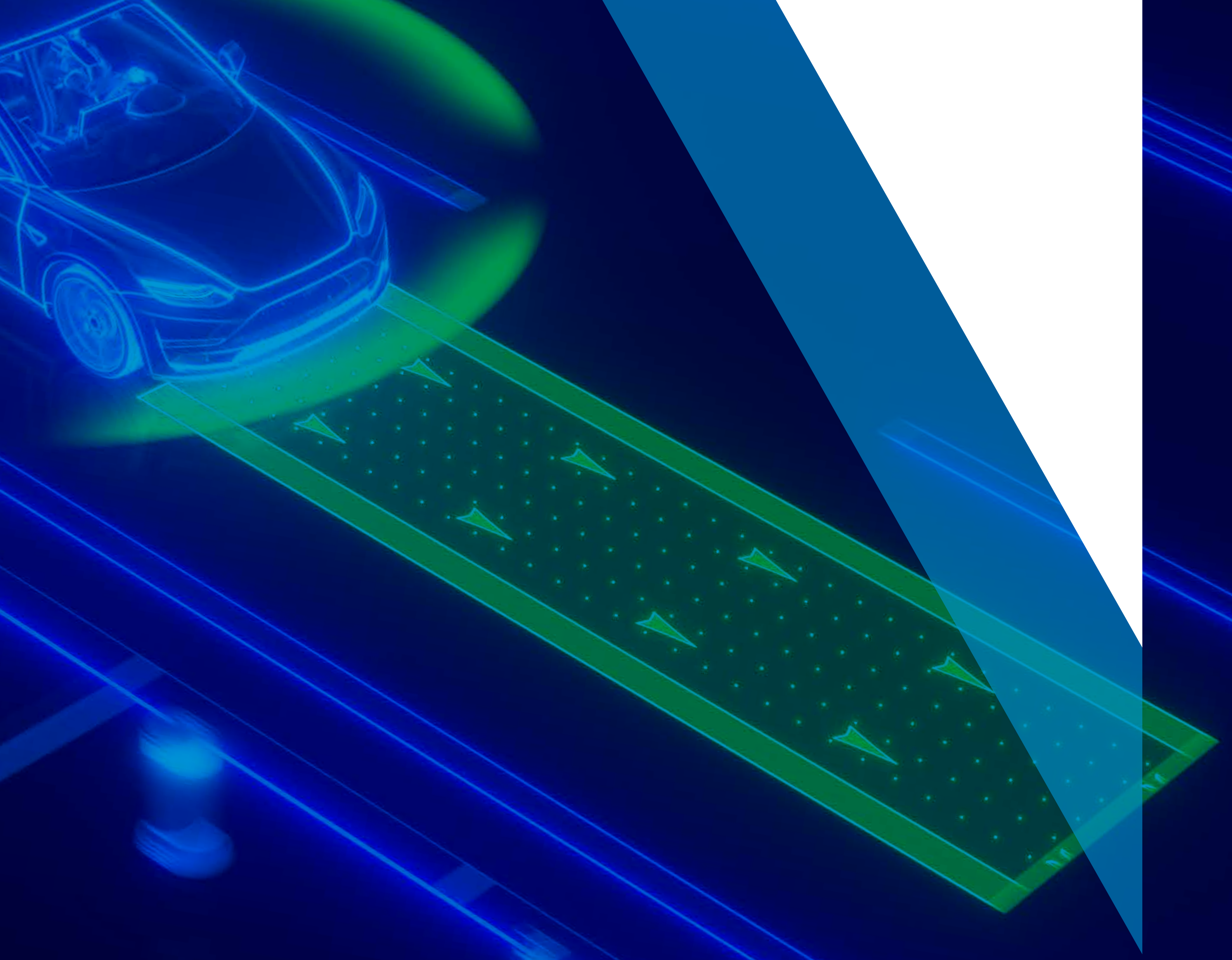

Value chain report:
How UK suppliers can support development and production of Connected Autonomous Vehicles

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"Transport planners and policymakers are increasingly seeking sustainable and practical options for personal mobility solutions"

Executive summary

WMG at the University of Warwick undertook the Connected Autonomous Vehicles (CAV) Value Chain Analysis project which completed in 2019. The project aimed to inform the Government and Zenzic's understanding of the emerging CAV supply base and value chain in the UK. The study examined the technologies and services required to bring CAVs to the streets, potential future use and deployment, and the gaps in existing UK supply capability. The low-speed transport environment provided a case study to understand in detail the immediate and practical needs of innovation and deployment, and the current constraints on innovation. This report summarises the findings of this project and results in a series of practical recommendations for how the UK can seize the opportunities.

UK suppliers and clusters in the automotive sector are already well established, particularly in the emerging capabilities around autonomous control systems and vehicle communication, but new entrants will be required to deliver a robust commercial application given the technological challenges. So, while the existing supply base offers a broad capability and meets many technological and system needs, there are still gaps to be addressed, largely the result of a lack of use case development and testing.

Furthermore, a number of technologies have not been deployed due to caution over cost and return on investment. Use cases will direct the technology and, in doing so, will help the industry separate the possible and speculative, from the viable and proven. Therefore, the market for secondary services and non-core technology will grow organically when business case concepts are proven. Trials create new relationships by bringing together technological and entrepreneurial expertise and, in doing, so help companies work together to deliver the best solution to a business case. Trials also help the industry better understand potential customer behaviour and so help stimulate new entrepreneurial business cases. UK manufacturers and service providers should examine the strategic opportunity in building new capability to fill gaps in the UK value chain, via involvement in new use case innovation and trials.

Therefore, while UK industry has a lead in this sector, maintaining that lead would benefit from further Government support in actively supporting use case deployment where the use of the product can be demonstrated and tested. Government can also support the sector in creating the strategic policy framework and legislation to enable deployment. They can also help by actively participating in international discussions on legislation and standards.

The UK supply chain has many strengths that can be leveraged to fill the gaps identified in this report, including skills and capabilities in companies that may not yet be involved in the CAV sector. Indeed, with ambitious targets set for net zero, transport planners and policymakers are increasingly seeking sustainable and practical options for personal mobility and last mile solutions. The CAV sector is building a new transport ecosystem, of which the vehicle is just one component. Government and industry both have a role to play in creating a new, collaborative and learning value chain, a world-leading solution to urban mobility, and an export-led sector capable of generating significant employment and growth to the UK economy.

Introduction

The UK has been a leading centre for research into connected and autonomous vehicles (CAV), and WMG has played a key role in that development through the establishment of a pioneering Intelligent Vehicles research group for CAV research, whose multidisciplinary approach encompasses a full understanding of the practical technical, commercial and usage application of these technologies.

Over 800,000 people work in the automotive sector in the UK, including around 150,000 in manufacturing. A 2019 forecast of the growth of CAV anticipated that it will contribute an estimated £62Bn to the UK economy by 2030 and generate 420,000 new jobs including 20,000 jobs in automotive[1].

The Intelligent Vehicles research group in cooperation with the Supply Chain research group evaluated the range of emerging new technologies and services required to deliver CAVs. Having established a clear view of the commercial landscape, the group surveyed UK industry stakeholders to understand the existing technology and expertise. Gaps were highlighted and the reasons for them were analysed. The challenge for UK industry and policymakers is to develop capability and capacity to fill the gaps to build a world-leading CAV sector that helps drive export-led economic growth.

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[1] Connected And Autonomous Vehicles, SMMT (2019)

Technologies and capabilities required

	New technologies	New services
New market offerings	Vehicle technologies	Business models
New ancillary support offerings	Infrastructure technologies	Supporting and enabling services

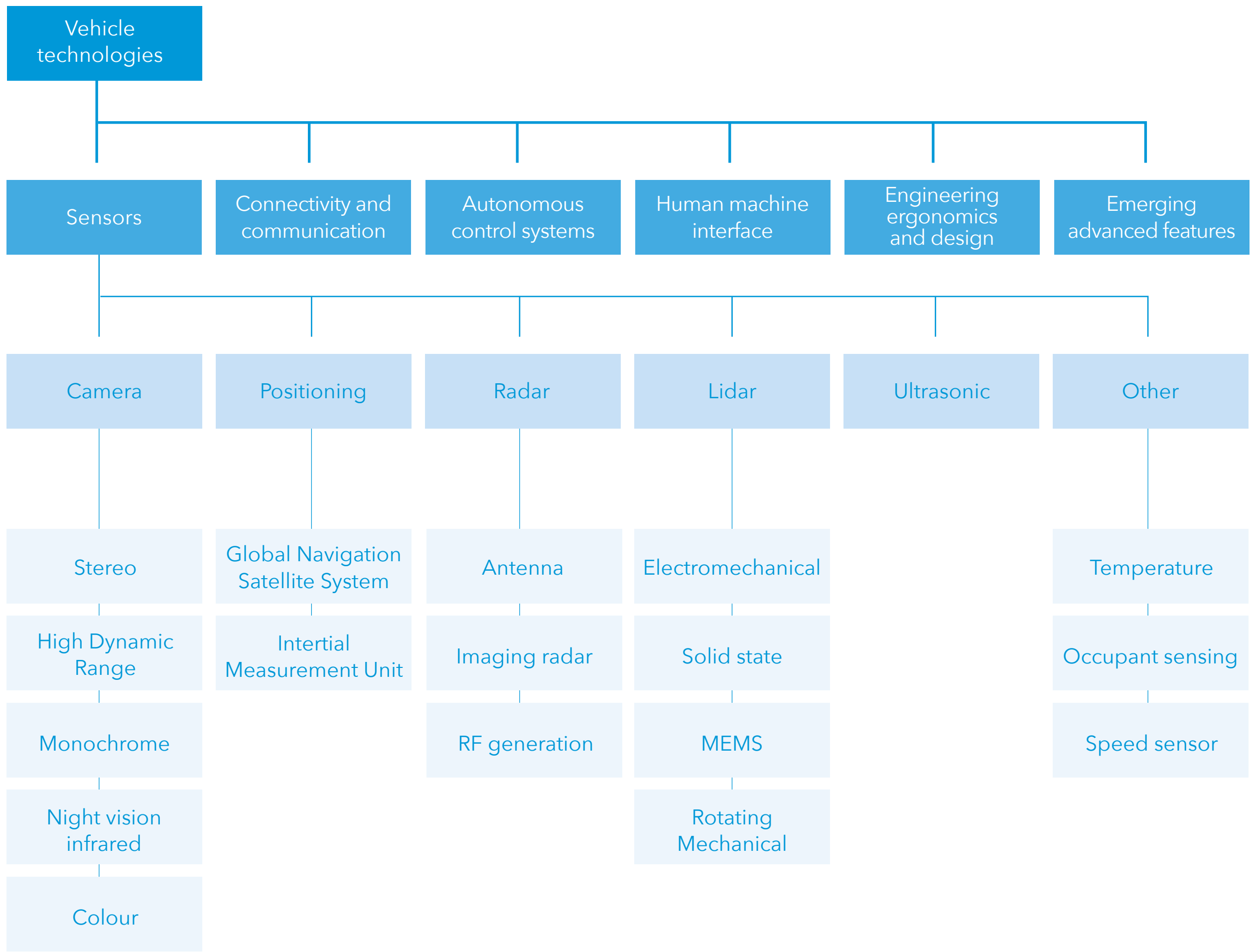
The development and market testing of CAVs involves new technology and new business offerings. The new technology is not limited to the vehicle itself; the connected environment must be created, which requires the development and deployment of roadside infrastructure. Equally, new supporting and enabling services are required to bring new products to the market.

