy of the data, in many examples government involvement (through provision, legislation or regulation) provides assurance to users that they can trust the data. The Geospatial Commission has developed an authoritative data assessment tool, designed to help identify data publishing organisations and datasets which can be considered trustworthy so that users can have confidence in the data they choose to use.[36]

Ordnance Survey (OS), the national mapping agency for Great Britain, provides foundational geospatial data on the road network that will support connected and autonomous vehicle deployment in the UK. This data is available through products such as OS MasterMap, OS Highways and the OS National Geographic Database (OS NGD).

The OS NGD Transport Theme covers 31 different feature types which together provide a definitive network dataset and topographic depiction of Great Britain's roads, tracks and paths. It brings together Ordnance Survey's large-scale road and path content, and routing information with authoritative information from the National Street Gazetteers and the Trunk Road Street Gazetteer.

OS data is made available to the public sector through the Public Sector Geospatial Agreement (PSGA). It is also made available under a range of commercial licences to the private sector both directly from OS as well as through OS Channel Partners, who can provide additional value-add services and solutions.

Improving data on the road network and the challenges

Currently, data held about the road network has varying levels of detail and not all of it is fully digitised. As a result, there is not a full understanding of road rules, the location of street furniture and road geometry at the level of granularity required to support many CAM use cases. The public sector and industry are leading initiatives to deliver data improvements on the road network, which will benefit multiple CAM use cases, as well as nearer term use cases, such as congestion reduction and traffic management. In many instances, these data improvements are significant undertakings for the public sector, as data is often held across multiple organisations with varying degrees of access and interoperability and in some cases not in a digital, machine-readable format. A 2019 Department for Transport study identified key change challenges, including the need for effective legislation, and opportunities, including to address issues of variation in operational practices across different highway authorities.[37]

Traffic regulation orders (TROs) are legal orders made by local authorities that specify the road rules and its use. They restrict or prohibit the use of the highway network and help manage the highway network for all road users, improving road safety and access to facilities.

TROs can be used to regulate the speed, movement and parking of vehicles on a road as well as which type of vehicles can use which part of the road. They can also be used to allocate road space to pedestrians, cyclists and buses. They can be permanent, experimental or temporary - closing roads for short events, such as parades, sporting events and markets.

Currently, not all TROs are digitised and the data held within the order, such as its location, is formatted and held in a variety of ways depending on the local authority. Some TROs are text only (with no maps or images) and therefore linking text to a spatial location can be challenging. Fully digitised TROs that are findable, machine readable, up-to-date and consistent across the road network will improve the safety of CAM. Better quality data

to plan more efficient routes by identifying roads have been closed or if temporary speed limits have been introduced.

The government's Plan for Drivers has backed the digitalisation of TROs which would require local authorities to send the legal orders they make to a central publication platform.[38] A range of organisations would be able to access TRO data in an accessible and digital format. The government will legislate for this when Parliamentary time allows.

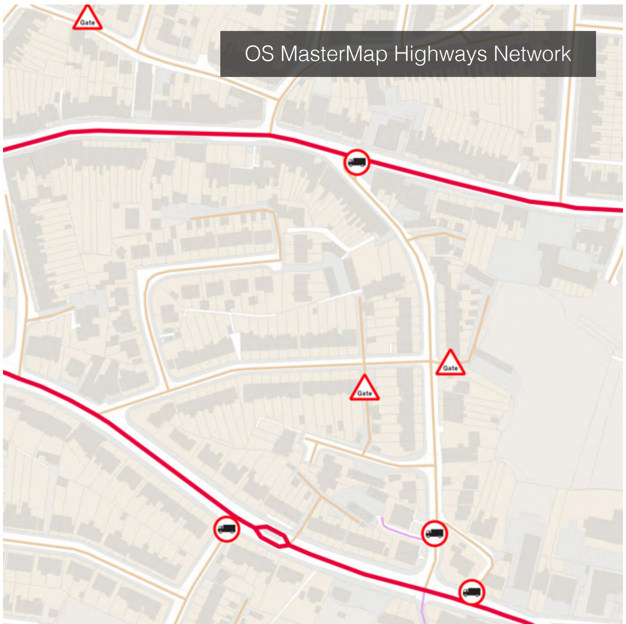
Similarly, the data currently held about street furniture, including the location of street lights and traffic lights, is not authoritative for the CAM use case. Authoritative data about street lights could support the efficient planning of the underlying infrastructure, including cameras and sensors, critical for at-scale deployment of automated vehicles. However, there is a lack of authoritative data on the location and height of street lights. Not all street lights have been mapped and in some cases the location data held by local authorities is imprecise.

