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# D.2.2

# Analysis of Market Needs

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| Abstract |
|---|
| This document presents the findings of Task 2.2 of the ICT4CART research programme on the Analysis of Market Needs for the information technology systems that enable connected and autonomous road transport.<br>The markets are presented as 6 subsectors of data services, accompanied by descriptions of services and a summary of the IT performance requirements. General information on the potential market structures of the ICT infrastructure and service provision is also presented. |



## Legal Disclaimer

## Abbreviations and Acronyms

| Acronym | Definition |
|---|---|
| AI | Artificial Intelligence |
| ABS | Anti-lock Braking Systems |
| AD | Automated Driving |
| ADAS | Advanced Driver Assistance Systems |
| AV | Automated Vehicle |
| CAM | Cooperative Awareness Message |
| CAV | Connected and Automated Vehicle |
| C-ITS | Cooperative Intelligent Transport Systems |
| DENM | Decentralised Environmental Notification Message |
| EC | European Commission |
| ETSI | The European Telecommunications Standards Institute |
| EU | European Union |
| EV | Electric Vehicle |
| GA | Grant Agreement |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| HD | High Definition |
| HGV | Heavy Goods Vehicle |
| IAM | Identity and Access Management |
| ICT | Information and Communications Technology |
| IoV | Internet of Vehicles |
| IT | Information Technology |
| ITS | Intelligent Transportation System |
| MaaS | Mobility as a Service |
| MEC | Mobile-Edge Computing |
| OEM | Original Equipment Manufacturer |
| OTA | Over-the-Air |
| PO | Project Officer |
| R&D | Research and Development |
| RTK | Real Time Kinematics |
| SAE | Society of Automotive Engineers |
| SOC | Security Operation Centre |
| V2I | Vehicle to Infrastructure |
| V2V | Vehicle to Vehicle |
| V2X | Vehicle to everything (other vehicles and connected infrastructure) |
| VMS | Variable Message Systems |
| WP | Work Package |

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## Executive Summary

The driving task is being increasingly supported through connectivity. Whether through the vehicles' on-board systems or through connected devices used by the vehicle's occupants, the ability to communicate directly with other road users, infrastructure and external systems is enabling safer, more efficient, more comfortable journeys. This is only likely to increase as more and more of the driving task is automated and vehicle connectivity will move from an optional extra to a key enabler for ensuring that these increasingly automated vehicles interact safely and effectively with each other, other users and the surrounding infrastructure.

The capability of telecommunications and data management infrastructure is improving, making new levels of vehicle connectivity increasingly possible. The advantages of connectivity are recognised across the industry, such that the full benefits of vehicle automation can only be realised with this additional capability.

The ICT Infrastructure for Connected and Automated Road Transport (ICT4CART) project has been launched to explore how this infrastructure should seek to develop in the coming years and further that development towards an effective ICT infrastructure for enabling the widescale roll-out of connected and automated vehicles (CAVs). ICT4CART aims to design, implement and test in real-life conditions a versatile ICT infrastructure for the needs of higher levels of vehicle automation.

One element of the ICT4CART project is to explore the market for this infrastructure, starting with an investigation into what the various associated users may actually need from this infrastructure in the coming years. Establishing the ways in which value is – or could be – generated by the infrastructure for groups such as road users, road network operators and fleet managers is an important first step in determining the business case for this infrastructure. Urban Foresight, as part of the ICT4CART consortium, has sought to undertake research in this space to support decision making regarding ICT infrastructure design and investment by exploring the needs of the end-users in this system and, hence, the market(s) for the services that this infrastructure enables.

Work has been undertaken in other contexts, not least the EC's C-ITS Strategy initiative, to describe the services that ICT infrastructure could offer. However, much of this work has been relatively narrow in its focus, too high-level or tied to a particular set of ICT technologies. To have a reasonable chance of understanding the value for the ICT infrastructure, therefore, there is a need for a holistic, value-based, technology-agnostic assessment of the potential demand for information services for CAVs.

Our approach to doing this has involved in-depth interviews with expert representatives from across the ICT4CART consortium and external organisations, supported by a wide-reaching desk study and a market structures workshop. The result was a framework and systematic categorisation of the information services which could make up separate 'markets', having have distinct user/value combinations, i.e. beneficiaries of services and associated primary benefits addressed by the services. The framework was structured around six groups:

1. Automated Driving: connectivity to support the automated decision making of road vehicles. E.g. Services that supply CAVs with information on the other road users in their immediate vicinity – or likely to enter their immediate vicinity within a short period of time.
2. Informed Journeys: connectivity to improve driving decisions, regardless of how automated the vehicle is. E.g. Services that supply CAVs with information about planned or unplanned 'events' which could relate to their onward journey, where an event is a real-world occurrence external to the normal operation of a road network but potentially having a noticeable effect

on that network.

3. Intelligent Management: connectivity to improve awareness of what is happening on a road network or other driving environment. E.g. Services that relate to the condition of the road network and surrounding environment derived CAV on-board sensors.
4. Coordination of Vehicles: connectivity to instruct automated vehicles in specific scenarios and coordinate their driving. E.g. Services that would supply a group of collocated CAVs with detailed, coordinated instructions on paths to take, manoeuvres to make and driving behaviours at specific times and under specific circumstances.
5. Connected Travellers: connectivity to connect vehicle passengers and improve their experience. E.g. Services for use by the passenger to access the web, consume on demand content and communicate (including internet calls).
6. Underpinning Services: connectivity and information services with commercial potential that enable a safe and effective CAV driving environment. E.g. Services that enable encrypted, private and secure communication between CAVs and infrastructure.

Within each of these markets, applications of CAV technology will advance first in use cases where significant cost savings can be made in the more efficient use of resources. Those most referenced in both interviews and existing literature are: platooning, parking and shared transport services.

For each of the six groups, the typical performance level was assessed. Research and publications on CAV information services do not yet agree on the standard performance levels required. In general, a lack of distinction between the information services' purpose, value and transmission methods has hindered the development of a consensus on this matter.

The approach that was used in this research was to define the performance levels across these parameters: privacy, latency, reliability, coverage, bandwidth, and granularity. The Automated Driving information services, for example, will require particularly low latency which will influence the technologies and architecture best suited to enable them effectively. Connected Traveller services, on the other hand, will require particularly high bandwidth but are not critical to the driving task.

We have also investigated the main elements of the market structures for the information services, namely who is likely to pay to have these services enabled and how that will differ in different contexts. The main factors influence this include the features of the markets from which these services have emerged; the ownership and operational responsibility of the environment within which the services are deployed; the type of value generated by the services; and the performance demands of the services. This particular element of the research was preliminary investigation only and will form the basis for other market analysis and business model work later in the ICT4CART project.

The framework presented as a result of this research will be useful for the development of more detailed system requirements of CAV ICT infrastructure along with more extensive service design. It can also be used to inform developments of other complimentary technologies within this sector. It can offer the basis for better dialogue and collaboration between the different parties, from local and national governments through to large established industries that need to work together in new ways. Finally, it can enable that collaboration to be centred around what generates value for users, and society at large.

# 1 Introduction

Connected and Automated Vehicles (CAVs) are road vehicles for which the driving task is, to some extent, automated and which have the capability to communicate with infrastructure and other road users. The advantages of vehicle connectivity are recognised across the industry, such that the full benefits of vehicle automation can only be realised with this additional capability.

Information and Communications Technology (ICT) infrastructure is currently in development that aims to enable the required level vehicle connectivity. There is still much to be determined about how this will work - technically, operationally and commercially. The ICT Infrastructure for Connected and Automated Road Transport (ICT4CART) project has been established to design, implement and test in real-life conditions a versatile ICT infrastructure for the needs of higher levels of vehicle automation.

This report in particular aims to support decision making regarding ICT infrastructure design and investment by exploring the needs of the end-users in this system and, hence, the market(s) for the services that the infrastructure enables.

The methodology underpinning this report required a research framework to ensure comprehensive coverage of industry opinions. To achieve this a mixture of desk research, expert interviews and a stakeholder workshop was carried out to inform the key findings. These findings will be relevant both to the ICT4CART consortium partners as well as organisations in relevant market sectors.

The report is a deliverable of Work Package 2 of the ICT4CART project.

## 1.1 Purpose

The purpose of this report is to capture the underpinning market needs of CAV ICT infrastructure, i.e. what end users need from this infrastructure and the value it could create for them. The report aims to inform those working in the CAV technology space on the potential markets for CAV information services.

It is particularly concerned with the transition from Level 2 CAVs to Level 3/4 CAVs (see Section 3.2 for information on SAE automation levels), such that drivers no longer need to be fully attentive, instead vehicles can complete all driving functions in certain environments. At this point, it is anticipated to be a shift from the use of automation purely for driver support and to automation for improving driving experience.

This document describes the demand for information services from different groups in the CAV market. This can form the basis for the development of more detailed system requirements of CAV ICT infrastructure along with more extensive service design. It can be used to inform developments of other complimentary technologies within this sector.

## 1.2 Target Audience

The initial readership of this deliverable is anticipated to primarily consist of the ICT4CART consortium partners. As this report aims to inform those in the CAV technology space on the potential markets for CAV information services, the information contained will also be pertinent for other organisations situated in sectors involved in the development, deployment and roll-out of CAVs and their supporting infrastructure. This includes the following categories of organisations:

- Telecommunications companies

- Automotive companies
- Information Technology (IT) companies
- Cybersecurity technology providers
- Road network operators
- Mobility service providers including public transit operators
- Policy makers

# 2 Background

This section provides an overview of the status of the CAV industry, the ICT4CART project and this sub-task.

## 2.1 The Connected and Automated Vehicle Industry

### 2.1.1 Vehicle connectivity

Vehicle connectivity is defined here as the ability for a vehicle or devices within that vehicle to transmit and receive information with other vehicles, systems or users through some means of telecommunications. This has been widespread in some forms for many years now, e.g. real-time traffic information utilised by satellite navigation systems.

Vehicle connectivity can be understood in terms of enabling *information services* to and from vehicles. This is distinguishable from services provided via "traditional" Intelligent Transportation System (ITS), road markings and signage. The "traditional" approach delivers information services through visual communication to drivers and – usually – passive, fixed location detection. On the other hand, the information services delivered through vehicle connectivity are communicated on a machine-to-machine basis and either present information to drivers internally within the vehicle or the information is used automatically by the vehicles on-board systems.

### 2.1.2 Automated Vehicles

AV technology operates in two dimensions: monitoring the surrounding environment and controlling the position of the vehicle. In more advanced applications, an additional layer of intelligence interfaces with these two functions, allowing the vehicle to make decisions about the motion based on its interpretation of the surrounding environment and curtailing the need for a human driver at all.

In the current road vehicle market, these functions are typically referred to under the umbrella term Advanced Driver Assistance Systems (ADAS). Common examples include:

- Blind-spot cameras
- Parking assistance, both warnings and automatic manoeuvring
- Cruise control and adaptive cruise control
- Anti-lock braking systems (ABS)
- Lane departure warning systems

The gradual addition of ADAS to new vehicles has been attributed to the demand to improve road safety through the mitigation of human error. As such, this technology is anticipated to continue to develop, likely in the using of additional data sources that are available through mobile connectivity.

Connecting the vehicle to external data sources – such as other vehicles, in-situ proximity infrastructure or a cloud network – adds an additional layer of input to be processed by the on-board systems that support automated driving.

### 2.1.3 CAVs and their Supporting Infrastructure

The potential for connectivity to improve both vehicle safety, efficiency and the comfort levels of the driving experience is widely recognised across industry, with acceptance from many consumers despite some concerns from change-adverse subsections.

CAVs are Automated Vehicles which have the capability to communicate with infrastructure and other road users. This broadly covers physical (e.g. road signs, road markings, communication infrastructure), and digital infrastructure (e.g. map data, traffic dynamic data) incorporating V2I (Vehicle to Infrastructure) and V2V (Vehicle to Vehicle) communication networks.

The advantages of rolling out connectivity are recognised across the industry, such that the full benefits of AVs can only be realised with this additional capability. Connectivity will underpin CAV functions:

- increased safety will be achieved from better positioning, owing to the V2V information exchange as well as the capability to pinpoint places with hazardous driving conditions;
- increased road efficiency will be delivered from communication with traffic signals, road signs and incident information;
- and driver experience will be improved from a less demanding driving function and data streaming services.

Experts anticipate that fully connected corridors will be established on motorways or urban arterials at the first instance, with a gradual expansion of these connected networks. This would offer fixed route vehicles, such as buses, an opportunity to fully utilise connectivity to improve services.

## 2.2 The ICT4CART Project

The main goal of the ICT4CART project is to design, implement and test in real-life conditions a versatile ICT infrastructure for the needs of higher levels of automation, up to SAE Level 4 (see Section 3.1 for background on SAE levels). The project was awarded through the European Commission Horizon 2020 funding program. Like many EU-wide programmes such as CARTRE, C-ROADS and C-MOBILE, the project aims to present a coordinated response to the challenges of the C-ITS strategy, which is presented in more detail in Section 3.6.

The ICT4CART project draws on expertise and technologies from across different industries, including telecommunications, ITS, automotive and IT. The consortium is comprised of 21 different organisations, working to combine, adapt, and improve technology applications for CAV infrastructure. The technology solutions underpinning the project will be trialled, demonstrated, and validated in four specific use cases. These real-world and challenging environments encompass a range of urban and highway applications with varying degrees of complexity. The project's test sites are located in Germany, Austria, Italy and the Italy-Austria border. Secondary outcomes from the project include analysis of the market, business model development, and an open cloud platform. This platform will aggregate data from across the IT environment and provide analytics services. It will be open for integration and exchange to allow third parties to develop and deliver innovative digital services in the CAV space.