This assessment of suppliers in the sector is, by nature, a snapshot in time, but does provide insight on the readiness of the UK supply base to scale up and support widespread adoption of CAV solutions.

Vehicle technologies

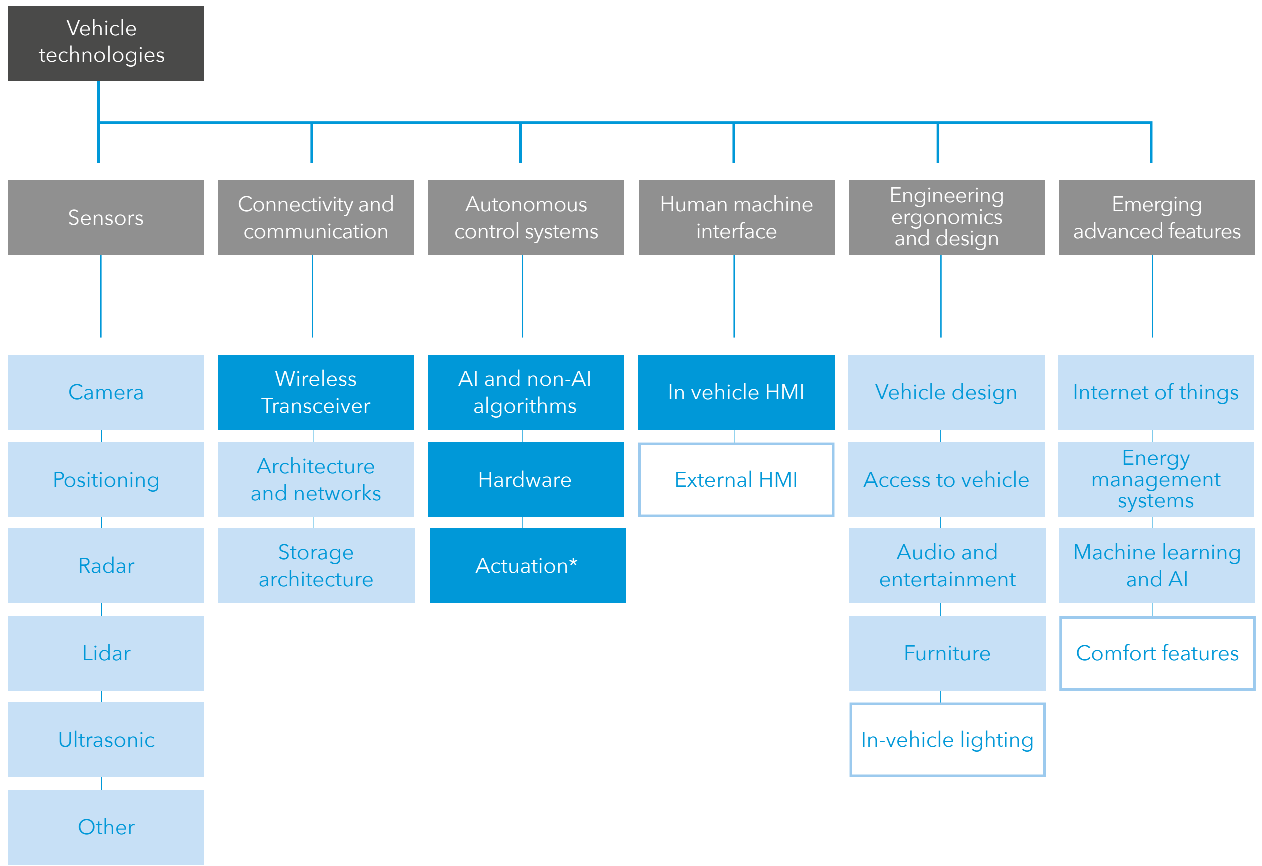
Connected and autonomous functionality requires new on-board vehicle technology. For example, the ability to detect and interpret the environment, to navigate hazards safely including pedestrians and other road users. Sensor and camera technology needed for detection will vary depending on the application.

This includes high definition cameras, infrared heat imaging, stereo camera vision for movement sensing and so on. The technologies chosen will be determined by balancing their effectiveness, the level of performance and functionality required and, of course, the total cost.



As shown above, available sensor technologies extend beyond mere visual detection. Each technology has specific capabilities that may or may not be necessary for a specific vehicle type. For example, radar is effective at detecting objects moving over longer distances, while ultrasonic technology is highly effective for detecting objects at short range, adding extra layers of hazard detection. A more capable vehicle can be deployed in a wider and more flexible range of environments and use cases, but again, this broader capability will need to be balanced by cost considerations.

The technology choices are mapped against the UK supply base below, showing both abundance and gaps in coverage. Given a long-established UK history in both automotive design and sensor technology, both sectors are well served by the existing UK supplier community. The analysis also demonstrates the leading-edge research and development in connectivity and communication technology, and in autonomous control systems – such as artificial intelligence and machine learning. The gaps in supplier presence and coverage are shown as uncoloured boxes that, together, present an identifiable cluster of vehicle occupant-facing solutions – lighting, comfort, and external vehicle Human Machine Interface (HMI).



Supplier presence and capability

High | Medium | Low

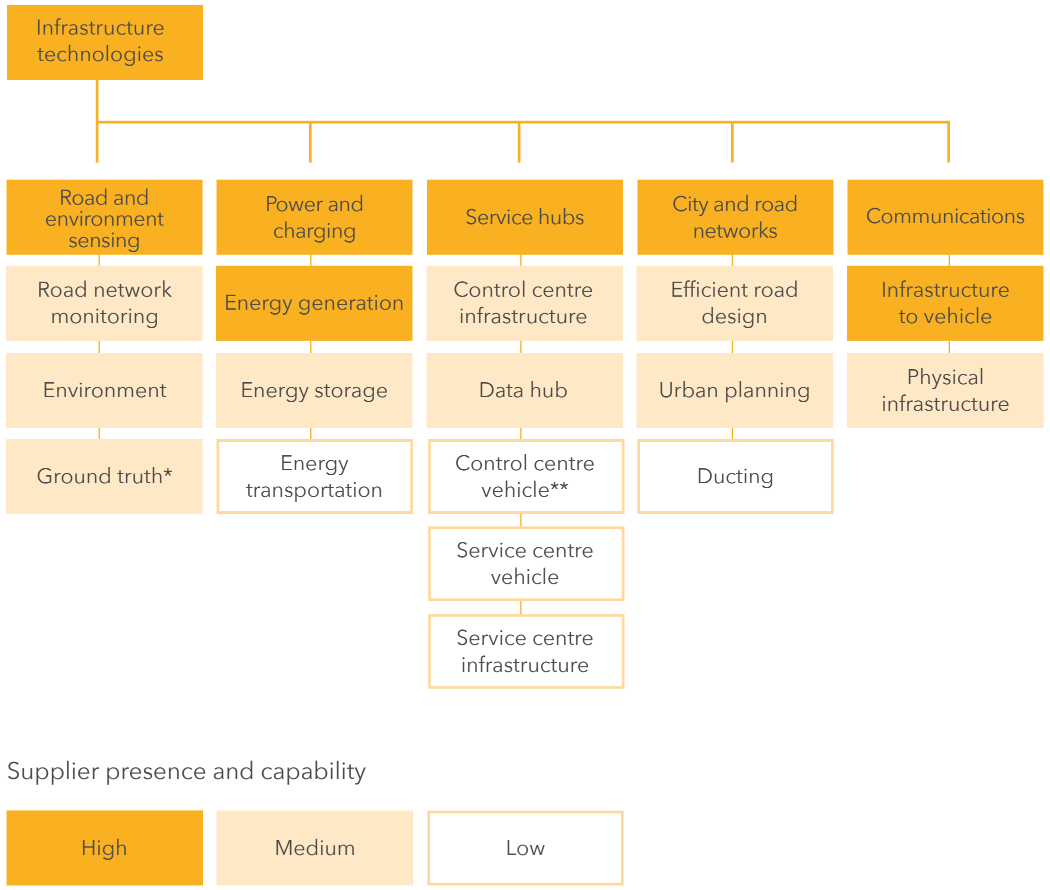
*Safety & convenience features apply actuation (e.g. cooperative cruise control, automated emergency braking)

Infrastructure technologies

Connected and autonomous vehicles (CAVs) require new infrastructure. Changes will need to be made to urban roads and pedestrian spaces, and the adaptations under consideration include lane segregation, charging points and road network monitoring. Motorways, although a much smaller proportion of the overall road network, will also require new technology and infrastructure. CAVs communicate with both the immediate environment and with remote data hubs. Localised monitoring enables traffic flow management, while remote monitoring allows for real-time vehicle oversight, network optimised routing and redeploying vehicles to points of greatest demand. Keeping electric vehicles on the road will also require an expansion of charging infrastructure and new maintenance, and repair operations.