Roadside based cameras and sensors, fixed on street lights, are already an important enabler of some of the UK's CAM Testbeds and could be deployed more widely as early automated vehicles are commercialised. The Smart Mobility Living Lab has located cameras on street lights around their testbed in Woolwich to monitor vehicles being tested and to provide them with useful beyond visual line of sight information.[39]

Some data is not accurate enough, while in other cases the location of traffic lights has not been fully mapped. High quality location data about traffic lights is critical for Green Light Optimal Speed Advisory (GLOSA), a vehicle to everything (V2X) technology which uses traffic signal information and the location of a vehicle to calculate the speed at which a vehicle needs to travel through a green light without stopping. If this data is not precise enough then it could potentially lead to the suboptimal performance of GLOSA systems and unsafe navigation decisions.

For data on the road network to be authoritative for CAM use cases it must also capture accurate lane-level detail. A more granular understanding of road geometry, the location of drop kerbs, the location and extent of road lanes and the location of hard shoulders, bus lanes and cycle lanes would enable automated vehicles to make safe navigation choices about when and when not to change lanes or overtake.

Some of this data is collected and held by Ordnance Survey and others in the market today. However an increase in the resolution and consistency of the data is needed to be able to support the rollout of automated vehicles.[40] For example, data offered within OS MasterMap and Highways products can support current use cases, but is unlikely to be sufficient to support the demands of emerging use cases in CAM. This requirement has been acknowledged and as part of the PSGA and Ordnance Survey's move to NGD data, new data on the road network is being captured, and in March 2023, PSGA began to provide new data on indicative speed limits, average speed and road widths, with additional data being delivered in the coming years.



Case study: Building the right environment for automated vehicles to operate

Connected and automated vehicles will need to be able to monitor the road environment to identify and track risks and navigate safely, especially in built-up areas. The challenge is ensuring that the vehicles are provided with real-time, appropriately accurate information to enable safe passage for the vehicle and pedestrians. A combination of sensors fixed on the vehicle and the surrounding built environment, HD maps and PNT technologies will help automated vehicles address this.

Smart Mobility Living Lab (SMLL) is a London-based real-world connected environment for testing and developing future transport and mobility solutions with locations in the Royal Borough of Greenwich and Queen Elizabeth Olympic Park.

The testbed provides a complex, uncontrolled testing environment, interacting with live traffic and other road users. It is designed to demonstrate and evaluate the use, performance, environmental impact, safety and benefits of connected and automated mobility technology and future transport services.

The SMLL testbed aims to help overcome this challenge by creating a real-world urban environment for in-depth testing of automated vehicles, utilising existing roadside infrastructure and installing new location technologies, including roadside monitoring equipment, a private fibre network and an extensive data platform.

Lamp columns serve as flexible mounting points for sensors and communication equipment, allowing for data collection and analysis, as well as real-time monitoring of traffic and environmental conditions. By integrating existing infrastructure, the testbed was able to support vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies, allowing vehicles to communicate with one another and with the surrounding environment.