The nature of the connectivity architecture and ICT technology that will be explored by the consortium is under development at the time of this report. It is anticipated that a hybrid configuration of ITS-G5 proximity networks, Mobile Edge Computing (MEC) and mobile networks will be used.

### 2.2.1 Work Package 2 within the ICT4CART project

Work Package 2, in which the task relating to this deliverable is situated, is intended to ensure that the project's main research and development activities are informed by the current literature and stakeholder perspectives. The scope of Work Package 2 includes: refining the CAV use cases, confirming the system requirements, and analysing market needs.

Task 2.2 covers the specific stand-alone research and analysis of the CAV supporting infrastructure market needs. The key output of Task 2.2 is this publication which is intended to meet all market research requirements for this programme. Figure 1 below illustrates the main interactions between this task and other tasks and work packages within the ICT4CART project.

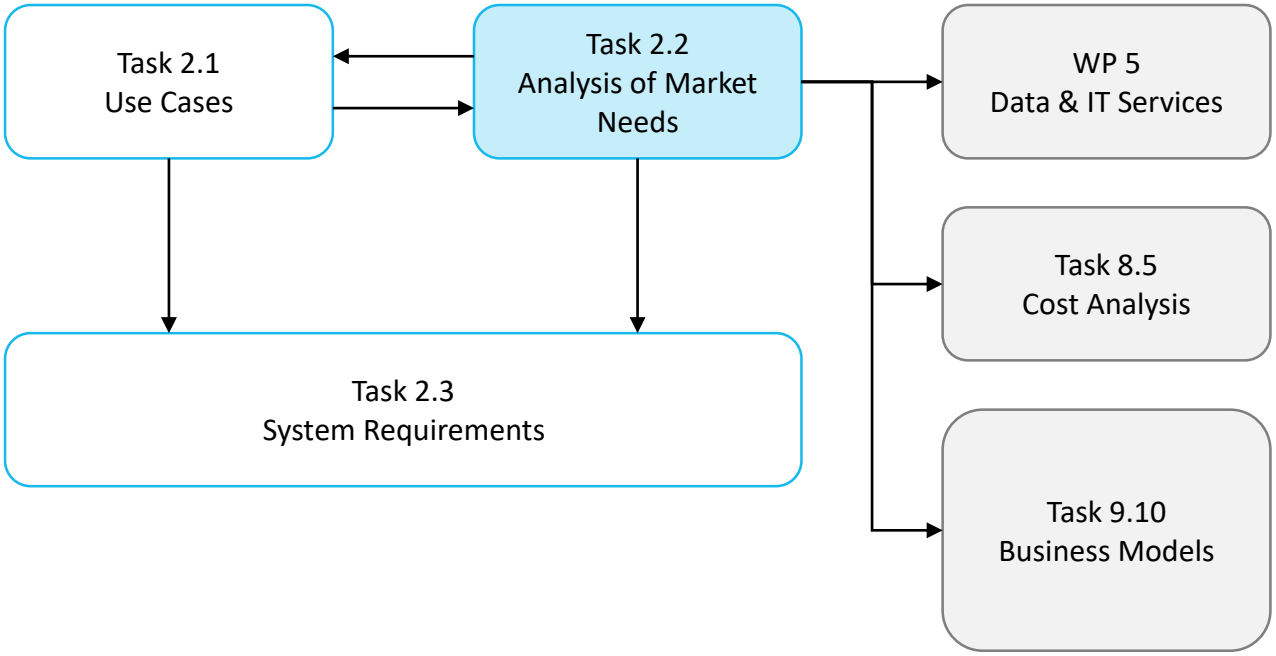


**Figure 1 Task 2.2 interactions.**

### 2.2.2 Market Research Requirement

The research and analysis activity in this report is unique within the CAV industry. The 'market needs' CAV ICT infrastructure literature that is currently available has not previously been reviewed in full and compared against the opinions of a range of industry stakeholders.

To develop an ICT infrastructure solution that brings enduring benefits to the consortium and wider industry, the commercial potential case must be made. As such, a review of the market at the front end of the project was required to help contextualise the main body of the project's research and development tasks. The market research from this task will also be referenced at the end of the ICT4CART project when evaluating the economic potential of the solutions developed.

It should be noted that, while much of the ICT4CART project focusses on specific use cases, it is recognised that the services related to these use cases do not represent the whole markets in themselves. Therefore, the focus for this research has not been limited to the four real-world use cases that the consortium will use to test and verify the operation of the ICT solutions developed in this programme of work.

# 3 Context

## 3.1 Introducing Connectivity

Connecting a vehicle to a wider communications network can be segmented into three technology spaces, this is ordered here by decreasing levels of technology and market maturity:

1. Connected mobile device that is in the vehicle to inform the human driver/passenger.
2. Connected hardware that is within the vehicle's architecture and informs the human driver/passenger through an interface.
3. Connecting hardware that is within the vehicle's architecture that integrates with the Automated Driving (AD) computing architecture to inform driving decisions.

The market on the first technology space is fully mature and competitive, dominated with products such as TomTom and Garmin, and service providers like Google Maps and Waze. The value of this market is in providing individual users of private transport with information and entertainment in order to reduce the stress levels induced by their driving experience.

Connected markets in private transport originally involved one direction of communication: to the vehicle. Radio and navigation units provided both information in the form of scheduled, generic traffic updates and in-advance routing guidance, as well as entertainment as broadcast audio. Now that the technologies underpinning mobile devices and navigation systems have developed to handle lower latency and larger message sets, more customised, relevant and real-time information is exchanged.

Drivers no longer need to prepare routes as standard; dedicated mobile applications or mobile apps provide them with instant routing guidance and update in real-time in the event of an incident or a change in traffic conditions. These alerts are informed by information that is collected from other road users. Entertainment is on-demand, with apps allowing drivers to stream audio over cellular networks and passengers to browse the internet and stream video content.

In public transport and other business fleets, drivers can be continuously connected to the depot via connected devices. Journey scheduling, payload information, paperwork and performance statistics are all transferred to a centralised location to optimise the use of both the driver and their vehicle as a business resource.

The markets that are anticipated to form from the ongoing development of connectivity capabilities (coupled with the parallel development and uptake of AD) will see deepen benefits for individuals and fleet operators. Driving experiences - facilitated by autonomous driving systems, informed of all aspects of their upcoming journey, and connected to entertainment systems - will become more comfortable for individual users of road vehicles.

Furthermore, as concentrations of CAVs in road fleets increases, the benefits of the fully informed and centralised decision-making that advanced connectivity enables, will be realised; road transport will become safer, more efficient and less polluting. With driving decisions being made by the vehicle's systems rather than the individual driver, calculation mechanisms and input information will be designed to align with policies on road transport use, rather than relying solely on the interests on the individual drivers.

This has thus far been supported by simulating road networks and modelling the results of different concentrations of AVs and CAVs across a range of programmed levels of caution. The harmonic average speed of the road network drops with the introduction of AVs but will be increased once the

vehicles were also connected. This is due to CAVs' ability to collaborate by travelling in platoons, dampening oscillations in traffic speeds and assisting the flow of vehicles through bottlenecks[1].

There is a consensus in literature and across stakeholders that at as low as a 20% concentration of CAVs on the road, the collective benefits of more efficient and safer driving decisions will become apparent.

## 3.2 Terminology and technology standards

One of the most ubiquitous terminologies used across the CAV industry is the Society of Automotive Engineers (SAE) standard for defining automation levels. That is:

- Level 0 – No Automation
- Level 1 – Driver Assistance
- Level 2 – Partial Automation (the driver is still engaged in the driving task and monitors the environment.)
- Level 3 – Conditional Automation (the driver is not required to monitor the environment but must always be prepared to take back control when notified by the vehicle.)
- Level 4 – High Automation (the vehicle performs all driving functions in certain environments.)
- Level 5 – Full Automation (the vehicle performs all driving functions in all environments.)

In developing a communication infrastructure to enable the evolution of connected vehicles as profiled above, standardisation and consistency in approaches is required. In the interviews with experts, it became apparent that consistency is important in enabling innovation. This is primarily because Original Equipment Manufacturers (OEMs) will not invest in funding research and development (R&D) into the industry if there is no guarantee that their solution can be implemented everywhere, ensuring highest potential returns. Network operators take their innovation leads from the technology providers that supply them; those interviewed lacked flexibility to invest in technology that may be superseded in the near future.

To enable a standardised platform or infrastructure to deploy solutions on, government support is needed. OEMs, again, will not commit funding to the development of a full network platform if there is a probability of a competitor doing the same.

Competing formatting standards for communication mediums can hinder adoption rates. As this technology space is related to telecommunications, standard agencies and representative bodies are working to ensure alignment in development is achieved as early as possible.

Standards are being developed in certain sub-sectors of CAV use by organisations such as 3GPP (3rd Generation Partnership Project) for CV2X (Cellular Vehicle to Everything) and infotainment signals[2] and ETSI for V2V "Collective Precision Messaging" on ITS-G5 networks[3]. One of the most advanced industry standards is the CAM and DENM message sets standards from 2014, which were also set by ETSI (The European Telecommunications Standards Institute):

[1] IET Journals, Simulating deployment of connectivity and automation on the Antwerp ring road, January 2018
[2] 3GPP, Initial Cellular V2X standard complete, September 2016
[3] IEEE Vehicular Networking Conference, Collective perception and decentralized congestion control in vehicular ad-hoc networks, 2016

- A Cooperative Awareness Message (CAM) is the syntax and semantics that will be used to handle awareness messages from road users. Via V2V and V2I signals, vehicles will distribute information on their position, dynamics and attributes.
- A Decentralised Environmental Notification Message (DENM) is a signal that is used to issue road hazard warnings to road users. Information on hazard or abnormal traffic conditions, including their type and position, are broadcast.[4]

### 3.2.1 ICT4CART Draft Architecture and Communications Standards

The draft communications architecture in the figure below reflects the state-of-the-art telecommunications standards that the ICT4CART consortium is intending to utilise to implement its ICT solution.

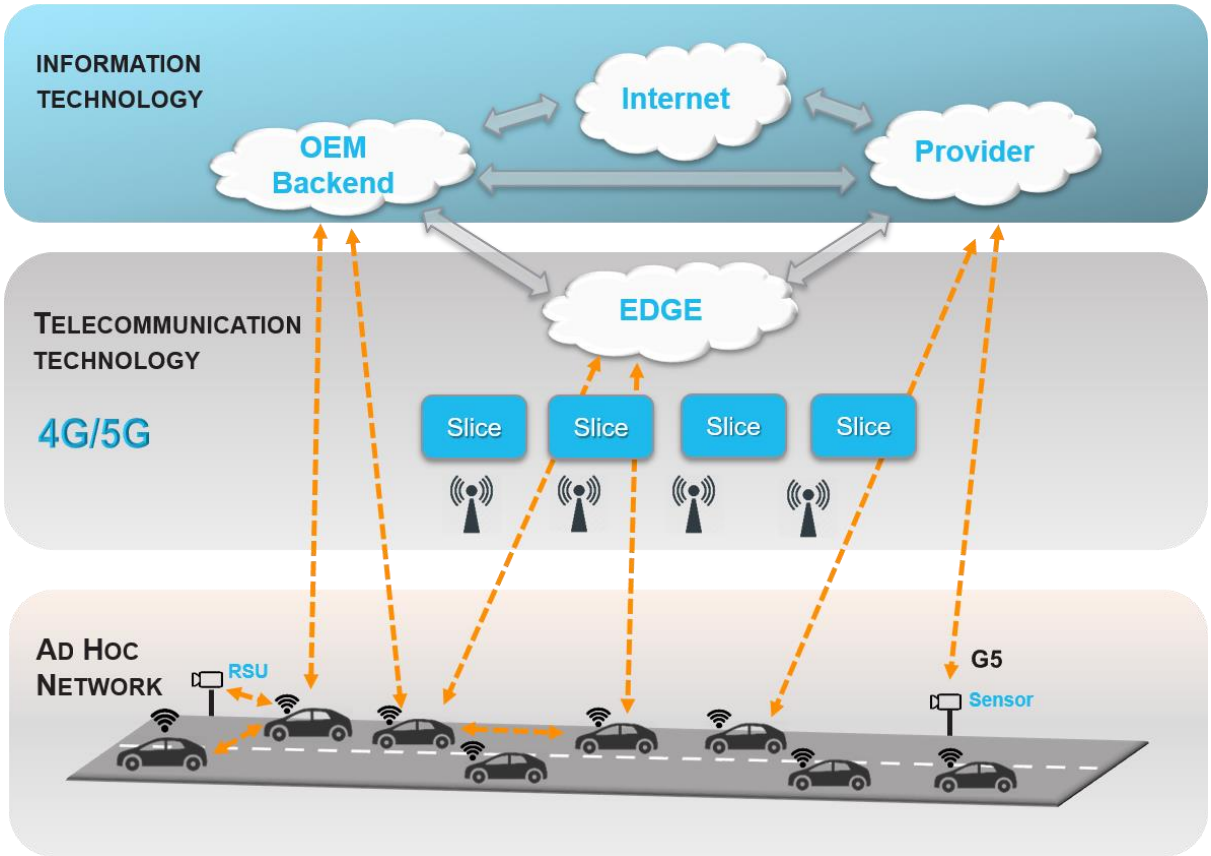


**Figure 2 The high-level draft communications architecture produced to inform the initial design of the ICT4CART platform.**

The communication channels and message sets will comply with the industry standards that have been established so far. The "Edge" space in the diagram refers to the IT service environment at the edge of the mobile network where processing can be completed within a shorter time frame than if it were completed in a cloud space. Mobile or Multi-access Edge Computing (MEC) will be used to enhance the performance of any Artificial Intelligence (AI) computing applications, such as hazard perception or routing decisions.