Technologies will need to be installed to enable specific 'Infrastructure-to Vehicle' (I2V) communication, such as 'Green Light Optimal Speed Advice' , which effectively informs the vehicle in real time the best speed to proceed at given the traffic light sequence ahead.

There are many energy companies in the UK who would be interested in supply agreements with a connected fleet operator, and I2V communication technology is well established. While there is an adequate focus overall on road and environment monitoring, environmental planning and the development of communication infrastructure, there are gaps in the support services required. Firstly, as vehicles are not yet deployed in significant numbers, there is no established service, maintenance, and repair network. Such a network may grow organically over time but, in early deployment, dedicated resources and contractual service locations will be required. Secondly, there are noticeable gaps in energy transportation. Electric vehicle charging points and bays will need to be installed, and the underlying energy transmission capacity will be required to build and serve these charging bays. Finally, despite the capability in the supply base for the provision of I2V communication, there are gaps in the existing provision of ducting services to help build the necessary fibre optic cabling capacity.

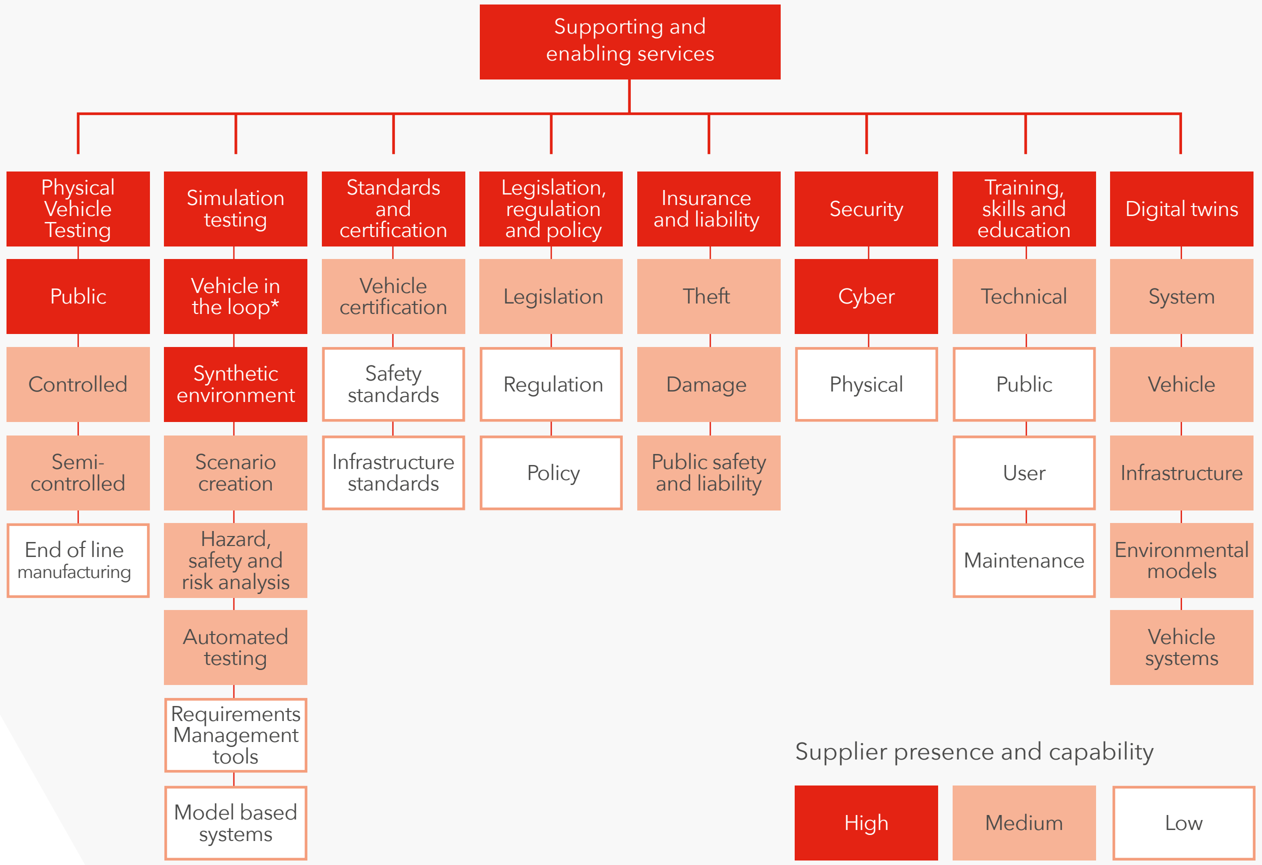


*Validates the ground truth (visibility) of a vehicle making sure that the sensors on the vehicle are still reading the correct values.

** Uses the information from the data centre to send out signals to control the traffic and the vehicles.

Supporting and enabling services

Many new business to business (B2B) services will be required to support research, development, deployment and management of connected autonomous vehicle (CAV) networks, much of which has yet to be developed. Real-world testing and simulation in a replicated digital environment are well established, while production quality testing is expected to emerge with mass production, as well as networked solutions as they mature as a new segment. Vehicles on UK roads must meet both existing EU vehicle standards homologation and UK standards (for example, on quadricycles). However, as a new product offering in the market, where the technology and solutions have yet to mature, standards have yet to emerge but will be developed alongside the testing.

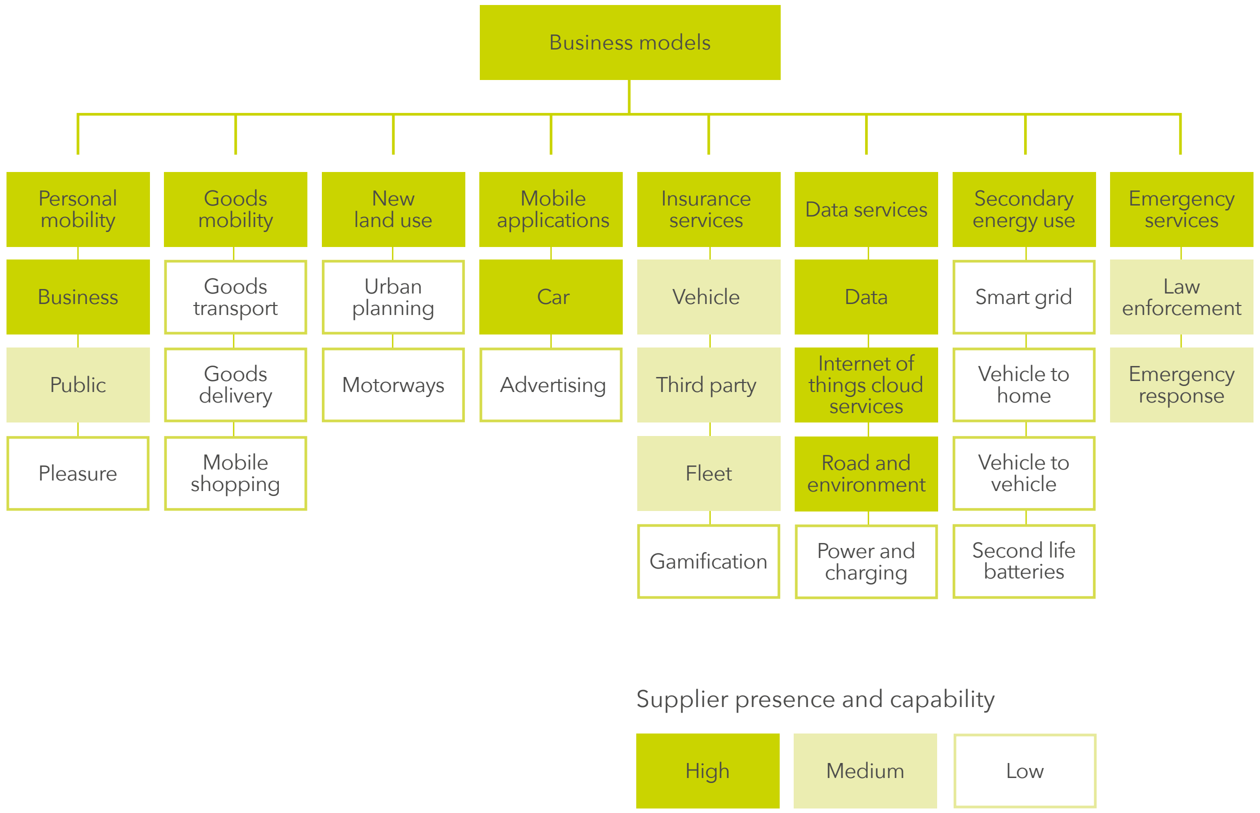


Equally, while legislation has been passed to enable deployment, wider regulation is lacking and will be developed in response to testing, and likely also emerge as case law in response to real world incidents and experience. The development of regulation can be directed and accelerated through the learning generated from controlled testing and regularised thorough the development of planning and testing policy and guidance. The insurance sector is well placed to cover theft and damage, and any losses will be expensive to recover as these vehicles are loaded with high value technology, which will raise questions as to whether to insure via a third party or as an overhead provision from the fleet owner or user. In addition, fleet operators and owners will need to address public safety and liability by complying with new legislations.