The existing Openreach duct network supported a private fibre network to enhance the efficiency and reliability of data exchange within the testbed. The installation of street cabinets for edge processing and the distribution of wireless technologies in localised areas facilitated the real-time processing of data generated by connected vehicles and sensors, enabling rapid decision-making and response in various traffic and mobility scenarios.

The testbed has investigated the effectiveness of messages being sent from fixed points at the roadside to moving vehicles, testing requirements including for latency, frequency, timing and location for different use cases. One key finding has been the distance necessary, from the vehicle to the point from which a message is sent, for the vehicle to make lane changes in advance.

The testbed has enabled partners in the consortium to secure additional CCAV grant funding to support UK supply chain readiness for future mass deployment of self-driving technologies in the UK.

Opportunity 2

Improve how location data and location technologies can work together by defining accuracy standards

Standards are critical to ensuring authoritative location data and technologies are interoperable. They assist in understanding how to interpret a dataset and its metadata and how to assess its suitability for a specific use case. With the variation in data models and data formats, standards can bridge the gap that aids machines in talking to machines in a common language and automating decision-making processes. Standards ensure datasets have greater usability, uptake and software support.

Standards setting out minimum accuracy and interoperability of location data of road features will support reuse by different actors, including OEMs, fleet operators and traffic authorities, to enable innovative geospatial applications and services and drive better safety and efficiency. More generally, interoperability will also enable the sharing of connected vehicle data between different domains, for example in conjunction with weather data or population mobility data.

Defining standards for HD maps and the challenges

Automated vehicles will combine location data gathered by on-board sensors with digital HD maps and add positioning, navigation and timing technologies to verify their data and provide beyond visual line of sight information. This will enable the vehicle to identify and track risks and navigate safely.

Self-driving vehicles need a precise understanding of the location of dynamic objects on the road, such as other road users and pedestrians, as well as static objects, such as the kerbside and traffic lights, in order to operate safely and effectively.

HD maps can provide granular information on road geometry, the location of key features of the road network, such as traffic lights and road geometry, and provide information on the rules of the road, such as speed limits. Further value can be derived from combining HD maps with different types of data, such as population movement data and weather data, to identify weather related hazards on the road, congestion and other features to improve safety and the passenger's experience. HD maps are currently produced by a variety of different companies and operators with little standardisation. As a result, most can only be used effectively for the purpose for which they are created. This has led to varying levels of accuracy, with different organisations and countries taking different approaches.[41]

We found that there is no consensus on the level of accuracy needed from HD maps for autonomous vehicles. Several countries have started, or completed, HD mapping projects with a horizontal accuracy of 20-25 cm and a vertical accuracy of 30-35 cm. Some CAM experts have suggested a much higher accuracy of 3-5 cm may be needed for fully autonomous vehicle operation as highlighted by Zenzic and OS consultation.[42] In practice what is required from HD maps will depend on relative strengths or weaknesses of other data inputs, such as those from onboard sensors, which CAVs can access.

To support the use of HD maps for CAM, the government will need to work closely with the sector to establish minimum standards of accuracy. It is likely that a minimum level of accuracy will be necessary to ensure the efficient and safe operation of automated vehicles at scale.