### 3.2.2 Performance levels

Research and publications on CAV information services do not yet agree on the standard performance

[4] ETSI, ETSI publishes European Standards for Intelligent Transport Systems, December 2014

levels required by these services. In general, a lack of distinction between the information services' purpose, value and transmission methods has hindered the development of a consensus on this matter.

The methodology section of this paper will cover in more detail the framework that was used in this research and analysis task to define the performance levels across these parameters: privacy, latency, reliability, coverage, bandwidth, and granularity.

The scales for the parameters were defined from use case exploration in the stakeholder interviews, but a baseline understanding was initially developed from an IEEE Journal article[5]. Here, it is stated that a bandwidth of 12-24Gbits/sec is required for safety critical services and 1-3Gbits/sec for infotainment. Latency requirements for information services that enable AD range from 10ms to 100ms, depending on the safety function of the service. Granularity is requirement to an accuracy of less than 0.5m for positioning information.

### 3.3 Security and privacy

Commercial services are rapidly evolving to use profiling and brokering of personal data as a source of value and differentiation. The secure handling of any data with personally identifiable information has been subject to increasing concern. In 2018, the EU introduced the General Data Protection Regulations (GDPR) that initiated a wider trend towards more stringent security in data handling. Compliance with these regulations and other EU laws on privacy are non-negotiable.

By connecting vehicles to a network, an attack interface is introduced. The nature of information transmitted may mean that it is a target for attacks (e.g. vehicle ownership information or routings). The cybersecurity of the vehicles will need to be of a high standard. Internet of vehicles (IoV) systems could face numerous types of attacks such as authentication, identification, availability, confidentiality and routing attacks. This results from the network characteristics which comprise of dynamic topological structures, large networks and mobile limitation[6]. Several trends are predicted for the security of future IoV systems including privacy protection in routing, risk analysis and management, trust and verification of data centre, privacy and security protection on Mobile Cloud Computing[7].

Within the stakeholders interviewed, two distinct schools of thought were expressed:

1. Privacy concerns are over-inflated, as all services will be designed as standard to be as "impersonal" as possible. Any entities that handles personal information will translate cybersecurity systems across from other industries (e.g. utilities and banking). Many services will only be handling data in aggregate (e.g. traffic data), making it impossible to gain individual information from it.
2. Users of services that handle their data will not be worried about their personal data privacy. Some existing markets have proven that users are happy to use services in exchange for their data (e.g. Google Maps and Facebook), as many assume that their data will be managed and regulated considerately.

There are questions on the ownership of data and the classification of data sets as impersonal or personal that may only be answered as the markets develop. ICT4CART is intending to address some

[5] Lee et al, IEEE Journal, Latency of Cellular-Based V2X: Perspectives on TTI-Proportional Latency and TTI-Independent Latency, 2017
[6] Sun et al, IEEE Journal, Security and Privacy in the Internet of Vehicles, 2015
[7] Joint Research Centre (JRC), The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART), 2017

of these questions as part of its R&D.

### 3.4 Market Sizing

The table below summarises some headline findings from market research into the size of the CAV market. It is worth noting that most research has been completed with existing auto manufacturers, OEMs and policy makers who are interested in adapting to the developing CAV market as the intended audience. As such, there is a significant focus on existing literature on the size of technology and vehicle sales, rather than the service market size value.

**Table 1 A selection of existing resources on market sizing.**

| Resource | Headline Findings |
|---|---|
| PWC Connected car report 2016 (Global & China) | • The auto industry's profits will rise by 50% to around $600 billion by 2030, with 5% of this attributed to "digital services". 60% or $360 billion will be captured by new entrants, who are primarily supplying innovative mobility services and new technologies including Fintech and EVs.<br>• Developments in the Chinese market will provide significant opportunity for commercialisation of connectivity.<br>• The Ministry of Industry and Information Technology announced that by 2025, connected vehicles would be leverages in order to reduce traffic accidents by 30%, emissions by 20% and energy consumption by 10%.<br>• More than 75% of Chinese customers would be willing to spend more on a car for safety features and more than 85% would switch to different brand of car if is offered reasonably-priced connectivity features. |
| A.T. Kearney market study 2017 (Global) | • Pay-per-use service revenues will outperform optional equipment revenues by 2025.<br>• Mobile apps that enable V2V telematics and Vehicle-to-everything (V2X) communications will be a $86 billion industry by 2030.<br>• Also, in 2030, revenues from the content, software and services used in CAVs will exceed revenues from CAV-enabling special equipment. |
| Transport Systems Catapult 2017 (UK) | • In 2035, the global market for sales of CAV road transport will be worth £907 billion. The UK will capture 3% of this at £28 billion.<br>• This value is derived from CAV technology prices plus a 50% mark-up for OEM profitability. |
| IHS Markit estimates in The Globe and Mail 2017 (North America) | • Two thirds of new vehicles in Canada and three quarters of new vehicles in the USA had embedded telematics capabilities in 2017.<br>• These differences will level out over time. By 2022, this will rise to 95% of new cars in Canada and 98% in the USA.<br>• High wireless prices are cited as holding back Canada's connected vehicles. |

Estimates on the value of connected vehicles to network operators is an area that is underreported. The A.T Kearney report in the table above offers an estimate into the value of fully autonomous and connected vehicle use to the US economy that totals $1.3 trillion and comprises of:

- $488 billion saved in accident avoidance
- $507 billion added due to increased productivity from drivers' idle time
- $138 billion added to due to increased productivity from congestion avoidance
- $158 billion saved in fuel
- $11 billion saved in fuel due to congestion avoidance

## 3.5 Early adoption applications

Applications of CAV technology is going to advance first in use cases where significant cost savings can be made in the more efficient use of resources. Those most referenced in both interviews and existing literature are: platooning, parking and shared transport services.

### 3.5.1 Platooning

The modelling study in Section 3.1 references platooning as a CAV capability that will positively impact on the average throughput times of vehicles on road networks. In the UK, 89% of goods are moved on the roads[8]. For longer-haul shipments, rail still outperforms road in terms of time. However, road transport is still favoured for its accessibility and flexibility. Improving road freight times will benefit companies in accessing larger geographical markets within the timescales demanded by a consumer base that is increasingly reliant on fast and reliable home deliveries.

Several of the experts interviewed cited platooning as being one of the first CAV applications anticipated to roll out due to these significant cost savings. One study concluded that platooning could save up to 11% in fuel costs and 60% in salary costs[8]. However, developments in this area are not as visible as the developments being seen in individual driver safety applications and there are no prominent resources on solutions under development.

For more information on the potential configuration of platooning services, see Sections 5.2.2.5 and 5.5.2.4.

### 3.5.2 Parking

Driverless parking, enabled by V2X connectivity, has the potential to increase the capacity of car parks by 2.5 times more vehicles[9]. The space for vehicles to manoeuvre around each other and stationary vehicles will no longer be required as vehicles movements are centrally controlled. Likewise, without people moving around the car park space for doors opening and closing, pedestrian walkways and headroom will be eliminated.

A public transport representative stated in their interview that automated parking will be one of the most desirable applications for fleet managers due to the reduction in labour time of drivers manoeuvring vehicles around depots.

Other closed environments such as ports and loading depots will see a similar uptake of CAV technology – echoing the benefits of automated "dark warehouses" that the logistics and storage industry are already experiencing[10].

### 3.5.3 Shared transport services

In the USA, both Uber and Waymo (owned by Alphabet, Google's parent company) are operating trial fleets of passenger vehicles in geo-fenced areas in select US cities that do not require a driver in the vehicle. In the case of Waymo, safety drivers are placed within the vehicles when new capabilities are

[8] UK Government Office for Science, Future of Mobility, February 2019
[9] UK Transport Systems Catapult, Future Proofing Infrastructure for Connected and Autonomous Vehicles, February 2017
[10] The Open University, A dark future for warehousing?, March 2013

tested; Uber's self-driving tests are continuously manned by a human safety driver[11].

When operating with existing capabilities and outside of the testing environment, Waymo's vehicles are still supported remotely by human drivers. The remote drivers are prompted to intervene in circumstances where the vehicles' on-board architecture is unable to process the input data. The highly risk-adverse units are continuously connected to a central control network where the "intervention team" are on hand to remotely react to unforeseen circumstances and incidences where the vehicle is unable to execute a task.

UK start-up FiveAI[12] are developing control software and a suite of hardware with partner OEMs that can be retrofitted to passenger vehicles to make them autonomous. They're intended to launch a fleet of driverless vehicles for Mobility as a Service (MaaS) use, specifically a ride-hailing first and last mile service. Currently, they are designing vehicles to operate without connectivity as a matter of ensuring reliability. But they do anticipate featuring connectivity in future to support safety-critical driving operations.

## 3.6 International and national approached and strategies

In these examples above of Uber and Waymo, the privately-backed ventures in the US work on the following assumptions:

- the focus is on the market positioning of the developer (not on wider benefits, such as road safety and air quality),
- connectivity is necessary for the vehicles to function,
- and the provision of connectivity is vertically integrated into their operations.

However, the European CAV market is developing on different assumptions; that AVs must be developed to operate in isolation (like FiveAI's technology) and public bodies will be invested in the development of connectivity services.

This is for the most part due to the involvement of the European Commission (EC) in funding research and publications in the area. The EC foresees CAV functionality extending to enable cooperative transport systems, where all vehicles are automated and coordinated to operate efficiently and safely in a fully driverless world. This vision – for a Cooperative Intelligent Transport Systems (C-ITS) – has been forecast for around 2045. In 2016, a strategy[13] for realising this was released that featured the following scenarios:

- Day 1 services (2019 onwards) "Cooperation": vehicles are connected to infrastructure and are cooperative; they share their details, including their location.
- Day 2 services (2023 onwards) "Automation": automation begins on some roads with human back up and perception data is shared.
- Day 3 services (2030 onwards) "Coordination": most roads host automated vehicles and vehicles share their routing and manoeuvring intentions.
- Day 4 services (2040 onwards) "The Driverless World": vehicles and fully automated, all routes and manoeuvres are centrally coordinated.

[11] The Verge, A Day in the Life of a Waymo Self-driving Taxi, August 2018
[12] FiveAI, accessed February 2019
[13] A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility, 30 November 2016

The C-ITS strategy's Day 1 services, for example, are listed in Table 2 below.

**Table 2 Transcription of the C-ITS Day 1 and 1.5 services list.**

| **Day 1 C-ITS services list** |
|---|
| **Hazardous location notifications:**<br>• Slow or stationary vehicle(s) & traffic ahead warning;<br>• Road works warning;<br>• Weather conditions;<br>• Emergency brake light;<br>• Emergency vehicle approaching;<br>• Other hazards.<br>**Signage applications:**<br>• In-vehicle signage;<br>• In-vehicle speed limits;<br>• Signal violation / intersection safety;<br>• Traffic signal priority request by designated vehicles;<br>• Green light optimal speed advisory;<br>• Probe vehicle data;<br>• Shockwave damping (falls under European Telecommunication Standards Institute (ETSI) category 'local hazard warning'). |
| **Day 1.5 C-ITS services list** |
| • Information on fuelling & charging stations for alternative fuel vehicles;<br>• Vulnerable road user protection;<br>• On street parking management & information;<br>• Off street parking information;<br>• Park & ride information;<br>• Connected & cooperative navigation into and out of the city (first and last mile, parking, route advice, coordinated traffic lights);<br>• Traffic information & smart routing. |

National strategies from European nations are based on these scenarios; a prime example being the Austrian C-ITS strategy[14]. In a recent ranking of AV readiness by country, 6 of the top 10 were European[15]. Topping the list is The Netherlands, followed by Norway, Sweden, Finland, the UK and Germany. The European countries rank highly due to their high scoring in the policy and legislation measures, as they are all demonstrating concentrated efforts to legislate the effective and safe testing of CAVs.

In comparison to the EC's efforts to produce clarity in direction on intelligent transport development, the US Government's activity in the industry has been stilted. In 2014, the US Department for Transport stated its intention to mandate a requirement for all new road vehicles sold in the US from January 2019 to be able to send a cooperative message. The "Basic Safety Message" would be like CAM and this move would be an internationally resonant step towards vehicle cooperation, given the size of the US market. However, as of November 2018 this is still listed on report for pending regulations with no explanation for the delay in processing it[16].

[14] C-ITS Strategy Austria, June 2016
[15] KPMG, 2019 Autonomous Vehicles Readiness Index, February 2019
[16] U.S. Department of Transportation, Report on DOT Significant Rulemakings, November 2018

# 4 Methodology

The approach underpinning this report required an extensive research framework to ensure comprehensive coverage of industry opinions. To achieve this, a mixture of desk research, expert interviews and a stakeholder workshop were aggregated together to inform the key findings.

## 4.1 Understand work to date

The first step in our methodology was to conduct a literature review to understand the full context for this research and what work has been carried out to date to understand the market needs for CAV ICT infrastructure. This is summarised in Section 3 above and generated the following conclusions which have shaped the rest of methodology:

1. While there has been a significant amount of research and development work carried out in relation to the technology options for the ICT infrastructure, there has been little work on understanding the future demand for this infrastructure in a systematic way.
2. Considerations around the demand for CAV ICT infrastructure has been strongly linked with the capabilities of particular technology architectures, and not the value of the services that they are enabling.

The proponents of these differing approaches are often in disagreement about the development of the technology landscape and there is much uncertainty surrounding the timescales for developing a consensus on communication infrastructure modes. There is a need, therefore, to consider demand whilst remaining agnostic to the various technology approaches and instead focus on the *information services* that are (or will be) desired by end users.