As CAVs are components within the transport 'internet of things', the development of digital twins will be required so that every real-world vehicle is replicated as a digital entity to allow tracking, monitoring, real-time optimisation and redirection (where a digital twin is the digital model of the real-world entity). Cyber security is already delivered by existing providers, although less attention has been paid so far to preventing damage or theft of costly high-tech componentry in the vehicles. Demand for cyber security skills and resource will continue to grow to ensure safety for users, operators and the public. More broadly, roll out of new services and technologies will require new technical skills. At present, technical training is emerging within the research and development base as it grows, but this training will need to be extended to service, maintenance and repair personnel, and once vehicles are rolled out in significant numbers, education of users and the public will be critical.

Business models

Connected and autonomous vehicles (CAVs) offer the opportunity for new and innovative business models, and they are likely to define and drive the technology and growth of the sector. The commercial deployment of the technology will create new business offerings and upgrade existing ones. The existing supply base is mainly focused around personal mobility, exploring how to take advantage of data and its associated services, as well as, re-examining how insurance business models will need to adapt to cover a connected and autonomous product and service offering. However, there are a lot more opportunities that will be explored and tested in the future. One of the clear advantages of driverless vehicles is that they widen access to personal mobility to people that are unable to drive, such as children, the disabled or simply those without driving licences.



Driverless last-mile delivery in urban areas is expected to grow and concepts are being tested by logistics companies and new technology entrants. Consumers may wish to own CAVs, while businesses may innovate to use autonomous vehicles as small private spaces for delivery of services such as dining or beauty treatments. Pods could be deployed as mobile retail units, for example, replacing mobile library services to meet the needs of those living in remote rural areas, or simply as for home delivery of food and other goods. It may also enable low-cost returns where this is a significant part of the business model, for example, in fashion retail.

Autonomous vehicles may mean the emergence of dedicated spaces, for example, on highways or in the urban landscape. Insurance is expected to become a growth sector for automated vehicles and, in theory, insurance products can be priced more effectively as risks can be monitored more closely in these dedicated spaces. Liability management will undoubtedly become more nuanced as the technology and sector matures. Some anticipated uses may never prove viable, but until they are trialled at scale, it is difficult to know which will emerge as sustainable business models.

For example, battery vehicles are seen as a key component in anticipated smart grid[2] development, allowing battery electric vehicles to be used as energy storage when not required for transport. Toyota and Nissan have dedicated research programmes examining this for passenger cars, and the principle can also be applied to smaller, autonomous vehicles. In a distributed energy management system, local generation, transport and storage of energy can potentially better match peaks of demand and supply.

[2] The term 'Smart grid' describes an electricity supply network that uses digital communications technology to detect and react to local changes in usage.

US-based Starship have been running a fleet of 70 autonomous delivery robots in Milton Keynes since 2018

(image: https://news.sky.com/story/coronavirus-robots-in-milton-keynes-deliver-shopping-to-nhs-workers-11978670

Getting ready for connected and autonomous vehicles

Many urban environments suffer from congestion and poor air quality, and city governments have responded by banning cars, adding tolls and withdrawing low-cost parking. However, people and goods still need to move around so, among other mobility solutions, micro-vehicle 'pods' have long been touted as a solution.

Advances in technology in recent years have enabled:

- Small Connected Autonomous Vehicles (SCAV) or 'self-driving' pods.
- Improvements in safety for vehicle passengers, other road users and pedestrians.
- Use of CAVs in a wider range of environments that, in turn, makes them more economically viable.

Example of a small connected autonomous vehicle (SCAV) on the Warwick University campus (source: https://warwick.ac.uk/fac/sci/wmg/research/cav/)

What do we mean by small connected autonomous vehicle?

An autonomous vehicle is one that can carry people or cargo without the need for an active driver. A connected vehicle is one that moves within the landscape as a digital presence and interacts with the surrounding environment, communicating with both local infrastructure (such as traffic lights), and the wider world through cloud-based data sharing.

The Society of Automotive Engineers defined a roadmap for the technical evolution of intelligent vehicles (shown below), and a CAV is generally recognised as meeting level 4 or level 5 capability.

Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
No Automation: The driver is in complete control of the vehicle at all times.	Driver Assistance: The vehicle can take control of either the vehicle's speed, through cruise control, or its lane position through lane guidance.	Occasional Self-Driving: The vehicle can take control of both the vehicle's speed and lane position in some situations, for example on limited-access freeways.	Limited Self-Driving: The vehicle is in full control in some situations, monitors the road and traffic, and will inform the driver when he or she must take control.	Full Self-Driving Under Certain Conditions: The vehicle is in full control for the entire trip in these conditions, such as urban ride-sharing.	Full Self-Driving Under All Conditions: The vehicle can operate without a human driver or occupants.

(Source: SAE International J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (Warrendale, Pa.: SAE International, June 15, 2018), www.sae.org/standards/content/j3016_201806)

Busy urban spaces present a particular challenge. While urban planners are keen to remove cars and larger vehicles to improve the safety, air quality and access for pedestrians, cyclists and other road users, there is still a requirement for moving goods and people through powered vehicles in a safe and manageable way. Small connected autonomous vehicles (pods) for the transport of people or goods fill this gap.

These 'low speed transport environments' form a good testbed for the development and testing of CAVs, and the UK has been a leading developer in this sector. These low speed vehicles are already being tested and deployed, for example the pods illustrated below were deployed in January 2020 at the National Automotive Innovation Centre (NAIC) at the University of Warwick to test the ability of the vehicle to form a platoon and safely navigate shared user space.

Case study

What will be required for the low-speed transport environment

Looking at the nascent small connected autonomous vehicle (SCAV) sector helps to focus on the specific capabilities and capacities required in the short to medium term. The low-speed transport sector is effectively trialling the technologies and offerings in a controlled and safe environment. Lower cost technologies are being deployed today where possible, to reduce to cost per vehicle. LIDAR (where light is used as a radar signal) is a useful detection technology, but the lower cost solutions are preferred.

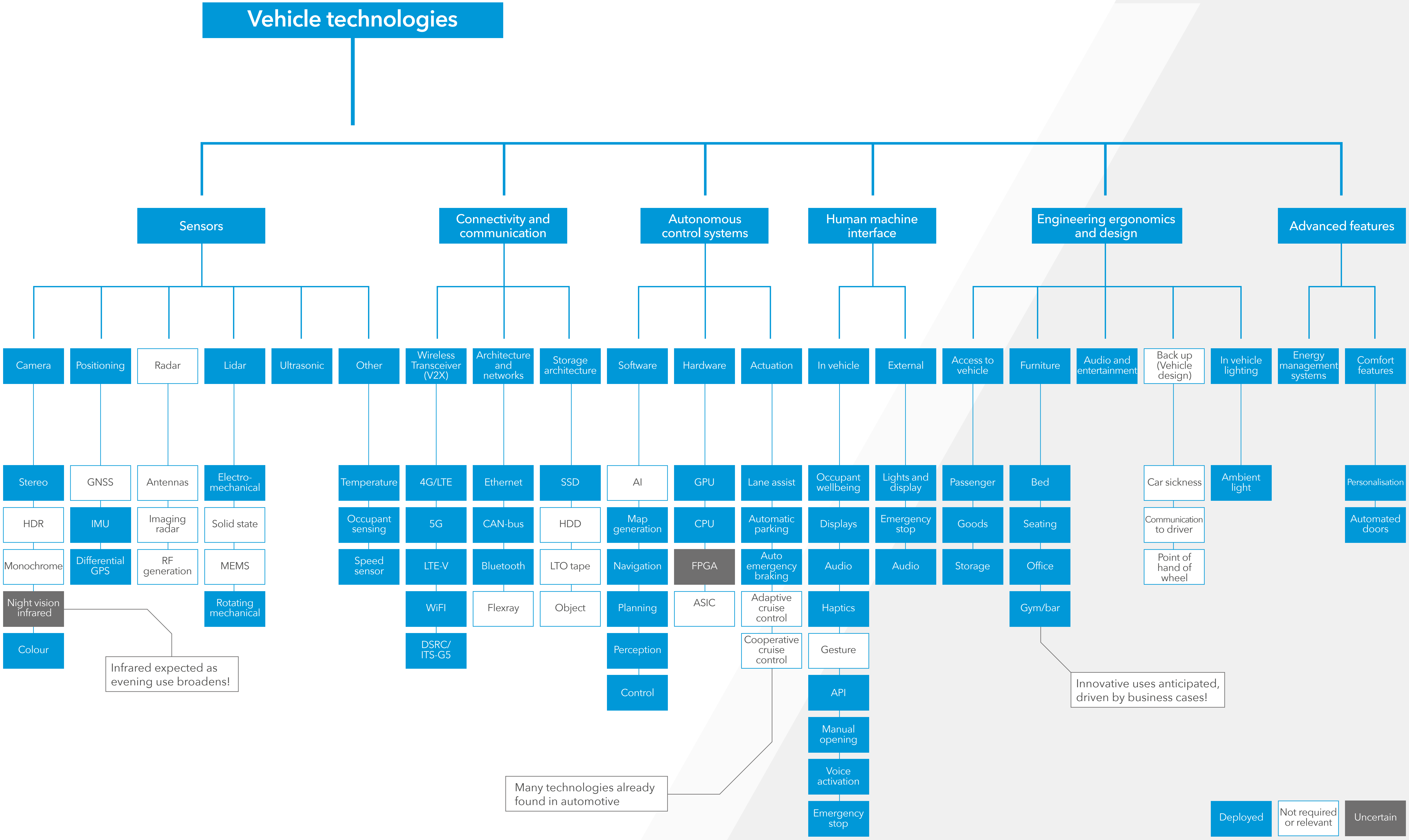
Of course, the cost per unit of any technology can and does change, and greater volume tends to reduce the cost per unit and so viability of mass usage. The on-board batteries are lead acid, rather than lithium, a constraint accepted due to low range and speed requirements between charging. Night vision cameras are not fitted today but are under consideration as options for future vehicles, depending upon customer interest and subsequent orders. This trade-off between cost and capability extend beyond the vehicle hardware. For example, although artificial intelligence (AI) and machine learning (ML) are, together, expected to become a core part of the software for autonomous control systems, current solutions do not employ these capabilities as their real world efficacy remains unproven. More research is required on how AI and ML enable CAVs to react to their environment, and in real-world driving conditions. The new technologies will have to do more than simply improve on replicated human driving patterns and behaviours, they should be able to make decisions that also evaluate the variety of possible behaviours and reactions of other road users, taking into consideration the range of responses that could be anticipated from other machines, pedestrians or human drivers.