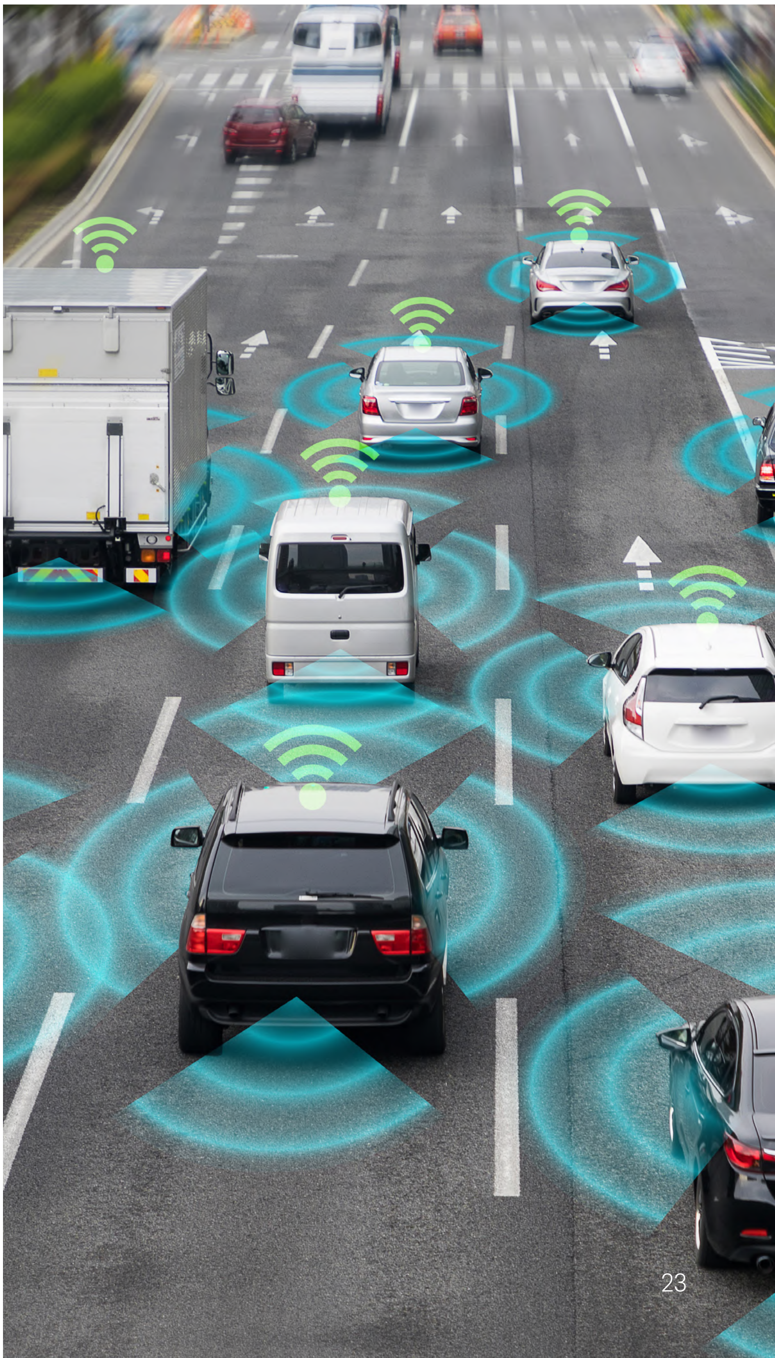
A similar challenge applies to geofences. A geofence is a virtual perimeter for real-world geographic areas, such as a specific road or an area in a city. They can be used to regulate vehicle behaviour in certain areas, such as speed, or enforce other transport related regulations, such as demarcating the zones in which self-driving vehicles can operate. Geofencing will play an important role in optimising the early deployment of self-driving vehicles.

The ability to geofence key parts of the UK's road networks, and define the condition in which certain drivers can use their automated vehicles, will help enable the safe deployment of early automated vehicle use cases. Currently, geofences are privately developed and deployed in standalone CAM trials, meaning that each geofence conforms to different standards and are therefore not easily interoperable. As geofences are deployed at greater scale and in greater numbers, the industry will need to develop more standardisation to ensure self-driving vehicles can travel seamlessly between them especially where they overlap.

Developing industry specific standards across location technologies requires cooperation and a commitment to adhering and maintaining the standard. Developing standards alongside an emerging industry can be difficult as the two are evolving simultaneously and it is hard to predict which direction the market may move in the future and there may be proprietary data that industry actors do not want to share. It is not always clear which aspects of the development will remain a permanent fixture and which are temporary decisions, and where standards are set it may not be clear who will maintain them. Other aspects, such as government regulations or country specific considerations, also may not yet be known.