## 4.2 Define the market

The CAV ICT market consists of a number of sub-markets, from mobile network operation to roadside V2I solutions. To enable a strong focus on end-users and to avoid distraction of the various technology options configurations available, this study has deliberately simplified the CAV ICT infrastructure into a single "system" used by vehicles, drivers, passengers and operators for various goals. It has focussed on the inputs and outputs of that system, i.e. the data and information services communicated through, and partly generated by, that system.

Figure 3 below summarises the framework that was applied to the ICT market. The research activities were structured around exploring three distinct groups of players, or sub-markets; CAV users, 3rd party providers, and network and fleet operators.

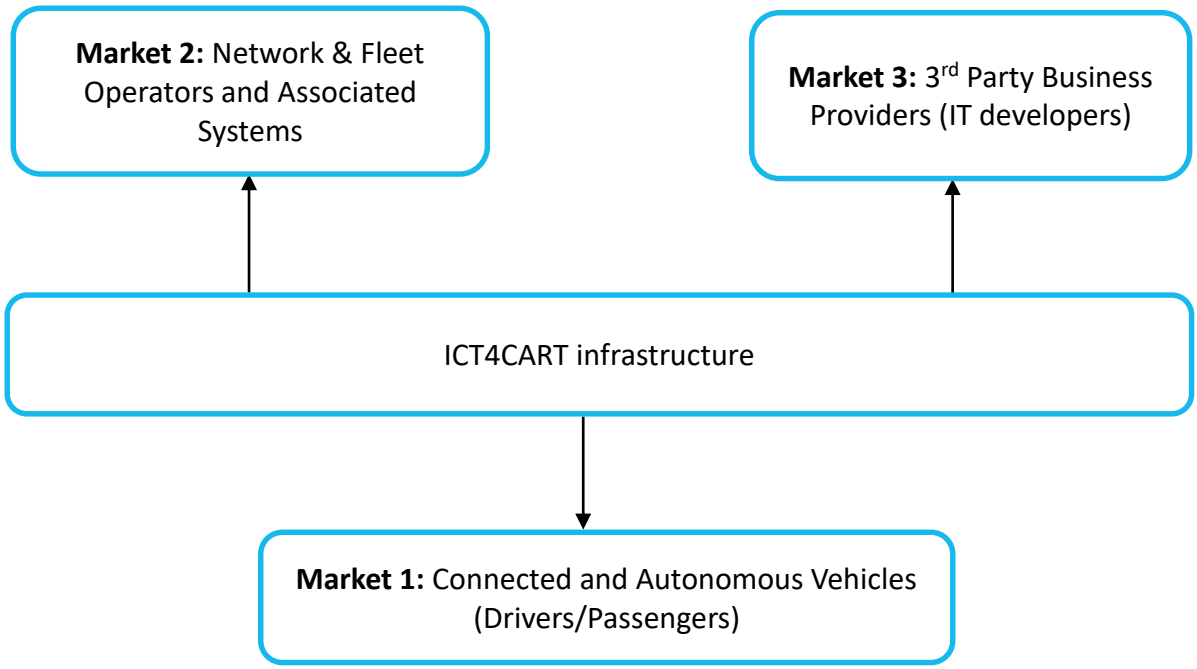


**Figure 3 A diagram summarising the distinct markets that utilise information services provided by the aggregate ICT infrastructure system.**

The transactions between these markets and the infrastructure as a whole were considered as services where value is delivered to the recipient, regardless of whether they are directly commercial services. These transactions provide actionable insight or other information of subjective value to a user, operator or system within the CAV industry.

This information could be generated by any another entity within the framework, or from other external sources. That is, some services will use data generated *by* CAVs for use by other parties, and others will be services *for* CAVs using data from other CAVs or other parties.

## 4.3 Desk-based research

The purpose of the literature review aims to cover the scope of the project. Areas include:

1. Evaluating the size of the current CAV market
2. Mapping the products and services, and their providers in the market
3. Identifying emerging technologies that may impact on the market
4. Identifying products and services that are using or could use this technology in CAVs
5. Reviewing the potential impact of these products and services on the market

The desk research aimed to ascertain the material in the public domain both within the academic and grey literature. The information found formed the basis for the interviews: informing the questions that were asked, focusing on areas without consensus.

The approach used for desk research involved an extensive search of both academic and grey literature. Generally, the academic literatures were found to be highly technical discussing ICT infrastructure architecture design which was not deemed within the scope of this deliverable. The majority of the reports gave high level opinions about the evolution of the industry without discussing the market potential for the different information services offered. Due to the novelty and sensitivity of this area, many of the industry opinions and recent developments were not in the public domain; this illustrated the need for expert interviews.

## 4.4 Expert interviews with project partners representing markets

To build upon the desk research, we conducted interviews with the consortium members and industry experts. The selection of experts interviewed provided specialist insight into the three sub-markets, their status and developments. As the European market is of primary concern for this research, interview participants mostly represented public authorities, automotive manufacturers, technology OEMs, start-ups and transport lobby groups from the EU nations. A US CAV expert was interviewed to provide comparable information on that market. In total representatives from 19 organisations were interviewed, where 16 of these were consortium partners.

The interviews were conducted within a framework of questions with the overall aim to investigate the perceived need, benefits and requirements of connectivity infrastructure, and the information services that could emerge.

The questions asked were designed either to fill gaps from the literature or to gain insight into the interviewees' understanding of the market and any perspectives on potential areas of opportunity. Separate question sets were developed for each of the sub-markets designed to structure the entire ICT infrastructure market (see Figure 3). Interviewees were aligned against the market that they best represent. Where broad industry specialists without a distinct market definition were interviewed, a generic set of questions was used. All question sets had a common structure, covering the following areas:

1. The role of their sub-market in the operation of AVs.
2. The information that will be transferred in order to fulfil this role.
3. Whether there are any information transaction services that will be required to operate continuously.
4. What particular services will require communication to or from road vehicles.
5. Whether any services will require supporting ICT infrastructure to be completed.
6. The performance levels that the information services identified will require.
7. Whether they anticipate the supporting ICT infrastructure being used for services other than those that enable AD.
8. The perceived levels of consistency in views on the information discussed within that market.

Many of these questions were intentionally written to provide a starting point for open discussion, such that there was often deviation from the script to explore use cases and deep dive into pertinent points and opinions. Finally, interviewees were requested to provide to the researchers any resources, including ongoing work or existing publications, that would be relevant to the subjects discussed.

The interviews were followed up with detailed summary notes from the research team. The interviewees were then given an opportunity to amend any details and add any further content they felt relevant.

## 4.5 Analysis frameworks

The services that were raised in interviews were grouped into the operation that they support. The potential performance levels and market structures of the services were defined from the aggregate research.

### 4.5.1 Performance requirements

The performance requirements that each market is rated against are defined in Table 3.

**Table 3 The rating framework for the market services.**

| Performance elements | Description |
|---|---|
| Privacy | Scale<br>1 = No private or sensitive information used<br>3 = Individual and private user information is transferred as part of these services but is not intrinsic to the operation of them and could be anonymised with correct handling.<br>5 = Private user information intrinsic to some of the services within this market and significant risk of security breach present.<br><br>Privacy is judged in this context by the type of information being transferred, specifically if it is personally identifiable and at risk of a security breach. |
| Latency | Scale<br>1 = Information services could generally be communicated within timescales of days or weeks and still be effective.<br>3 = Information services are in real-time but are not safety-critical, so need to be delivered within timescales of around 1 to 2 seconds.<br>5 = Information services are in real-time and are safety-critical, so need to be delivered within timescales of less than 100ms to be effective<br><br>Latency in this context refers to the time interval between a signal being instructed to transfer across a network and the network's devices receiving it. |
| Reliability | Scale<br>1 = Information services need to communicate accurate information more than 60% of the time to be effective<br>3 = Information services need to communicate accurate information more than 80% of the time to be effective<br>5 = Information services need to communicate accurate information more than 99% of the time to be effective<br><br>The accuracy of the data transferred across the network. This is predominantly defined by the source of the data, rather than the design of the ICT infrastructure, but the two may be dependent on each other. |
| Coverage | Scale<br>1 = Information services can be available intermittently and covering local area only and still be effective<br>3 = Information services need to be available consistently within certain operating areas to be effective<br>5 = Information services need to be available consistently over an entire road network to be effective<br><br>The geographical area that the connectivity is enabled in and the consistency of the connection at that location. |
| Bandwidth | Scale<br>1 = Information services require only a very small amount of data to be transmitted over a short period of time (typically less than 1Kbps) to be effective |

| | |
|---|---|
| | 3 = Information services require a medium amount of data to be transmitted over a short period of time (typically greater than 10Mbps) to be effective<br>5 = Information services require a large amount of data to be transmitted over a short period of time (typically greater than 100Mbps) to be effective<br><br>The size and the rate of the data packages that are being transferred will determine the bandwidth in the network required. |
| Granularity | Scale<br>1 = The level of detail of the data sets required to support this service is low. For example, on a scale of 1 km.<br>3 = Data sets are on a scale of 10m.<br>5 = The level of detail of the data sets required to support this service is high. For example, on a scale of 1 cm[17].<br><br>The granularity of a data set characterises the level of detail that is held in it. The higher the granularity, the larger the information set. |

### 4.5.2 Market structures

A workshop held with the consortium members was intended to test, verify and expand the information collected through our desk research and expert interviews. The main workshop activity aimed to explore attendee's understanding and opinions on how the various market players will be acting in a number of future scenarios. The consortium members reviewed a series of possible future scenarios for the operation of CAVs on road networks. The scenarios differed on connectivity levels and payment structures. In groups loosely arranged by the market that the consortium members represent (see Figure 3), the attendees explored how realistic these scenarios are, the opportunities they could present and potential positive and negative outcomes.

The workshop took place after the stakeholder interviews; therefore it was used as a sounding board for the preliminary findings. The workshop moved on from defining the market services to considering the funding options. Funding is two-fold: paying for the enabling architecture and for the services themselves.

The workshop was not intended to gather new information or views, but to explore and compare standpoints and consistencies in the consortium's views on the ICT infrastructure market for the CAV industry. In total, 29 attendees from the consortium attended, with Paul Blakeman and Emma Clement from Urban Foresight facilitating the session.

The five scenarios that were explored are captured in Table 10. Each presented a different combination of investment in infrastructure and provision of services, from the public sector or users/private sector. These scenarios are based on two assumptions:

1. Connectivity is provided to a sufficient level to enable any services envisaged,
2. There is sufficient concentration of connected vehicles for CAV operations to work.

Within the ICT4CART project, this report will inform further deliverables; in particular, Task 9.5 which

[17] Novatel, An Introduction to GNSS: Real-Time Kinematics (RTK), accessed January 2019.

develops exploitation strategies for the consortium's new ICT solutions. It will ensure that the solutions explored and defined by the consortium capture their commercial potential and so is a valuable late-stage deliverable. As such, the workshop was designed to inform Task 9.5 as well as Task 2.2 (this task).

### 4.6 Reporting

The research findings were compiled by the full research team into a report for the purposes covered in Section 1.1.

# 5 Findings

## 5.1 General

This section amalgamates the research findings into a framework that is based on the user-value configuration of each potential service.

### 5.1.1 Market Sectors

The services captured in the research have been categorised into 5 groups:

1. **Automated driving:** connectivity to support the automated decision making of road vehicles.
2. **Informed journeys:** connectivity to improve driving decisions, regardless of how automated the vehicle is.
3. **Intelligent management:** connectivity to improve awareness of what is happening on a road network.
4. **Coordination of vehicles:** connectivity to instruct automated vehicles in specific scenarios and coordinate their driving.
5. **Connected travellers:** connectivity to connect vehicle passengers and improve their experience.

Our analysis has treated these 5 groups as separate 'markets' as they all have distinct user/value combinations, i.e. beneficiaries of services and associated primary benefits addressed by the services.

As well as these 5 groups, we have identified a sixth information service market:

6. **Underpinning services:** connectivity services with commercial potential that enable a safe and effective communication network.

While these services do not directly provide valuable information services to users, they make it possible for many of the other services to be deployed in a safe, secure and effective way.

The value of information services in each of these markets ultimately relates to either improved safety, improved efficiency of an individual vehicles or road networks or to driver and passenger comfort and experience. The value generated can also be either for individual vehicles (and their drivers/passengers) or for the wider, collective benefit of lots of vehicles adopting a particular course of action.

Figure 4 below illustrates the user/value combinations for each of the markets.