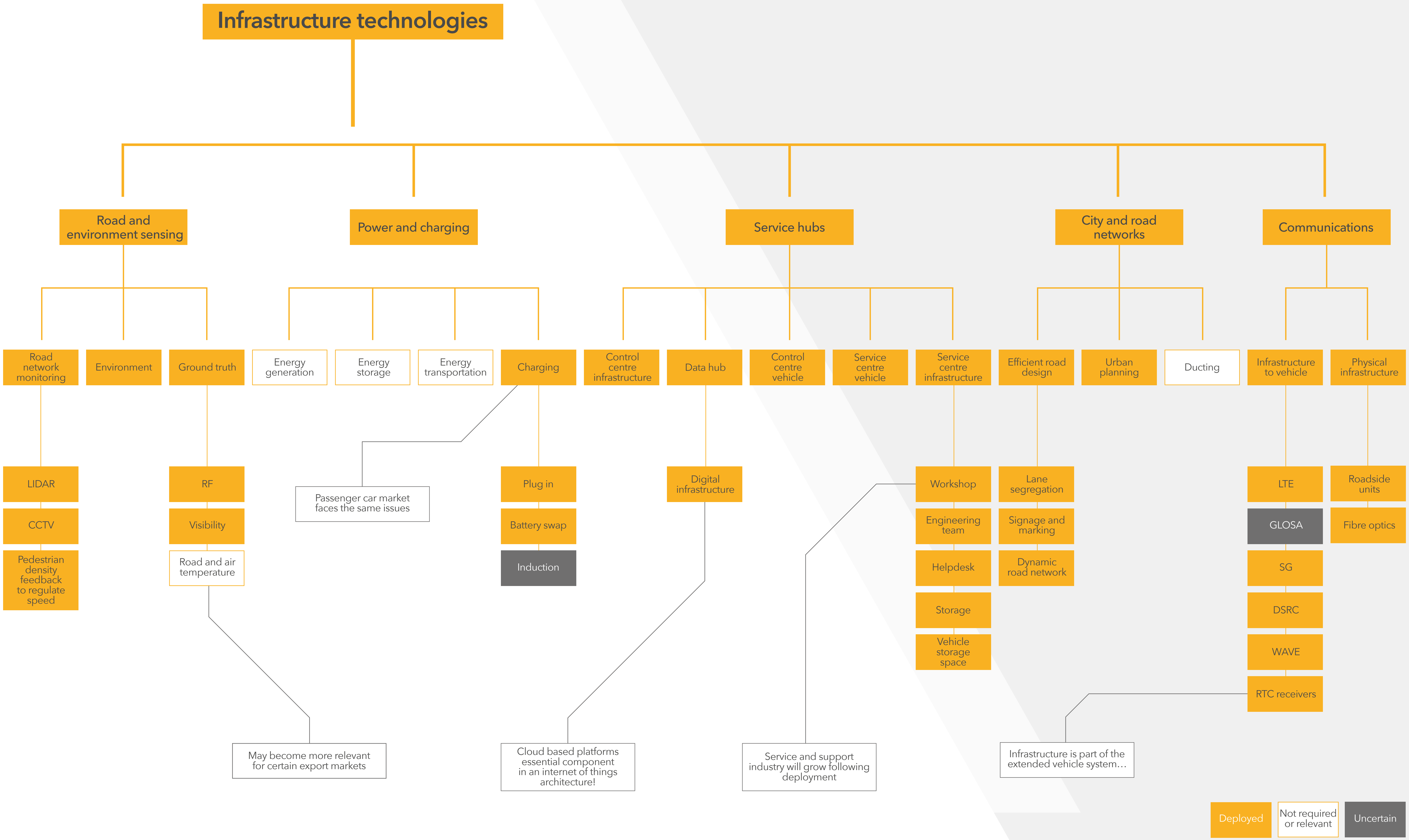
The communication and non-SCAV infrastructure can be viewed as a natural extension of the vehicle itself. As with all autonomous vehicles, safety of the occupant and other road users are essential to acceptance and take-up. Therefore, the technology and research is very much focused on this area. Equally, the resilience of the SCAV and cyber security of the wider networked solution will be essential to reassure business case owners and users alike.

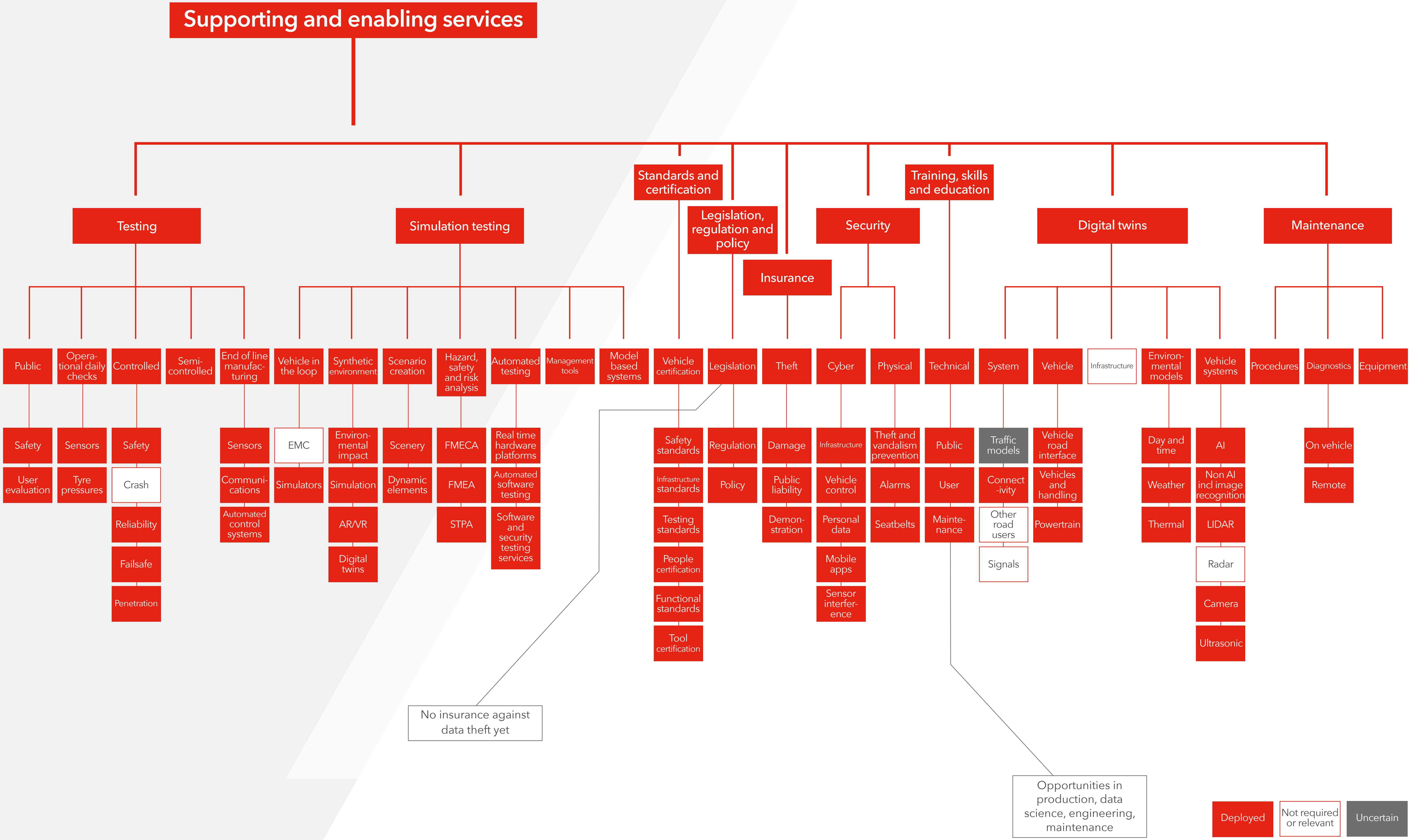
Personal mobility and service sector deployment of the SCAV will drive the direction of vehicle and infrastructure technology. Volume production is likely to change the technology deployed in the vehicle and infrastructure and, more broadly, increase the viability of business models for dedicated secondary services such as service, maintenance, and repair. Even within the early growth of SCAV research, development and testing, solutions will tend towards low cost and simple, until volumes make more sophisticated solutions viable. For example, data gathering is essential to understanding the use and performance of trial vehicles and the use case requirements and, although over-air data transfer capability exists, the current small connected autonomous vehicle store data on a solid-state drive (SSD). These in-vehicle drives are removed and replaced as a permanent means of storing data, more data is expected to be stored within cloud services as the product and service matures.

The technologies, business cases and support services currently in development for the low-speed SCAV sector is an indicator to the supply base for where to invest. Suppliers should be focusing on where they are able to grow their capabilities in research and development (either to reduce vehicle costs or improve performance), or in winning contracts as a form of preproduction ahead of scaled mass production.