The British Standards Institute (BSI) launched the CAM standards programme in 2019 to bring together industry, academia, government and other key stakeholders to establish and advance good practice in support of the safe trialling and development of CAVs.[43] This in turn has helped to advance the state of the UK CAVs industry by establishing common terminology, operational safety practices, and processes in support of trialling and development testing of CAVs.

There are challenges to fostering agreement on standards but industry, regulators and the public sector should continue working together to test and develop minimum standards for geofences and HD maps to foster interoperability. These standards could set minimum requirements for accuracy and stipulate data formats and frequency of updates, building on BSI's CAM standards programme.



Case study: Mapping roads in Singapore

HD maps are used by businesses and governments to better understand environments and inform decisions, including about transport infrastructure. Automated vehicles will combine location data gathered by on-board sensors with digital HD maps and PNT technologies to identify and track risks and navigate safely.

The Singapore Land Authority (SLA) is a statutory body in Singapore, with developmental and regulatory functions, which optimises land resources for economic and social development. The SLA has developed a high resolution 3D map of the country, using aerial and road-based mobile surveys, adopting lidar scanning and imagery technology on different platforms, to produce a digital replica of the physical environment with 'point cloud' at a resolution of 40 points per sqm. Point cloud is a set of discrete points that represent the actual shape and size of real world features such as roads and roadside objects.

The 3D map was developed following the launch of a 2D format in 2010 and aims to transform how businesses and citizens use maps in Singapore. Businesses and property agents can use the map for a better representation of properties and citizens can orient themselves with landmarks to scale.

The map and data are shared with automated vehicle researchers and used in simulations and in limited road-based trials. Point clouds are important data sources for CAM because they provide vehicles with high resolution, 3D geoinformation which helps vehicles to localise themselves and avoid obstacles.

The OpenDrive data format is being explored, which provides a common base for describing road networks, though it is currently unclear whether this will be the standard format used by automated vehicles in the future. Despite having an advanced map of the country, the SLA is currently deciding whether to continue with the development of even higher resolution maps which they believe would be more suitable for CAM.

The SLA's national 3D map has increased the availability of data for policy formulation, risk management and planning beyond CAM and the use of rapid national street mobile mapping could help the government make savings of at least SGD 5 million.

Opportunity 3

Improve data sharing practices to make connected vehicle data more accessible and reusable

Substantial benefit from the evolving CAM sector lies in the sharing of authoritative and interoperable connected vehicle data. Connected vehicles will collect and generate vast amounts of location data, from the location of potholes to the frequency of harsh braking in particular areas, that could be usefully shared with the public sector to realise major economic and societal benefits. OEMs must be supported to share this data with relevant public sector agencies.

Supporting data sharing and its challenges

The private sector collects and holds large quantities of connected vehicle data. However, this location data is not routinely shared. Local authorities and the central government could use this data in numerous ways. For example, a connected vehicle can share incident data to enable traffic authorities to have a wider operational understanding of incidents on their road network and respond accordingly. Figure 3 sets out further use cases for connected vehicle data.

The British Standards Institute has begun to define standards in this area, setting out best practice for traffic authorities when investigating accidents using CAVs data.[44] There are also further use cases for data sharing between private sector actors in CAM. For example, the Law Commission has recommended that a duty should be imposed on those controlling automated vehicle data to disclose data to insurers where the data is necessary to decide claims fairly and accurately.[45]

The private sector is already starting to commercialise this data with companies, such as Gaist, providing paid-for connected vehicle data insights to local authorities.[46] Convex, part of the UK's CAM Testbed, is developing services to enable the sharing, transformation and integration of dynamic mobility data between organisations and systems.[47] Convex hosts a mobility data hub to help transport authorities better understand live transport network operations and manage the evolution of their networks. Convex also collates and integrates a range of data from real-time traffic systems in the West Midlands, enabling the data to be used in tactical network management and new integrated transport schemes.