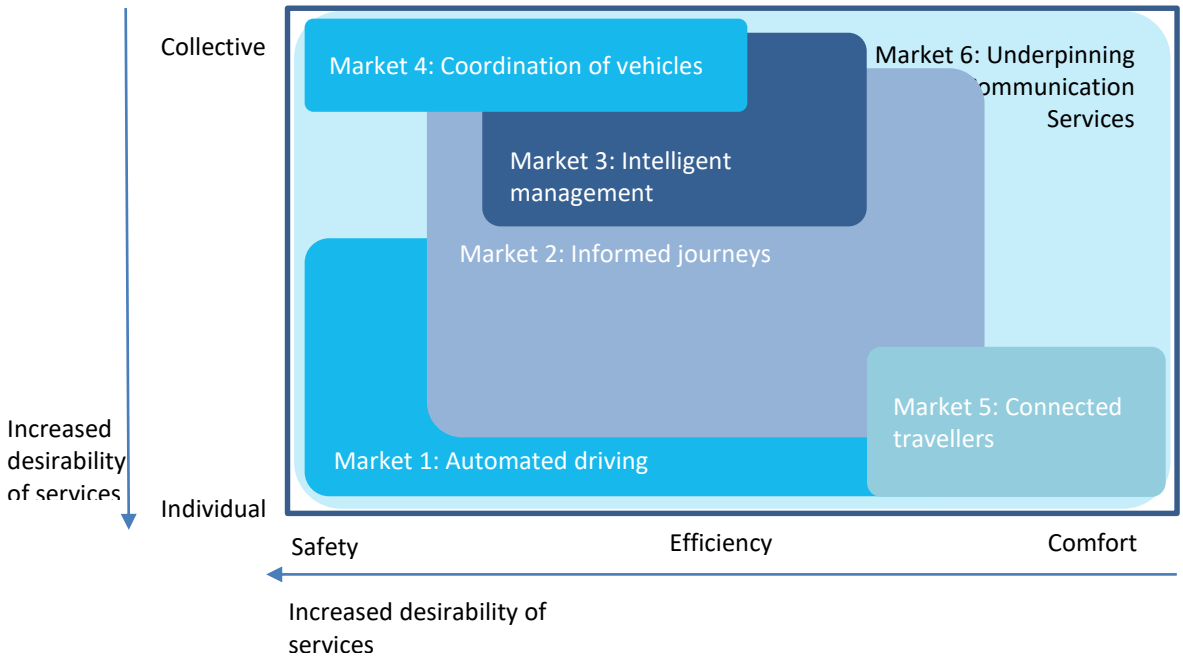


**Figure 4 A map of connectivity service market sectors against their scale of application and primary function.**

The "desirability" scale referenced in the Figure 4 above is derived from a ranking of desirable services completed by Deloitte University Press[18]. This ranking is based on the consumer's perspective of desirable services in driverless cars. The ranking reflects that services that the most desirable services are currently those that improve the individual consumer's safety, whilst allowing them to retain a degree of control over their driving experience.

The markets are each covered in detail in this section, with details of the potential services and information on the expected performance requirements of the connectivity. The performance requirements that each market is rated against are defined in Table 3.

[18] The desirability of services is derived from Figure 6 in the report "Development of self-driving vehicles in the United Kingdom", Deloitte University Press, 2017

## 5.2 Market 1: Automated Driving

### 5.2.1 Overview

Connectivity can be used to directly support the operation of automated vehicles. This market consists of information services communicated to vehicles which can supplement information from sensors on the vehicle and stored data sets on board the vehicle (e.g. HD maps and road laws). These information services are such that they can only be reasonable processed by an autonomous control system, i.e. they require action on a timescale and with a granularity which human drivers would generally be unable to perform.

Using its sensors and stored data, CAV autonomous control systems will determine the risk of a particular course of action which will determine the speed and smoothness with which the automated driving system chooses to navigate a section of road or perform a particular manoeuvre. For Levels 3 and 4 it will also determine whether or not the system seeks to hand back control to the human driver.

Connectivity can increase the vehicle's awareness of its environment beyond the capability of its sensors and, hence, reduce the risk associated with vehicle decision making including:

- Collisions with other road users.
- Collisions with road infrastructure.
- Infringement of traffic legislation.

With enough information, vehicles will be able to automatically complete manoeuvres and journeys safely and efficiently, with consideration for other road users. However, the value of these services is not directly based on safety. CAVs are being designed to behave safely without dependence on connectivity. The information services are instead about increasing a vehicles' speed, smoothness and ability to "stay automated" whilst maintaining the same level of safety. They may be the difference, say, in the time it takes for a CAV to traverse a busy intersection or whether or not it has to hand back control to the driver as it approaches temporary traffic management controls, e.g. cones and variable message systems (VMS).

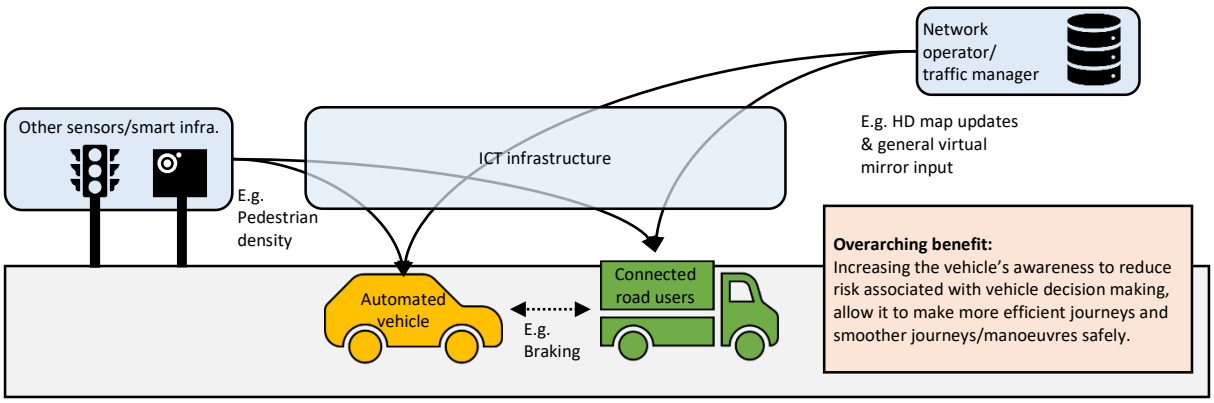


**Figure 5 Diagram summarising Market 1 structure.**

### 5.2.2 Services

The services below are delivered as part of Market 1. These services all support the tactical operation of AVs, i.e. how a vehicle moves on second-by-second and metre-by metre basis rather than route choice or longer term behaviours.

Each service defined against which environments they are expected to apply in from the following list:

- Urban road networks
- Rural road networks
- Motorway networks
- Closed environments (e.g. a car park or logistics depot)

#### 5.2.2.1 Environmental information

**Primarily applied in:** rural and motorway environments.

**Environmental information**

These services supply CAVs with information on infrastructure, road layout, fixed signage and environmental conditions in their immediate vicinity and the route immediately in front of them.

In most cases, this will be either information collected about the environment through some other sensor located in the relevant region or pre-prepared digital representations of the environment likely to be communicated in the form of updates to high definition (HD) maps.

The data sets that could contribute to this subset of services are:

1. Road width
2. Road condition
3. Linings and markings
4. Fixed street signs
5. Gradient
6. Temporary traffic management layouts

Information relating to weather will be important – particularly in the colder climates of Northern Europe, where the risk of untreated road ice on more remote road networks is significant. “Blitz ice” or “black ice” can form quickly, significantly reducing the traction of road surfaces and proving extremely hazardous to road users.

Network operators currently rely on weather forecasts and learned experience to anticipate and react to conditions that induce road ice.

Already, many cars monitor their surrounding environments as an ADAS function: automatic windscreen wipers, headlights and temperature control are all subject to monitoring the external environment. Similarly, ABS is triggered when the coefficient of friction between the vehicle’s tyres and the road’s surface is detected as being too low.

If issued as an alert of slippery road surface, this signal could be used by other road users and network operators in managing their own response to road ice on their route or network. V2X connectivity can enable this.

Similar alerts can be applied to other hazardous weather conditions. For example, in the event of fog or other poor visibility conditions that would restrict the abilities of CAVs that rely on visual data, a geotagged warning signal would be pertinent.

The data sets that could contribute to this subset of services are:

1. Coefficient of friction between the vehicle's tyres and the road surface.
2. Ambient temperature.
3. Precipitation status.
4. Light levels.
5. Visibility.

Services would also vary depending on the timescale that the information relates to:

- Static info – Information about specific relatively fixed elements of the environment. For example, traffic cones are positioned at this space from position X to position Y.
- Dynamic info - Information about constantly changing elements of the vehicle's environment. For example, flood risk of this section of road is currently Z%.
- Forecast info – Information about future status of the CAV's environment. For example, this section of road is likely to experience this drop in temperature over the next X minutes

#### 5.2.2.2 Smart system information

**Primarily applied in:** all environments.

**Smart system information**

These services supply CAVs with information about the status, behaviour and intentions of infrastructure-based technology systems, such as smart city systems and ITS.

With CAVs traffic management information that is currently communicated only visually can be – and is being - directly transmitted to the road vehicles via connectivity. For example, any signage or traffic light colours could be transmitted to connected vehicles over a proximity network such that the vehicle is not solely relying on its own visual sensors.

It is likely that in early generations this transmission would not be the sole source of information collection. Rather, the vehicle will rely on its own visual interpretation of traffic signals, compare it against the network transmission, and in the event of an inconsistency, alert the human driver or enact another fail-safe procedure.

In contrast, closed environments where infrastructure is built with connectivity as a default will mean that visual signals will not be needed for vehicles navigate the area. They will use only the information they receive remotely.

The types of data that can be transmitted as part of this services are those that are currently transmitted to drivers via visual road infrastructure, such as traffic signal status, variable speed limits and VMS. Some infrastructure to support these services is already being introduced, particularly in

relation to traffic control[19].

As CAV concentrations increase, so too will the compliance with traffic signals. Variable messaging can be transmitted instantly across a whole network of road users, rather than those in line of sight of the physical VMS boards. As such, greater control over reactive speed limits or immediate routing guidance will be realised. (See also Market 2 on Informed Journeys).

Services would also vary depending on the timescale that the information relates to:

1. Live info – Information communicated by smart infrastructure passed on to the receiving CAV about its current status. For example, Barrier A is currently in the raised position.
2. Forecast info – Information communicated by smart infrastructure passed on to the receiving CAV about its future status. For example, traffic signal B will turn from red to green in Y seconds.

#### 5.2.2.3 "Sensed" road user information

**Primarily applied in:** all environments.

**"Sensed" road user information**

These services supply CAVs with information on the other road users in their immediate vicinity – or likely to enter their immediate vicinity within a short period of time. This will be information collected about those users through some other sensor(s) located in the relevant region. This would include information such as the location, speed, trajectory and type of road user within a limited geographic range.

Environments where there are many road users, at a variety of automation and with different behaviour mechanisms are challenging to process for an AV with line-of-sight sensors and onboard processing. External proximity sensors, computers and transmitters can support a connected vehicle in alerting them to potential hazards or areas of difficulty.

For example, at a busy intersection this may relate to the pedestrians and cyclists as well as road vehicles of various types on or approaching that intersection. CAVs can receive notifications as to when a location that is upcoming on their route is pedestrian-heavy at that time. The human driver may take on control of the vehicle, or the route can be altered to reduce the risk posed by automatically navigating a route with pedestrians.

In a motorway context, the information could be provided to merging vehicles about the vehicles immediately upstream of the merge on the main carriageway.

Services would also vary depending on how information is processed before it is delivered to vehicles.

1. "Raw" data – Information about specific users passed on to the receiving CAV as it is collected. For example, at point of X, Vehicle A is located here.
2. Aggregated info – Summary information relating to a group of users. For example, there is a high number of pedestrians waiting to cross from east to west at crossing Y.
3. Forecast info – Information providing a prediction about the behaviour of one or more fellow

[19] Sky News, Smart traffic lights which could cut vehicle emissions to be trialled in the UK, accessed February 2019

road users. For example, Vehicle B will arrive at the merge point in Z seconds.

Underpinning data services required to enable these services include:

1. Positioning information or Global Navigation Satellite System (GNSS) correction data to support Real Time Kinematics (RTK), i.e. enabling the vehicle to ascertain more accurately and with more confidence where it is in the world.
2. Location and movements of related road users
3. Information on the density of hazards on the vehicle's intended route; particularly where there is a high concentration of vulnerable road users (pedestrians and cyclists)

#### 5.2.2.4 "Directly communicated" road user information

**Primarily applied in:** all environments.

**"Directly communicated" road user information**

As with the services described above, these services supply CAVs with information on the other road users in their immediate vicinity – or likely to enter their immediate vicinity within a short period of time. The important distinction, however, is that the information is communicated *by* the road user (i.e. V2V applications) rather than simply *about* it. This would include information such as the location, speed, trajectory and type of road user within a limited geographic range but could also include information which would not be accessible to fixed location sensors.

Traditional communication infrastructure on roads is designed for human drivers to process. It is technologically challenging for equipment to monitor the environment using visual signals only. Connected vehicles can gather information about their surroundings directly from other devices on the network.

In the case of V2V communication, connected vehicles can be notified to the movements of others on the road. Rather than relying on positioning data or proximity sensors that detect when a vehicle's motion changes, surrounding vehicles can receive a timelier, near-instant signal as soon as the control mechanism is triggered.

For example, if an unconnected vehicle brakes suddenly, connectivity will improve the reaction times of surrounding road uses. At current technology levels, they will only recognise the change once the vehicle begins to slow; relying either on the visual input and reaction from the human driver or the detection and response from the onboard proximity sensors. If the vehicle were to transmit V2X signals, other connected vehicles can be notified of the change as soon as the command to brake is triggered.

Services would also vary depending on the timescale that the information relates to:

1. Live info – Information communicated by specific users passed on to the receiving CAV about its current status. For example, I am Vehicle A and my location is X.
2. Forecast info – Information communicated by specific users passed on to the receiving CAV about its future status. For example, I am Vehicle B and I intend to take this particular path through this intersection at X km/h in Y minutes' time.

**Case study: Virtual mirror input**

The information services described in the previous four sections can be combined to offer a service package of Virtual Mirror inputs. An AV's Virtual Mirror is the digital rendering of the surrounding environment that is used to inform driving and vehicle control decisions. The road layout and other road users are captured on it. It is resolved from two primary inputs; the vehicle's onboard HD map and the vehicle's sensors, including positioning systems.

Where connectivity is available, inputs from external sources can be used as an additional layer of information to inform the Virtual Mirror. This data can be generated from other vehicles, in-situ sensors and any other connected devices.

In this context the main value to be captured by connectivity is in the provision of information that is out of the line-of-sight of the vehicle's onboard sensors and in the efficiency of information transfer. It can also increase certainty about objects it is detecting via its sensors.