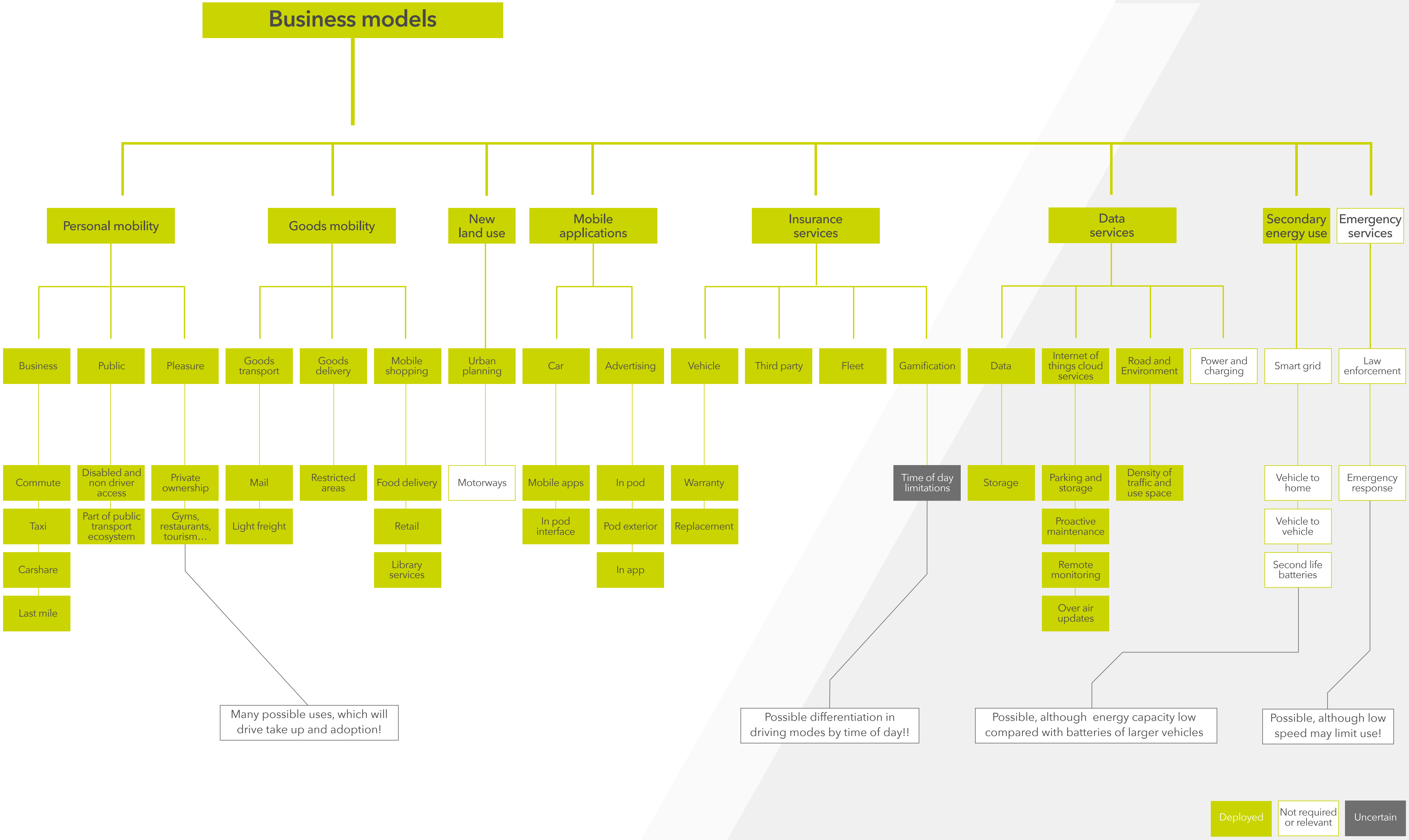
"Personal mobility and service sector deployment of the SCAV will drive the direction of vehicle and infrastructure technology."


Vehicle technologies
Sensors
Connectivity and communication
Autonomous control systems
Human machine interface
Engineering ergonomics and design
Advanced features
Camera
Positioning
Radar
Lidar
Ultrasonic
Other
Wireless Transceiver (V2X)
Architecture and networks
Storage architecture
Software
Hardware
Actuation
In vehicle
External
Access to vehicle
Furniture
Audio and entertainment
Back up (Vehicle design)
In vehicle lighting
Energy management systems
Comfort features
Stereo
HDR
Monochrome
Night vision infrared
Colour
GNSS
IMU
Differential GPS
Antennas
Imaging radar
RF generation
Electro-mechanical
Solid state
MEMS
Rotating mechanical
Temperature
Occupant sensing
Speed sensor
4G/LTE
5G
LTE-V
WiFI
DSRC/ ITS-G5
Ethernet
CAN-bus
Bluetooth
Flexray
SSD
HDD
LTO tape
Object
AI
Map generation
Navigation
Planning
Perception
Control
GPU
CPU
FPGA
ASIC
Lane assist
Automatic parking
Auto emergency braking
Adaptive cruise control
Cooperative cruise control
Occupant wellbeing
Displays
Audio
Haptics
Gesture
API
Manual opening
Voice activation
Emergency stop
Lights and display
Emergency stop
Audio
Passenger
Goods
Storage
Bed
Seating
Office
Gym/bar
Car sickness
Communication to driver
Point of hand of wheel
Ambient light
Personalisation
Automated doors
Infrared expected as evening use broadens!
Many technologies already found in automotive
Innovative uses anticipated, driven by business cases!
Deployed
Not required or relevant
Uncertain


Infrastructure technologies
Road and environment sensing
Power and charging
Service hubs
City and road networks
Communications
Road network monitoring
Environment
Ground truth
Energy generation
Energy storage
Energy transportation
Charging
Control centre infrastructure
Data hub
Control centre vehicle
Service centre vehicle
Service centre infrastructure
Efficient road design
Urban planning
Ducting
Infrastructure to vehicle
Physical infrastructure
LIDAR
CCTV
Pedestrian density feedback to regulate speed
RF
Visibility
Road and air temperature
Passenger car market faces the same issues
Plug in
Battery swap
Induction
Digital infrastructure
Workshop
Engineering team
Helpdesk
Storage
Vehicle storage space
Lane segregation
Signage and marking
Dynamic road network
LTE
GLOSA
SG
DSRC
WAVE
RTC receivers
Roadside units
Fibre optics
May become more relevant for certain export markets
Cloud based platforms essential component in an internet of things architecture!
Service and support industry will grow following deployment
Infrastructure is part of the extended vehicle system…
Deployed
Not required or relevant
Uncertain



Supporting and enabling services
Testing
Simulation testing
Standards and certification
Legislation, regulation and policy
Insurance
Security
Training, skills and education
Digital twins
Maintenance
Public
Opera-tional daily checks
Controlled
Semi-controlled
End of line manufac-turing
Vehicle in the loop
Synthetic environment
Scenario creation
Hazard, safety and risk analysis
Automated testing
Management tools
Model based systems
Vehicle certification
Legislation
Theft
Cyber
Physical
Technical
System
Vehicle
Infrastructure
Environ-mental models
Vehicle systems
Procedures
Diagnostics
Equipment
Safety
User evaluation
Sensors
Tyre pressures
Safety
Crash
Reliability
Failsafe
Penetration
Sensors
Communi-cations
Automated control systems
EMC
Simulators
Environ-mental impact
Simulation
AR/VR
Digital twins
Scenery
Dynamic elements
FMECA
FMEA
STPA
Real time hardware platforms
Automated software testing
Software and security testing services
Safety standards
Infrastructure standards
Testing standards
People certification
Functional standards
Tool certification
Regulation
Policy
Damage
Public liability
Demon-stration
Infrastructure
Vehicle control
Personal data
Mobile apps
Sensor interfer-ence
Theft and vandalism prevention
Alarms
Seatbelts
Public
User
Mainte-nance
Traffic models
Connect-ivity
Other road users
Signals
Vehicle road interface
Vehicles and handling
Powertrain
Day and time
Weather
Thermal
AI
Non AI incl image recognition
LIDAR
Radar
Camera
Ultrasonic
On vehicle
Remote
No insurance against data theft yet
Opportunities in production, data science, engineering, maintenance
Deployed
Not required or relevant
Uncertain


Business models
Personal mobility
Goods mobility
New land use
Mobile applications
Insurance services
Data services
Secondary energy use
Emergency services
Business
Public
Pleasure
Goods transport
Goods delivery
Mobile shopping
Urban planning
Car
Advertising
Vehicle
Third party
Fleet
Gamification
Data
Internet of things cloud services
Road and Environment
Power and charging
Smart grid
Law enforcement
Commute
Taxi
Carshare
Last mile
Disabled and non driver access
Part of public transport ecosystem
Private ownership
Gyms, restaurants, tourism…
Mail
Light freight
Restricted areas
Food delivery
Retail
Library services
Motorways
Mobile apps
In pod interface
In pod
Pod exterior
In app
Warranty
Replacement
Time of day limitations
Storage
Parking and storage
Proactive maintenance
Remote monitoring
Over air updates
Density of traffic and use space
Vehicle to home
Vehicle to vehicle
Second life batteries
Emergency response
Many possible uses, which will drive take up and adoption!
Possible differentiation in driving modes by time of day!!
Possible, although energy capacity low compared with batteries of larger vehicles
Possible, although low speed may limit use!
Deployed
Not required or relevant
Uncertain

Gaps between the emerging sector and today's supply base

Vehicle technologies

The UK supply base has strengths in autonomous control systems, connectivity and in-vehicle Human Machine Interface (HMI), but gaps in coverage of some advanced features such as user personalisation, and external HMI (communications via the exterior of the small connected autonomous vehicle or larger vehicle).