Making this location data more accessible would help unlock the public sector use cases for this data. In 2020, the Department for Transport identified opportunities and barriers to realising the benefits of connected vehicle data to improve journeys, reduce traffic congestion, boost road maintenance and improve transport planning, while generating cost efficiencies for the taxpayer. They proposed a strategy for how the government could invest to progress the application of connected vehicle data at scale, including through at-scale demonstrations, the provision of national facilities, better training and standards to provide road authorities with the information they need to design and implement connected vehicle data services.

The public sector must also be willing and able to share its data, where appropriate. Local authorities are responsible for 97 per cent of the UK's roads and therefore hold a significant amount of relevant data but this is not standardised, therefore making sharing between local authorities, central government and OEMs a challenge. Earlier this year the government published the 'Transport Data Strategy' that aims to improve the discoverability, accessibility and quality of transport data, including the development and promotion of data standards.[48]

Figure 3: Spotlight on public sector use cases for connected vehicle data

Use case	Example
Environmental Monitoring air quality	Connected vehicles could act as roaming sensors, helping to reduce a dependency on static infrastructure. For example, data collected by connected vehicles on air quality could be centrally aggregated and used to augment air quality data collected by static monitoring stations, giving a more real time and granular picture. This could be important in cities and towns that have few monitoring stations.
Safety Designing safer infrastructure	City planners could use connected vehicle data to inform decision making on where to site or adapt new infrastructure. For example, an enhanced understanding of traffic flow and routes could inform a decision on where to install a cycle lane. Harsh braking data could reveal accident hotspots and show where a roundabout needs to be adjusted.
Network efficiency Real-time traffic analysis	The real time data generated by connected vehicles could be used by road authorities to aid the smart management of traffic. Real time CVs data would help road authorities to analyse traffic flows, and traffic patterns, evaluate traffic light set ups and junctions. Live analysis would help traffic authorities to make adjustments to traffic analysis in real time.
Economic efficiency Monitoring roadside infrastructure	The UK's roads currently use static infrastructure, such as CCTV and radar, to monitor road users and gather data. This infrastructure is expensive, both to install and to maintain. These static assets cannot be easily redeployed to optimise their effectiveness. The data collected by connected vehicles could be used by road authorities to help monitor and maintain road infrastructure. In certain cases, connected vehicle data could even replace roadside infrastructure, with in-vehicle signalling potentially reducing the need for the installation of new road signage.

The collection, sharing and use of connected vehicle data also poses ethical considerations, particularly around privacy. It will be essential to maximise and retain public trust and confidence in how private and public sector organisations gather, hold and share their data. Shared location data should be appropriately aggregated and anonymised so that it cannot be used to identify individual citizens, the location of their vehicle or the routes they take.

In June 2022, the Geospatial Commission published a policy paper on location data ethics which outlines how to unlock value from location data while mitigating ethical and privacy risks, ensuring compliance with legal principles and retaining the trust of citizens. Public benefit outcomes can be a necessary motivator for individuals to support the use of location data relating to their movements, but alone they are not sufficient and organisations should ensure accountability, mitigate bias and maximise clarity.[49]

Automated vehicles provide an opportunity to transform the UK's transport sector and connected vehicle data offers new sources of information to improve public sector decision-making about infrastructure beyond our road network. Realising these opportunities will require a whole-of-sector approach to build an ecosystem which supports the seamless sharing of authoritative and standardised location data between OEMs, local authorities, the central government, regulators, insurers and more.

Case study: How Blackpool Council uses connected vehicle data to enhance road safety

Connected vehicles will collect and generate vast amounts of location data, from the location of potholes to the frequency of harsh braking in particular areas, that could be utilised to improve road safety. Today, location technology is being used by local highway authorities to quickly generate rapid insights to help us understand and improve road conditions.