OEMs are developing automated vehicles under the assumption that they can't rely on external data sources to generate and maintain a virtual mirror which it can use to drive safely. However, additional layers of complementary information could be used to compare and confirm against the vehicle's own sensor inputs; supporting the accuracy of the virtual mirror. It can also expand the field of perception of the mirror

One developer confirmed that they are currently using Global Positioning System (GPS) to detect the vehicle's location, but that the granularity is not sufficient for accurate operations, so this information is supported by the on-board cameras and the HD maps. They anticipate further supplementing this with LiDar connectivity in future.

#### 5.2.2.5 Platoon coordination

**Primarily applied in:** motorway environments.

**Platoon coordination**

Motorway platooning is a key use case for future CAVs on long journeys where potential efficiency gains for all road users are significant. Using a connected network to coordinate them, vehicles would be grouped together to travel as a unit. The vehicles all accelerate, decelerate and complete any manoeuvres in synchronicity. The distance between them is reduced as reaction distances are eliminated by this central control. The coordination of the vehicles may be managed either by a proximity computing infrastructure (see Section 5.5.2.4) or by one of the vehicles, nominally the vehicle at the front of the group.

Platooning increases road capacities and improves journey speeds for users both in the platoon and travelling in parallel to it. Other than ensuring the communication and remote vehicle control technology is at the required performance levels, platooning requires a degree of trust that will take time to develop in the current user base. For many users – particularly haulage firms with valuable payloads – conceding control of their vehicle and information about their vehicle (particularly intended route) to a remote-control system is a step change that may face resistance.

Vehicles would be required to process the following data:

1. A signal to indicate when vehicles are willing and able to join a platoon.

2. Routing intentions of vehicles that have the communication and connectivity capabilities required for platooning.
3. Transfer of information between vehicles in the platoon with the central system to ensure that their speed and position remains aligned with the intended grouping.
4. Location and movement of other vehicles in proximity.

#### 5.2.2.6 Predictive quality of connectivity

**Primarily applied in:** all environments.

**Predictive quality of connectivity**

On determining the route that it is intending to take, a CAV can use connectivity to verify the status of the network through the route. The operating system is then informed of where it will be unable to rely on connectivity to support AD along its future journey.

Compensation can be made to alleviate the issue, by downloading maps data, hazard alerts or environmental data about these connectivity black spots that it would typically only receive when in proximity to these areas.

The data that would be transmitted between the CAV and the network to enable this are:

1. The CAV intended route (see Market 2).
2. Connectivity quality information that is geotagged against the road network.
3. Any information that would be transferred to the vehicle when it was in proximity to the poor connectivity areas, as discussed in the previous sections.

### 5.2.3 Performance Requirements

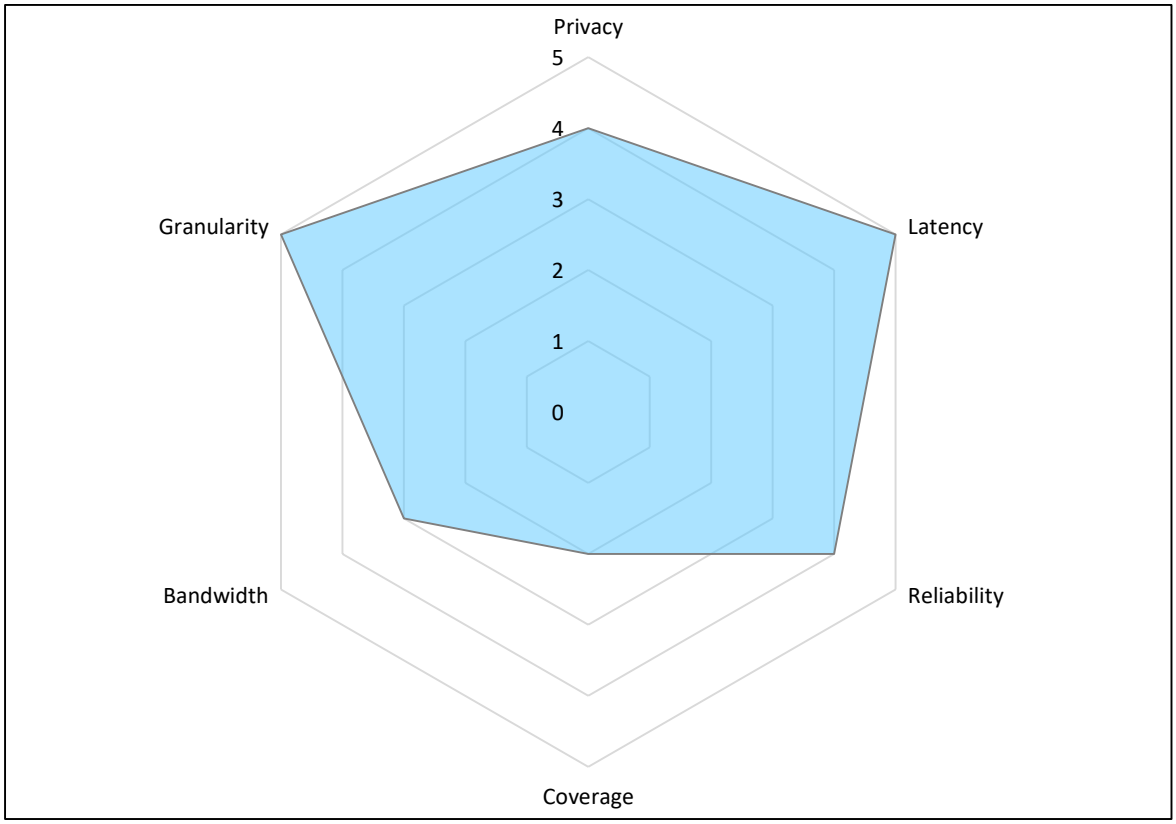


**Figure 6 Market 1 performance requirement ratings.**

The performance requirements for this market sector are high, primarily due to the safety-critical nature of the AD functions that it is enabling. Coverage is rated as relatively low as the scale of infrastructure required to roll out this connectivity is large; full coverage will not be designed for several technology generations.

**Table 4 Performance ratings for Market 1.**

| Performance elements | Rating | Description |
|---|---|---|
| Privacy | 4 - Majority of services could operate with anonymised private user information. | Some information services within this market may make it possible to derive information about a particular road user, albeit probably only certain information and in a confined space and timeframe. Identifiable information will need to be secure. Transfer of vehicle-specific data, for example in virtual mirror input and hazard perception, pertains to the personal data handling issues summarised in Section 3.3. Platooning poses specific security concerns, as logistics organisations may object to details on their fleets, including routings and perhaps payloads, being shared openly. Opt-in and consent will need to be carefully managed. A standard practice should be |

| | | |
|---|---|---|
| | | developed to ensure that the barriers to use of these services are low, else uptake may be stunted.<br>Services that utilise V2I data transfer can be designed to be "impersonal" as a default. Environmental conditions, traffic information and connectivity details can be collected and distributed in aggregate. |
| Latency | 5 – Real-time and safety critical information services. | These services support the effective processing of information by the vehicle's automated driving systems. As such, it is critical to the safe operation of the vehicle that data is transferred often extremely quickly. |
| Reliability | 4 – High reliability is desirable but safety-critical operations will not be solely dependent on these information sources. | Information that supports decision-making will only be utilised by AD systems if it is from reliable sources. As above, the safety critical nature of this processing will mean that this is highly desirable. |
| Coverage | 2 – Services will need consistent coverage within certain operating areas, but coverage is not critical to them. | CAVs will be designed to complete AD operations without the guarantee of connectivity. Due to the complexity and high performance requirements of these connectivity services, high coverage would be costly and unlikely to be realised until the market and technology are fully mature.<br>It is anticipated that high-volume traffic corridors and areas with a high concentration of public transport fleets (see Section 3.5**Error! Reference source not found.**) will be the first to benefit from coverage. |
| Bandwidth | 3 – Medium data sizes required. | The information packages transferred for these services are of variable sizes. The bandwidth will depend on the driving environment and the services that it is supporting.<br>It should be designed to ensure that latency and reliability are not compromised by insufficient bandwidth, but it is not a critical requirement.<br>V2V comms have relatively low data requirements (20MB/car/mth) but, once scaled, this could become significant. |
| Granularity | 5 - High level of detail required. | Positioning correction and other virtual mirror support will need to be highly granular to provide the level of accuracy requirement.<br>One stakeholder stated that GNSS correction |

| | | |
|---|---|---|
| | | data will need to be within 1-2cm for safe operation of vehicles and that connectivity is necessary to achieve this level of accuracy. |

## 5.3 Market 2: Informed Journeys

### 5.3.1 Overview

Connectivity has been used extensively for many years now to provide drivers with information on their journey ahead. This market consists of information services communicated to sat nav systems, smart devices, fleet telematics or any other connected system as part of or within the vehicle. These information services are used to improve driving safety, efficiency and experience regardless of how automated the vehicle is.

Current market leaders Google Maps and Waze use mobile network connections and smart phone interfaces to inform drivers about downstream events and conditions on their route. These services are popular due their success in reducing journey times and in reducing driver stress by helping them to be informed and feel prepared for unexpected events.

Safety is also improved with informed driving; serious traffic delays are reduced, and driver fatigue is mitigated. Personal safety of drivers is perceived to improve as users can share their routes and expected times with mobile contacts.

In the case of automated vehicles, connectivity can increase the vehicle's awareness of its environment beyond the capability of its sensors and, hence, improve the decision making of the vehicle, mainly, in terms of route choice and driving behaviour. When enabled to, CAVs will bypass the human processing of this information, to receive information on the surrounding environment, process it and use it to inform driving decisions in one system.

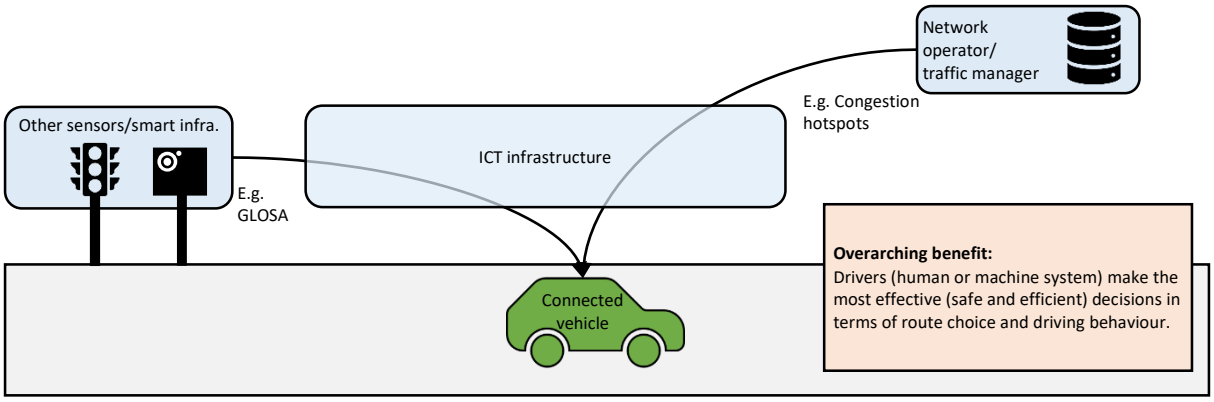


**Figure 7 Diagram summarising Market 2 structure.**

### 5.3.2 Services

The services that support informed driving can be understood as either:

1. Tactical services: supporting driving behaviours and ad-hoc decision making; or
2. Strategic services: supporting route choices and other long-lead time driving decisions.

This market is similar to Market 1 in many ways; it consists of similar types of information but, crucially, over a longer time horizon and greater geography. As such, the categories for the information services largely mirror those of Market 1.

Both service categories ensure that drivers enjoy an efficient and comfortable journey without facing uncertainty when making decisions.

All services are also listed against the environments that they can be applied in (see Section 5.2.2).

#### 5.3.2.1 Event information

**Purpose:** strategic
**Primarily applied in:** Urban, rural and motorway road networks.

**Event information**

These services supply CAVs with information about planned or unplanned 'events' which could relate to their onward journey, where an event is a real-world occurrence external to the normal operation of a road network but potentially having a noticeable effect on that network. Realtime information on events can be used to plan journeys both in advance and once they are underway.

Planned events could include:

- Roadworks (covered in more detail in 5.3.2.2 below)
- Festivals, sporting events, music concerts, etc
- Opening and closing times of schools, shopping centres, major employment centres, etc

Unplanned events include:

- Traffic incidents (accidents or obstructions) that could result in delays.
- Weather conditions that will affect driving speeds and road safety.

The notifications inform the driver as to when and where the incident is occurring, as well as what the impact on driving times will be. The navigation system, whether it's an in-vehicle processor, external connected device (e.g. smart phone) or the driver themselves can then make an informed decision about altering their intended route.

Information would be collected through a variety of sources. Data is gathered from both in situ sensors and on-vehicle sensors to inform these notifications.

Services would also vary depending on the timescale that the information relates to:

1. Static info – Information about known planned events. For example, the concert at location X will open its doors at 7pm and close at 11pm.
2. Dynamic info - Information about unplanned events or constantly changing elements of planned events. For example, a multi-vehicle collision has occurred at Y and Lanes 1 and 2 are now closed.
3. Forecast info – Information communicated by smart infrastructure passed on to the receiving CAV about its future status. For example, this section of road is likely to experience snowfall over the next X minutes.

#### 5.3.2.2 Traffic management information

**Purpose:** tactical and strategic
**Primarily applied in:** Urban, rural and motorway road networks.

**Traffic management information**

These services supply CAVs with information about any temporary layout changes or location specific restrictions and regulations that are in place. These services may often relate to events (see above) but are about how the traffic manager is responding to the event rather than about the event itself. For example, information on how events such as festivals can temporarily affect road restrictions, regulations and parking availability. The road closures, diversions and temporary speed restrictions that relate to roadworks and other examples.