At present, there is not much demand for the latter features but, as the sector matures, these should provide valuable additional functionality to fleet owners and users. The SCAV sector has shown that the drive for low cost means that the technology deployed is not necessarily the most effective, but rather meets the immediate business case, low production and testing requirements. The focus on autonomous control systems is a great advantage, as this forms the core functionality of the vehicle, to which new features such as external HMI and comfort features such as user personalisation can be added. However, it is important to get the foundations of the vehicle in place before spending too much time and resource on non-essential features, even if some of these may become a core part of the business model. It is possible that secondary revenue streams may be generated via services sold in the vehicle, or advertising, an income stream that may be critical to delivery of a sustainable and cost-effective offering. There are also benefits in not fixing some solutions until user testing validates requirements. For example, while there may be a clear requirement for an external HMI, external screens and audio for vehicle-to-pedestrian communication, there is not a standardised interface evaluation procedure and optimal interface specifications are still lacking.

> The SCAV sector has shown that the drive for low cost means that the technology deployed is not necessarily the most effective, but rather meets the immediate business case, low production and testing requirements.

Infrastructure technologies

Infrastructure to vehicle (I2V) technology is well covered by UK suppliers, which again provides a significant advantage, as this is the foundation for a connected and networked vehicle.

The small connected and autonomous vehicle should be viewed as a component within an operating system, and so the technologies that connect the vehicle with road and traffic management, cloud-based services and other vehicles is as much a part of the overall offer as the technology in the vehicle itself. However, there are gaps in coverage, related to the emerging and unproven nature of the small connected autonomous vehicle sector.

Firstly, there is a dearth of electric vehicle charging infrastructure. At present, trial small connected autonomous vehicles examined in the case study use lead acid batteries. This presents issues as the charging infrastructure and cycles are quite different to that required for lithium batteries used in plug-in passenger cars. Over time, the battery technologies may converge and, certainly, the business case for using lithium batteries in small connected autonomous vehicles may change as production volumes increase, and as global battery production capacity increases Also other solutions are explored in battery research and development projects that may result in a better solution relying on different resources and/or securing a less dependent supply source other than lithium/cobalt. An opportunity exists for the development of UK battery production capacity, and this strategic industry would benefit many other technologies and sectors beyond small connected autonomous vehicles. The lack of existing charging infrastructure presents a wider challenge to the nascent and growing electric vehicle (EV) market. There are many energy providers, many EV charging infrastructure providers, but a lack of interoperability, both technical and commercial, is hindering the development of a reliable and flexible charging network. Certainly, the need for networked solutions and flexibility suggests that the SCAV battery and charging technology should align with that of EVs and other products and services deployed into the economy at scale.

Secondly, despite the UK strength in I2V communications, the emerging nature of the sector means that beyond a few test tracks and trial areas, the roadside infrastructure is yet to be built. Ducting of fibre optics and energy cabling would help create a low-speed transport network, but represents a significant speculative investment. Therefore, while building infrastructure must follow demand (to avoid redundancy, waste and the risk of aiming for unrealistic targets), creating a cost-effective, reliable and replicable approach to building the under-road ducting will mean that deployment can be scaled rapidly as the number of CAVs and areas served by these vehicles increase. The Midlands Future Mobility (MFM) programme is a good example of early development and deployment of agencies with expertise in creating infrastructure. The MFM testbed is building real-world ecosystems for Connected and Automated Mobility (CAM) technology development, acting as the springboard for scalable, future mobility technologies and services[3]. The aim is to co-ordinate the creation of a network of corridors (motorways, urban, rural) in and around the Birmingham and Coventry area, and WMG plays a leading role in this initiative.

Thirdly, due to lack of current demand, there is currently no regular, professionalised and independent supply base for the service, maintenance and repair of small connected autonomous vehicles, including passenger SCAV. When new technology is developed and tested, it is entirely appropriate that the manufacturing consortium and lead company within that network generates its own dedicated, small-scale solution for keeping vehicles on the road. However, as the number of vehicles and areas covered by these vehicles increase, business cases will demand a more cost-effective, replicable solution that can be outsourced. The commercial vehicle markets provide possible franchising models for service, maintenance and repair, and these service centres can be multi-brand, multi-user and multi-outlet.

[3] Midlands Future Mobility (MFM) offer services from initial virtual development, to real-world trials and market deployment. We work with companies both large and small, in long-term strategic projects or for short-term testing and validation. For more details please go to https://midlandsfuturemobility.co.uk/

Supporting and enabling services

The UK has a well-evolved vehicle-testing sector, including test track facilities for vehicles and road infrastructure. At present, the small connected autonomous vehicles in testing and development do not need to go through a crash-testing regime as they are classed as quadricycles, but as the vehicles are deployed in greater numbers, the sector may come under pressure to prove the safety of the vehicles in a crash test environment. Furthermore, other markets may have different requirements that manufacturers will want to meet.

There is also a mature simulation testing supply base, able to provide much of the vehicle testing ahead of real-world deployment, essential in reducing the costs of prototyping and trials. Given the UK supply base expertise in automated control systems and communication, it is also reassuring that the supply base includes leading-edge cyber security expertise. This testing and security expertise provides a solid foundation on which to build ancillary services. As a new and emerging sector, it is unsurprising that sector regulation, standards and training regimes have yet to be established, but these will need to be developed, through brining in accreditation and education providers into the low-speed transport network.

Manufacturing quality testing will be required as production is scaled up. Skills and knowledge should be transferable from the mainstream automotive and aerospace sectors. The existing simulation testing capability in the UK can be expanded to incorporate systems engineering tools and model usage of the small connected autonomous vehicle service as a holistic system.

As the service and repair requirement for CAV grows, so will the need for appropriate workshop skills, training, technical equipment, and quality-approved processes, and this will need to be developed with digital capability in mind. Many of the diagnostics, remote testing and repair skills will require specialist IT and systems skills that may be quite distinct from workshop maintenance and repair activity. This wide remit for skills and training also points towards a much wider education and training piece for the sector – users, potential fleet owners, business case developers and regulators will all need to understand what a low-speed transport environment offers, and what it can and cannot do.

Beyond the need to raise awareness, low-speed transport network operators, participants and regulators will also need to understand how the system is operated and deployed, its strengths and limitations, and the implications of requests for new use cases. There is, therefore, scope for training and accreditation service providers to help underpin the new market as it grows. Beyond training, turning a small connected autonomous vehicle from an experimental to proven product and service will mean convincing hearts and minds, and this is about safety concerns as much as the usefulness of pods.

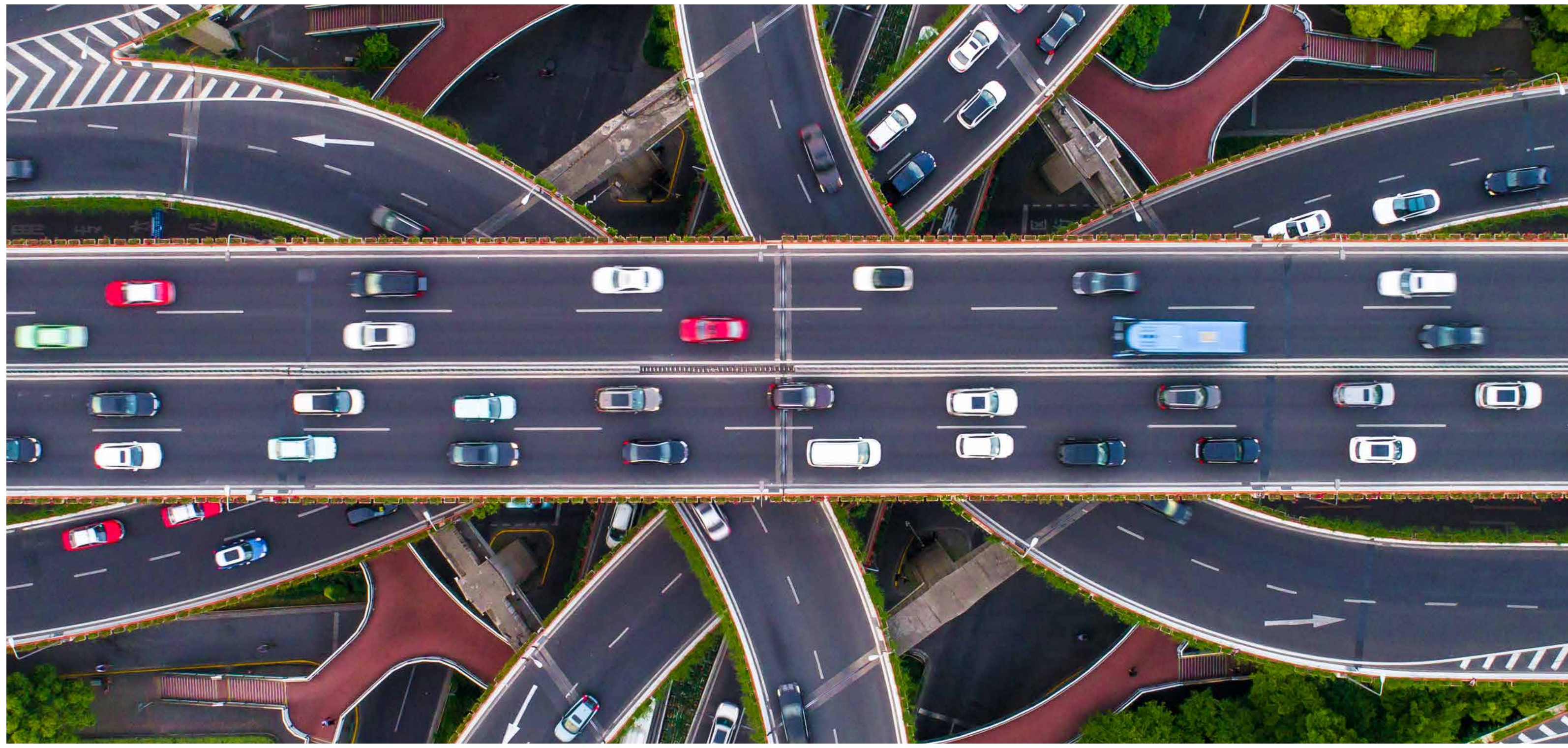
Regulation and standards can be developed as products and services are trialled, which will require co-ordination with governments, professional bodies and international standards organisations. Clear safety standards will be essential to Government regulation and, beyond that, the emerging low-speed transport network will need agreed operating standards across a number of areas including infrastructure, testing, functional roles and tools. Skills will need to be standardised and certified to enable recognised professional qualifications as a requirement for staffing the manufacturers and suppliers within the sector.