Poor road conditions, such as potholes and uneven surfaces, can lead to accidents, skidding, vehicle damage, and injuries among motorists, cyclists, and pedestrians. They result in increased maintenance costs, congestion and have an economic impact. Businesses may suffer due to transportation difficulties and property values may decrease in areas with deteriorating road infrastructure.

Local highway authorities monitor, maintain and repair the road network, fixing potholes, resurfacing and addressing drainage issues. They coordinate with other government agencies and utility companies to ensure that road works are planned and executed efficiently and respond to emergencies such as accidents, floods or severe weather events that can damage roads. Before the widespread use of technology, such as driver camera network inspections and the use of AI, local authorities relied on visual inspections and community feedback.

Blackpool Council has used RoadTrace, a product delivered by Aisin and Gaist, to identify ten harsh braking areas in their town. RoadTrace is able to leverage connected car data to help transport authorities detect unusual driving patterns such as harsh braking, sudden steering or near misses. The data is collected from existing sensors already available in current cars and HGVs that record the position, speed, acceleration or braking of the vehicle. Insights can indicate problems of road surface deterioration, signage, lining and road geometry or infrastructure design issues.

Connected vehicle data has helped Blackpool Council improve road safety around a local school. The data identified repeated harsh braking incidents at three sites related to one local cut-through route around a school, where vehicles were avoiding traffic lights to save time on their journeys. After reviewing the data, the council launched a scheme to refresh the road surface in specific areas, replacing old speed cushions and potentially increasing the number of speed cushions on the route. This cut-through is now also related to a local review of school parking and in due course there may be a follow-up scheme to alter the route to one-way, further reducing the impact of vehicles braking harshly in both directions.

In the future, Blackpool Council hopes to expand this data-driven approach to include speed monitoring and skid resistance of road surfaces. Speed data could be used to optimise traffic flow, manage congestion and improve commuter experiences. Meanwhile, monitoring road surface skid resistance could proactively identify hazardous conditions, allowing for timely maintenance and enhancing overall road safety.

Annex

Understanding the landscape: A rapid review of location data and CAM

To develop this report the Geospatial Commission has engaged across the connected and automated mobility (CAM) sector including industry, public sector and academia.

In February 2023, the Geospatial Commission began work with the Open Innovation Team (OIT) to conduct a rapid evidence review into how location data can support the development and deployment of road-based CAM technologies in the short and medium term. The rapid evidence review identified areas where location data improvements will directly address the challenges related to the introduction of CAM and made recommendations for further action in these areas.

The review focused on five themes:

1. Understanding the geospatial data requirements of CAM
2. The role of geofencing
3. Public sector use cases for connected vehicle data
4. The role of High Definition (HD) mapping
5. Positioning, navigation and timing technology (PNT) capability and CAM

OIT is a government team that works with academics to generate analysis and ideas for policy. They help officials work with evidence and expertise and help academics understand how they can work more effectively with the government. They work on a project basis for teams across the public sector to provide: a better understanding of the evidence base for their policy area, engagement with a more diverse range of experts, innovative ideas and help framing problems and defining solutions using the latest evidence.

As part of their review on the relationship between location data and CAM, OIT analysed existing literature, drew on an expert network and conducted in-depth interviews. They consulted 22 national and international experts across the public sector, industry and research and academia:

Public sector: National Highways, Ordnance Survey, Swedish Transport Administration and Singapore Land Authority

Industry: Gaist, Zenzic and Mercedes Benz

Research and academia: Connected Places Catapult, Coventry University, University of Surrey, University of Westminster, University of Technology Nuremberg (Technische Universität Nürnberg), University of York and Imperial College London

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Mercedes Benz

National Highways

Open Innovation Team

Ordnance Survey

ServCity

Singapore Land Authority

Smart Mobility Living Lab

Swedish Transport Administration

Transport Research Laboratory (TRL)

University of Surrey

University of Technology Nuremberg (Technische Universität Nürnberg)

University of Westminster

University of York

Zenzic

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