Road users can be informed of these instances in advance of approaching them in order to optimize their route. In some cases, it would not be necessary for users to know of this information in advance and it would only be supplied at the point where the vehicle needs to react to it. This use case is reflective of the variable messaging systems currently used by network operators as an analogue method for informing road users.

There is some degree of overlap between these services and those described in Market 1 under 'Smart system information'. For example, the phases of traffic signals; the timing of a red or green traffic light can make a difference to a vehicle's approach speed. The distinguishing feature between the two categories is whether or not the information would such that it can be processed and acted on by a human driver or by an automated vehicle only.

#### 5.3.2.3 Traffic conditions

**Purpose:** tactical and strategic
**Primarily applied in:** Urban, rural and motorway road networks.

**Traffic conditions**

These services supply CAVs with information about traffic conditions further on their journey or the surrounding road network. These could relate to events and traffic management or be the result of more subtle and emergent properties of traffic on a road network.

This information could be derived either from fixed location sensors or crowdsourced from other connected vehicles – or a combination of both. These data are already extensively used to provide in-vehicle information services and are used to calculate traffic flow, speed and density as well as more granular information such as lane utilisation or turning counts.

CAVs can use these information services to determine the location and extent of congestion, journey times and the relative merits of different route options in the way that many satellite navigation applications do currently.

#### 5.3.2.4 Availability of supporting service infrastructure

**Purpose:** tactical and strategic.
**Primarily applied in:** all environments.

**Availability of supporting service infrastructure**

To complete informed journeys, drivers should be made aware of the location, availability and status of supporting infrastructure that they will require, including but not limited to:

1. Parking spaces
2. Charge points and petrol stations
3. Connectivity facilities

This information will be collected from in situ infrastructure monitoring and processed with the preferences of the driver in mind. As such, there are opportunities for intelligent processing algorithms to learn these preferences and make routing decisions based on them.

**Case Study: Electronic horizon support**

The information provided by the services above can be amalgamated into a data set which supports a fully informed driving experience for either the driver or the autonomous control system.

Reacting to changes in driving conditions, whether that be the shape of the road, the sensors and infrastructure available, the connectivity conditions, or any unforeseen events or circumstances, can be done within a larger timeframe with an Electronic Horizon. This service plays a key role in enabling more comfortable, efficient and safe driving experience in the ADAS and CAV spaces.

Electronic horizon can be supplied as an integrated solution that uses the anticipatory data and vehicle sensors to control a range of driving support processes, from dynamic headlight alignment to improved fuel efficiency, and routing and rerouting[20].

[20] HERE Electronic Horizon Service, Product page, accessed February 2019

### 5.3.3 Performance Requirements

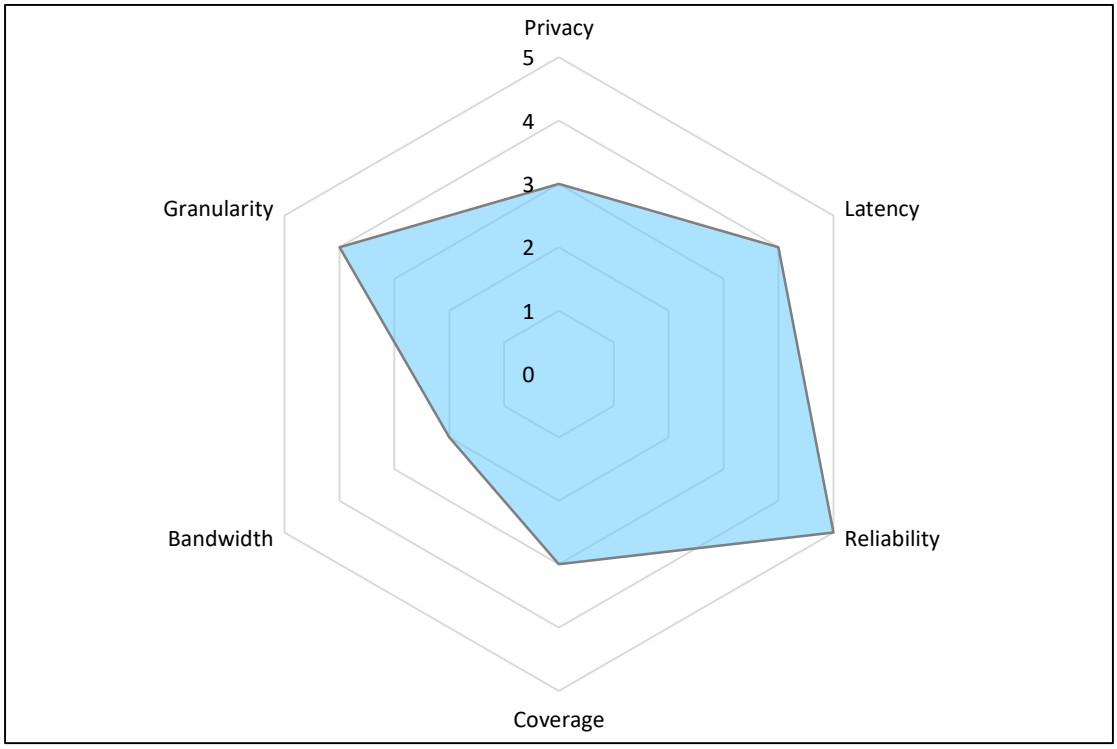


**Figure 8 Market 2 performance requirement ratings.**

Reliability is the most important performance factor in this market, followed by granularity and latency.

Connected navigation systems are popular and smart phone apps are currently leading the market. Network operators are aware that this is a competitive market and that a loss of dominance in this is affecting their ability to effectively inform drivers.

For example, a navigation system deciding to collectively re-route a proportion of a motorway's users away from a congested motorway and onto an alternative rural route can exacerbate congestion and may not be in line with the strategic priorities of the network operators.

For any provider to be a primary source of information for drivers, the messages must be reliable, accurate and timely.

**Table 5 Performance ratings for Market 2.**

| Performance elements | Rating | Description |
|---|---|---|
| Privacy | 3 – Private user information can be anonymised for these services. | As with all connectivity services, compliance with privacy regulations is a must. In these cases, information on individual road users is not transferred. There may be some V2V communication when in proximity to events and incidents, but largely all communication in this market will be handled centrally – allowing it to be scrubbed of identifiable information before being transmitted. However, as in the case in existing services |

| | | |
|---|---|---|
| | | provided by the likes of Google and Waze, user data is exchanged for use of these services. In these cases, privacy will need to be transparent and compliant. |
| Latency | 4 – Real-time information in required but is not necessarily safety critical | Timeliness of information services is necessary to ensure that decision made based on them are accurate. User confidence in services is reliant on this performance requirement. |
| Reliability | 5 – Information needs to be accurate to be of use. | As with latency, receiving information that is reliable is intrinsic to the use of it when making driving decisions. |
| Coverage | 3 – Information services need to be available consistently within certain operating areas to be effective. | Services in this market are already operating over mobile networks with limited connectivity. Though the timeliness of information for tactical decision making is important, many of these services provide the bulk of their value at the strategic decision-making navigation stage and do not require continuous connectivity. |
| Bandwidth | 2 – Only small to medium information packets are transmitted. | These information services are not continuous transmissions. Packets of notifications will be sent as and when there are any changes in the information. As such, bandwidth is not a significant performance criterion. |
| Granularity | 4 – Detail is variable but potentially large. | The level detail required in the notification will be dependent on the service. For location-based notifications such as traffic incidents and their impact on journey times and rerouting options, the level of detail is a competitive factor. |

## 5.4 Market 3: Intelligent Management

### 5.4.1 Overview

As well as providing information directly to CAVs on the road network, connectivity enables valuable information services to various parties responsible for, or interested in, the behaviour and performance of some or all of the vehicles on road network. These are services that present insight to operators, managers and influencers.

In this market, information transmitted by connected vehicles is input into the management processes of road network operators and the like. This awareness of what is happening on the road network is supplementing and perhaps ultimately replacing existing data sources. Strategic management tools are also used by fleet operators and the insurance market.

In the daily operation of road networks, information about the road fleets from CAM data sets can be used to manage variables like diversions, toll rates, emission restriction zones and other flexible factors.

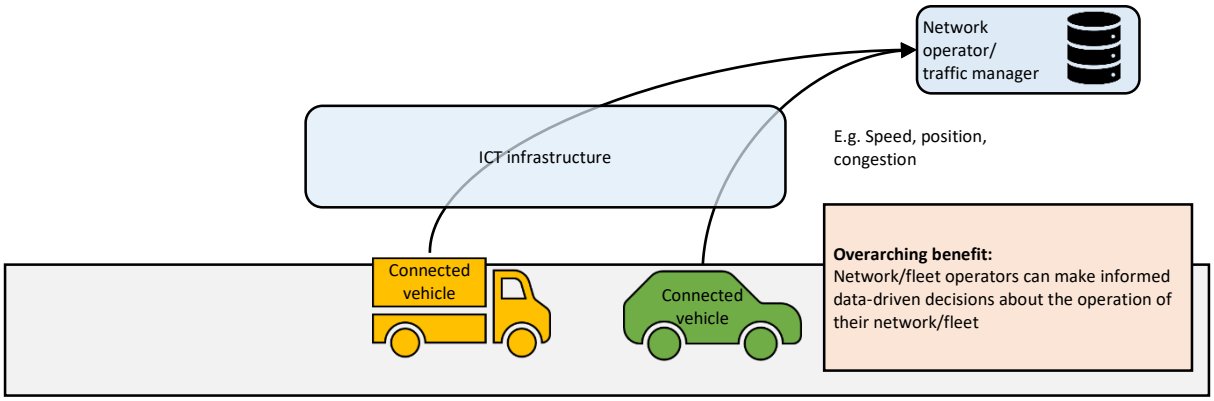


**Figure 9 Diagram summarising Market 3's structure.**

### 5.4.2 Services

The services in this market relate to either the tactical and strategic management of road network and of vehicle fleets (passenger, private and logistics).

#### 5.4.2.1 Basic vehicle information

**Purpose:** tactical and strategic.
**User groups:** Road network operators

Current network management services use cameras and in-road capacitance sensors to monitor congestion levels and input into decisions. These decisions result in actions such as variable speed limits and lane closures or other diversions.

**Basic vehicle information**

With a greater volume of detailed information on the vehicles using a network, the real-time management of the network use can become more intelligent. CAM data sets can provide a view of the status of each vehicle on the network, including their AV capabilities and fuel/emission type.

These information services depend on the following aggregated data sets communicated from

connected vehicles:

- Position
- Speed
- Direction of travel
- Acceleration and deceleration patterns
- Origin and destination data

This opens the opportunity to manage the restrictions and regulations imposed on individual vehicles or types of vehicles at different time periods or in certain circumstances. Flexible management are mostly motivated by policy stances (pollution and emissions restrictions etc.) and journey efficiency. Examples of services raised by network operators in this research include:

1. Smart Motorways
   Many ITS services deployed on motorway networks are dependent on real-time traffic information. For example, variable speed limits set in response to slow moving vehicles or dynamic hard shoulder running initiated in response to high traffic density. This information is currently collected through fixed location sensors such as inductive loops. The Basic Traffic Information services described here could complement these data sources in operating Smart Motorways solutions, or indeed replace the need for fixed location sensors altogether.

2. Emissions management: location and speed restrictions.
   With a real-time understanding of the mix of fuel types in a network fleet, variable restrictions on speed and the location/size of emissions restricted zones can be altered accordingly.
   This was highlighted as being a valuable service for Austria's network operators, where pollution thresholds result in them closing the highways to Heavy Goods Vehicles (HGV)s around 10 times a year.

3. Flexible tolls
   Demand for routes across the network will be visible to the operator. They can manage the balancing of network use by altering tolls in real-time. Coupled with the informed journeys market services, drivers can make decisions on how these tolls affect their routes and may alter them according to the intention of the network operator.

4. Flexible road side uses
   A potential benefit of CAVs identified by the Arup in the UK is the flexible use of road side kerbs[21]. As urban network operators have a more detailed insight into the type and volume of road traffic at different times, they are able to model the most efficient use of kerbsides. For example, allowing wider pavements for more pedestrian traffic at times of low road transport demand, or allocating a lane to public transport during certain timeframes.

With a longer-term, more detailed model of road network use, decisions on the maintenance and development of it can be based on analysis. User behaviours can be modelled, and intelligent mapping services used to understand and predict where action needs to be taken.

[21] ARUP, FlexKerbs, August 2018

#### 5.4.2.2 User specific journey information

**Purpose:** tactical and strategic.
**User groups:** Fleet operators

**User specific journey information**

These information services enable fleet operators of various kinds to manage and optimise the movements of the vehicles under their control as well as enabling mobility service providers to manage the journey of individuals across one or more vehicles. The key distinction between these and the basic vehicle information services described above is that these services largely depend on vehicle-specific information rather than aggregated data about a number of unidentifiable vehicles.

On a tactical level, passenger and logistics fleets connected via a central network and communicating their status are supporting the real-time management of their operations; improving flexibility in response to business opportunities. For example, the smart phone app used by Uber manages surges in prices when the service is in demand.

On a strategic level, the activities of road fleets will be recorded to a higher level of detail and processed for use in decision making. For example, optimising logistics schedules by learning from the operation of the fleet over time.

These information services depend on the following data sets communicated from individual and identifiable connected vehicles:

- Position
- Speed
- Direction of travel
- Origin and destination data
- Acceleration and deceleration patterns
- Route choice, including pick up and drop off points

#### 5.4.2.3 Infrastructure and environmental information

**Purpose:** strategic
**User groups:** Network operators

**Infrastructure and environmental information**

These information services relate to the condition of the road network and the environment in which is situated. Through their on-board sensors, CAVs will be collecting and processing information about their environment which could be useful beyond the immediate needs of the particular vehicle. Network operators are concerned about both the condition of the infrastructure under their management and factors which could have an impact on the operation of their network. For example, CAVs could collect detailed information about the condition of road surfaces which can be communicated to network operators to inform maintenance schedules and the like.