Underpinning all these supporting services will be policymakers, who, alongside regulators, will help strengthen the vision and scope for growth of the low-speed transport sector. By providing guidelines for local authorities and businesses, and promoting certain solutions and suppliers, policymakers should help the sector align to wider strategies for sustainable cities, urban development and transport.

Business models

Viable use cases and business operations will be essential to the establishment of the low-speed transport economy, but it is also important to recognise that use cases will also drive size and direction taken by technology, services and modes of deployment, both in the UK and across global export markets.

Pods offer access to low-carbon, low-congestion and low-cost personal mobility, and the existing supply base is clear in offering this to the market. The UK also benefits from a strong, well-established and globally recognised automotive sector, and that includes the provision of mobility services through traditional channels such as fleet and equipment finance and leasing as well as sharing economy innovators such as Citymapper (who in London have been trialling their multi-modal mobility platform CitymapperPlus, which provides users with a single route planning, ticketing and booking app that incorporates bus, ferry, train, car rental, car sharing, taxis, bikes, and scooters). Micro-mobility solutions such as small connected autonomous vehicles will benefit from being integrated into the wider mobility marketplace. Beyond personal mobility, developers see a number of light freight opportunities as outlined earlier, and use cases may evolve that bring personal mobility and service provision together (for example, through the provision of safe and private mobile dining or retail experiences).



Again, although the impact of a SCAV network is hard to predict, widespread use and adoption would prompt significant changes in urban and transport planning, and how those environments are served by ancillary services such as medical response (where local response is important without speed or complexity, such as automated defibrillator small connected autonomous vehicles), and in turn, these use cases would also have a feedback impact on the design and capabilities of the small connected autonomous vehicles and network (in the current climate, Covid testing SCAV could be deployed but would require some form of self-cleaning technology, perhaps building on technologies deployed in public toilets).

Underpinning the evolution of new mobility services, the UK supply base has good coverage of data services, including internet of things cloud data services and road and environment tracking and monitoring. The growth of new business models is, inevitably, difficult to predict, but beyond the main services offered, a growing sector will necessarily create secondary markets, some consumer focused such as mobile applications for retailers (for example, enabling booking SCAVs for retail activity), others more clearly aimed at the business to business sector, (such as the potential for new markets in second-life batteries and smart-grid services).

Technology and service clusters

This study was focused around density of businesses providing specific services and products and have revealed several clusters in the UK supply base for CAV, notably around automotive legacy skills, advanced IT and AI services, and vehicle and network connectivity and control systems.

Looking at the scope of supplier products and services required for small connected autonomous vehicles operating in the low-speed transport environment, it is clear that a network of companies working together begins to generate a collective knowledge and expertise greater than that of the individual companies in the supply chain, and this feedback loop has the potential to help fill gaps and generate new partnerships.

For example, the existing UK supply base for internet of things cloud services could work closely with those working in I2V communication and in autonomous control systems, enabling more reliable vehicle connectivity and control through the deployment of additional layers of failsafe redundancy communication and data networking.

Addressing the gaps

The gaps between required technologies, services and relationships emerge from the analysis of the existing business ecosystem for low-speed small connected autonomous vehicles, and from considering the wider possibilities for these and other forms of small connected autonomous vehicles.

As an emerging sector, new partners and partnerships will be forged to fill gaps in products and services. Encouraging UK businesses to fill the gaps, delivers clear benefits to the UK and the ability to retain global leadership.

- Building physical clusters of suppliers in the UK will build a more resilient, competitive and responsive supply chain. Regardless of the outcome of future UK trade negotiations, global shocks and turbulence have demonstrated the benefit of locating core supplier capacity in a localised tariff, trade and transport region.
- UK businesses can become part of a leading-edge sector, gaining first-mover advantage in development and delivery of new products and services.
- UK companies joining the sector are also joining a network of other suppliers moving in the same direction. The creation of a network of similar enterprises working towards the same or similar goals is recognised to accelerate innovation. The network effect generates a deeper and wider dialogue among participating enterprises – as demonstrated by similar innovation clusters (Silicon Valley, California, and Biopharma clusters in the UK, Singapore and Boston, Massachusetts[4]).

Suppliers can map out their capabilities, expertise and their own supply base. The leadership team in UK companies looking to develop expertise in this sector should look to the gaps in provision and see where there might be synergies with existing skills and services.

For example, businesses engaged in service, maintenance and repair operations could consider what would be required to build a service centre, recruit technicians and build a support infrastructure that connects with the vehicle and cloud platforms being developed. In doing so, the business can then evaluate what gaps exist today, this could be building the appropriate information technology, or certifying technicians in high voltage workshop skills, and then consider how to close those gaps, either through building the capability internally or through external support. Again, the benefit of a network of businesses engaged in a similar enterprise is that the skills may be developed by one company and then transferred to another within the network. In this example, the technical skills developed by the company building the small connected autonomous vehicle should be able to transfer maintenance and repair skills and knowledge to a company looking to provide a service centre.

The mapping of current enterprise networks should help suppliers better understand the existing landscape and their position within it and, in doing so, help them navigate and contact other companies within the network. A business can apply this mapping approach to their own network, to understand where they may have relationships that can be further cultivated, and also reveal where they might want to focus business development activity to build new relationships.

[4] https://www.bidwells.co.uk/insights-and-research/cambridge-and-oxford-biopharma-clusters-research-findings/

Test cases and trials form the bedrock of the development of a new supply network, so getting involved in such product development should be a priority for any business looking at the market opportunity. The Coronavirus pandemic has led to delays in test trials and will, in the short to medium term, influence the pace and direction of investment in connected autonomous vehicles, and it may affect the availability of investment funds because of economic disruption.

However, people and goods will need to move around safely, securely and in a sustainable way, and small connected autonomous vehicles clearly present a viable alternative to both traditional passenger car and public transport, offering private space in a shared and sustainable transport system.

The gaps between today's supply base and the needs of the emerging sector create commercial and strategic opportunities for UK suppliers and policymakers, which are summarised below.

Vehicle technologies

- Private & Public investment in R&D programs for vehicle technologies
- Development of external HMI (Human Machine Interface), Luxury features such as passenger lighting and comfort enhancements, which could be developed in partnership with the well established luxury vehicle design capability in the UK auto industry
- Government support for the creation of supplier trade organisation for companies developing new CAV technologies in the UK

Business models

- Development of commercial propositions in personal and goods mobility segments, via support of more start-ups in CAV assisted home delivery and urban transport
- Development of more 'living labs' for new customer solutions that would involve urban planners, transport planners, property developers and CAV suppliers
- Smart grid and EV network expansion require collaborative development to meet ambitious targets and expectations

Infrastructure technologies

- Development of service, maintenance and repair centres and fleet management technologies, drawing on expertise in facilities management and fleet and leasing sectors within the UK
- Development of energy transportation infrastructure in conjunction with non-automotive expertise in the UK such as National Grid and energy distribution companies

Supporting and enabling services

- Development of cyber and physical vehicle security specialist providers, in conjunction with leading UK research expertise
- Supporting standards and policy formulation for creating global best practice
- Development of a CAV training academy able to deliver expertise in a number of areas including safety, user training and vehicle service, repair and maintenance
- Expansion and support for of modelling and simulation services, to bring together the physical internet and new CAV infrastructure

Summary

Strategy for R&D and production supply

The connected and autonomous vehicle (CAV) framework summarised in this report allowed visibility of the existing technology landscape and provided an overview of the services required to develop a CAV. A key conclusion is that deployment of use case innovation, via supported business case development, should guide the testing, proving and eventual commercial direction of the sector.

The emerging CAV economy provides potential for global leadership and export-led growth, and a strong UK supply base will help build a resilient, agile and dynamic new industry.

Suppliers should look at the growth and innovation opportunities that this new market offers, where they have compatible skills and capabilities, and where there is a clear gap in the existing UK supply base, an opportunity exists to fill that gap. The low-speed environment case demonstrates the benefits of bringing together a consortium of manufacturers and service providers to build a learning supply chain, and the direct and indirect benefits to a company in getting involved in a new product and service early in the development and testing phase.

Policymakers can provide strategic goals and direction, which help steer industry and Government working together to generate investment, regulation and standards. Research and development programmes show the benefit of direct Government investment in building a new industry or sector, and in reducing the cost and complexity of serving a global customer base within a sector via active participation in international co-operation over regulation, standards and legislation.

This study of the low-speed transport environment SCAV supply requirements and the existing capability and scope of the UK supply base for small connected autonomous vehicles was aimed at understanding the enablers and gaps in the supply chain. The research was undertaken in 2019, prior to the global COVID-19 pandemic when new mobility concepts were attracting significant investment and venture capital (for example, Lyft and Uber). The global pandemic has impacted investment markets, transport, manufacturing and even how people view personal mobility. At this stage it is impossible to gauge the long-term impact of COVID-19 on transport and mobility demand and services, but personal pods and home delivery solutions have clear advantages that could prove attractive to current investors and potential users, transport planners and policymakers.

The UK has technological lead in this sector, and now is the time for suppliers and Government to work together to fill gaps in capacity, capability and to build a roadmap for the future.

How WMG can help

WMG is keen to help suppliers and policymakers build new supply chains for emerging technologies, explore the potential of manufacturing in the UK to address the gaps identified, and support further development of capabilities for the existing supply base. For more details on how WMG can support. please contact SCIP@warwick.ac.uk.

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Excellent transport and road links

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- Nearest airport - Birmingham International (approx 20 minutes by car)
- Nearest train stations - Coventry or Canley (approx 10-15 minutes by car)

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