### 5.4.3 Performance Requirements

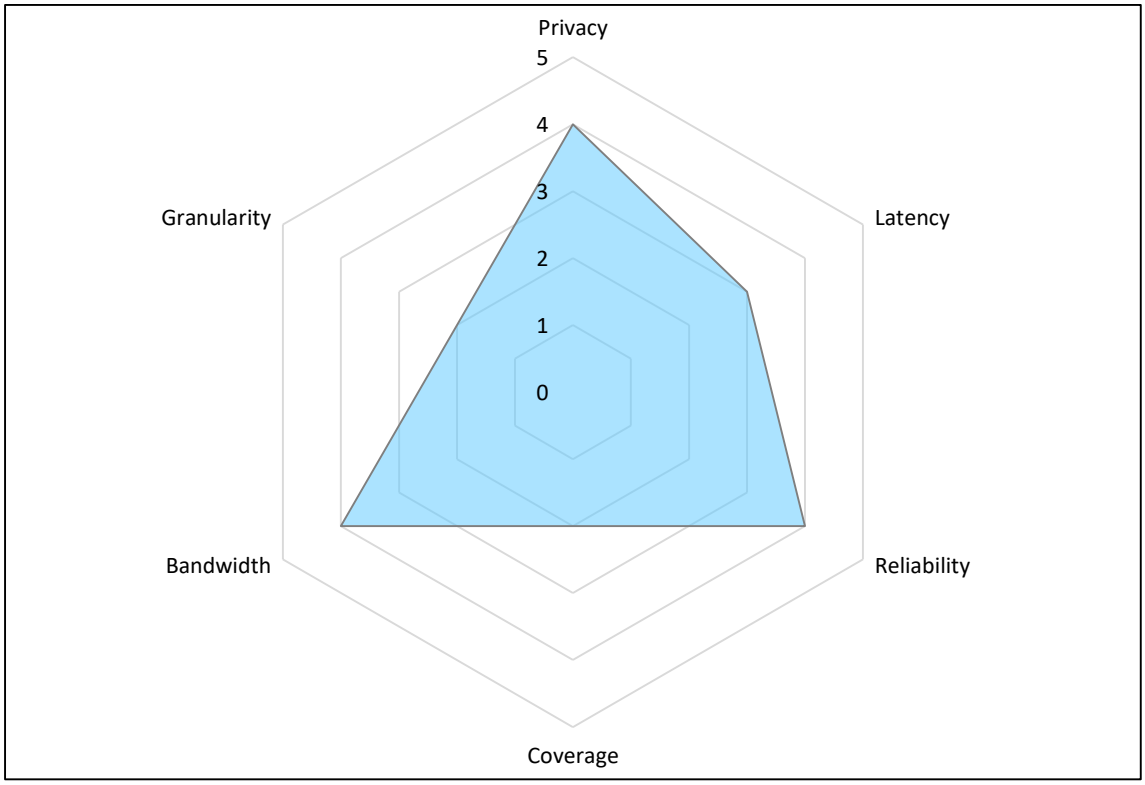


**Figure 10 Market 3 performance requirement ratings.**

Privacy and bandwidth are the most important requirements for this market. Large quantities of data relating to individual vehicles is to be exchanged.

Coverage is of low priority for these services, many of which are already operating based on other data inputs. This connectivity layer will add additional information and will only be of significant cost benefit to high-volume road networks or large fleets at first.

**Table 6 Performance ratings for Market 3.**

| Performance elements | Rating | Description |
|---|---|---|
| Privacy | 4 – Personally identifiable information will be used by some services, but it may be possible to anonymise it. | In some services, individual car's data will be handled by network operators, public services and other third parties. Depending on the application, the data will either need to be de-personalised or specific consent for it to be used must be obtained. |
| Latency | 3 – Real-time information is used, but the speed of it is not critical to operations. | The tactical services discussed will be using real-time insight into the road traffic to operate. As such, any delay would impact the value of these services.<br>Strategic processes require large and historic data sets, for which timeliness is not a concern. |
| Reliability | 4 – Most services will require highly accurate | Safety-based decisions (i.e. managing flexible road regulations) and processes that involve |

| | | |
|---|---|---|
| | information to be effective. | complex modelling will require a minimum level of reliability in their input data sets. |
| Coverage | 2 – Services are only required in local areas. Consistent availability is desirable, but not critical. | This connectivity will support and ultimately replace existing network and fleet management functions. Current sensors and connectivity are not ubiquitous. |
| Bandwidth | 4 – Large data sets will be transferred, but the speed of their transfer is not intrinsic to operations. | CAM data sets from every road vehicle will constitute a large volume of data. Transfer of this data will require significant bandwidth. However, continuous data transfer is not a requirement and each vehicle may transmit periodically – reducing the overall bandwidth required. |
| Granularity | 2 – Detail scales are relatively low. | Many services use data sets in aggregate and individual details are not necessary. |

## 5.5 Market 4: Coordination of Vehicles

### 5.5.1 Overview

All other markets considered here relate to *information* communicated to and from connected vehicles. However, there are some circumstances in which connectivity may be used to transmit *instruction* to automated vehicles, i.e. where an external system or operator has some degree of control over the actions of the CAV in particular scenarios.

Current applications pertain to specific scenarios and fleets. For example, Waymo's trial fleet of unmanned CAVs are in contact with a remote team that intervene and direct the vehicle's driving decisions when it is unable to process the surrounding environment[22]. Another example would be the coordination of unmanned buses in a depot for the most efficient use of space.

This market is the least developed of all the markets analysed and is highly dependent on the environment in which the information services are applied.

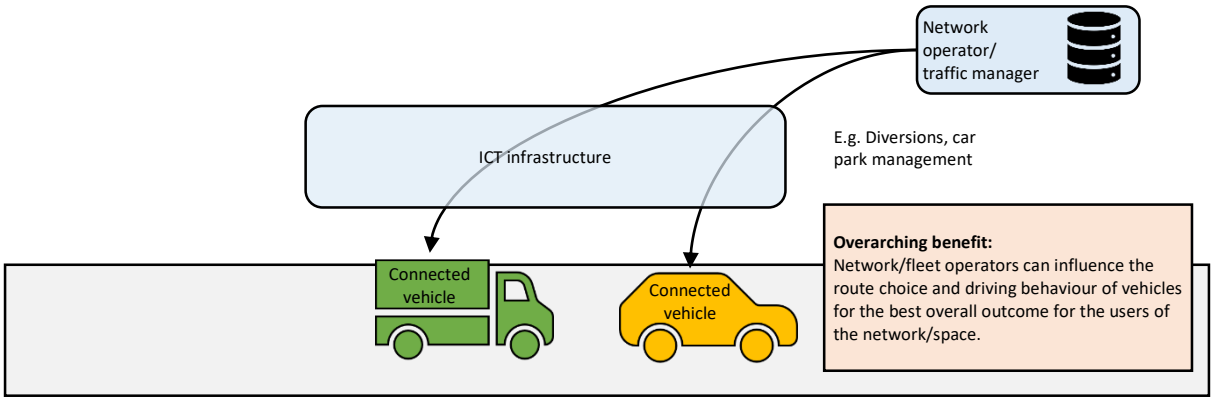


**Figure 11 Diagram summarising Market 4's structure.**

### 5.5.2 Services

The information services which could make up this market are grouped below into broad categories and listed against the environments that they can be applied in.

#### 5.5.2.1 Space management

**Primarily applied in:** closed environments

**Space management services**

These services would supply a group of collocated CAVs with detailed, coordinated instructions on paths to take, manoeuvres to make and driving behaviours at specific times and under specific circumstances.

The assumption behind this category of services is that, in some scenarios, optimised movement of CAVs to achieve the most efficient use of space and aggregate movement of vehicles within that space is best achieved by an external arbitrator determine the movements of all vehicles in the scenario rather than letting the vehicles make their own decisions.

It is highly unlikely that CAVs will follow these instructions 'blindly' even in highly controlled private

[22] The Verge, A Day in the Life of a Waymo Self-driving Taxi, August 2018

sites, but they will still make use of their on-board sensors and autonomous control system to ensure safety and prevent any collisions unforeseen by the optimising system.

This service category has the potential to be highly valuable to fleet owners. Coordinating CAVs without the need for a human driver to be present means that resources – including labour (of drivers), the physical space available and the vehicle itself – are more efficiently used.

In depots, ports and other closed logistics environments, vehicles can be coordinated to the locations where they're needed for loading and unloading without the presence of a driver. When the vehicle is idle, a driver is not needed and there is no delay in moving the vehicle once the operation has been complete. Loading and unloading bays are therefore used as efficiently as possible.

Coordinated parking of vehicles is another highly valuable operation, with added safety benefits. Car parks for fleet vehicles or private passenger vehicles are used efficiently as the vehicles can be parked without concern for the access requirements of passengers and the safety of pedestrians in the area. Space is more effectively utilised as vehicles can be "stacked" and moved independently when needed without the driver/owner needing to be present.

An extension of this service includes the coordination of electric vehicle charging points; moving unmanned vehicles to and from the charging points within a car park with consideration for the charging requirements of other vehicles in the area.

#### 5.5.2.2 Incident management

**Primarily applied in:** motorway and urban road networks.

**Incident management**

These services would instruct CAVs in the vicinity of a traffic incident of a particular diversionary route to take. These services are in many ways similar to some of those described in Market 2 but, importantly, differ in two ways:

1. Where Market 2 services provide information on diversionary routes to take in the event of an incident or unexpected traffic congestion, the decision on whether or not to follow that advice is left entirely to the discretion of individual drivers/vehicles. Here we are referring to diversions that to some degree mandated.
2. In the event on an incident, equivalent Market 2 services are likely to provide the same information to all vehicles in a particular vicinity. With the incident management services discussed here, it may be that different sub-sets of vehicles are given different routes to spread the impact of the incident on the surrounding network rather than putting pressure on a single route. The differing instruction may be derived based on, for example, the vehicle's intended destination or the vehicle type, e.g. a different route offered for HGVs.

It is highly unlikely that CAVs will follow these instructions 'blindly' even in highly controlled private sites but that they will still make use of their on-board sensors and autonomous control system to ensure safety and prevent any collisions unforeseen by the optimising system.

These services are likely to originate from network operators and traffic managers and communicated to all connected vehicles in the effected region. This would be an evolution of their traditional role of managing incidents through diversions, reduced speed limits and the like. However, similar services could be provided to sub-sets of vehicles managed by a third party. This is addressed under the next category – fleet optimisation.

#### 5.5.2.3 Fleet optimisation

**Primarily applied in:** urban road networks.

**Fleet optimisation**

These services would instruct CAVs that are part of a fleet (e.g. logistics, public transport, taxis) on which route to take in real-time in response to changing traffic conditions and demand for their services. This is an established approach in a fleet management context, particularly where in concerns last mile logistics operations in urban environments. Equivalent information services are increasingly used for passenger transport as public transport and shared mobility options become more demand responsive and coordinated.

In the future we could see more and more coordinated unmanned vehicles used to offer MaaS solutions. Particularly in urban areas, AVs can provide economical solutions to the first- and last-mile transit problem. Multi-modal journeys enabled by unmanned vehicles coordinating with public transport aligns with transport policies and cultural trends in private vehicle ownership and the sharing economy.

The journeys that the CAVs take between jobs can be coordinated by a central network that monitors the efficient use of the full fleet.

#### 5.5.2.4 Coordinated corridors

**Primarily applied in:** motorway road networks.

**Coordinated corridors**

One of the Market 1 subsectors relates to enabling information services for the operation of platooning where CAVs communicate between each other to coordinate a platooning group.

In the future, this type of service could be extended to all vehicles on a stretch of road to efficiently move them without any driving decisions being made by the vehicle's driver. After transmitting the routing intention, control of the vehicle is complete rescinded to a central controller. This infrastructure coordinates all connected vehicles on the road segment, using algorithms and risk profiles to move them efficiently and safely.

#### 5.5.2.5 Smart city management

**Primarily applied in:** urban road networks.

**Smart city management**

These services would instruct CAVs in relation to variable restrictions applied in an urban context, e.g. to create pedestrian zones or dynamically manage on-street parking. These restrictions can be more stringently applied when a subset of road traffic is coordinated and following road regulations mostly without fail. Law enforcement and other emergency scenarios that require access via roads will be more efficient and effective as road transport is coordinated and – if regulation extends to it – cooperative.

Furthermore, urban traffic management of the future could use a real-time information services to influence CAVs route selection according to the relative performance priorities for every link and node on the authority's network. In this model, highway authorities would determine policies and strategies in relation to the desired performance on the network. These requirements would then be interpreted into 'performance profiles' for each link on the network, consisting of a range of variables from desired throughput to pedestrian safety. Dynamic elements would then be applied to a link's performance profile to model the link in different scenarios, for example: timetable or external input based triggers; a 'playbook' of coordinated profiles to be implemented in the course of certain kinds of incident; and thresholds for certain variables (e.g. air quality). The intention is that the profiles would be distributed in real-time to route generation engines, which could generate individual vehicle routes and behavioural profiles and pass these to CAVs. The aggregation of 'controlled' vehicle routes and behaviours will result in an overarching network performance best aligned with citizen needs.

This approach will help secure the road safety benefits from CAVs by influencing vehicles to be more cautious in some areas than in others (e.g. around schools). It will help enable road network performance to be tackled at a granular level, addressing the fact that we may care more about the journey time reliability of public transport, say, or about the congestion levels on a local high street than overarching journey time goals. It can also help encourages the uptake of shared mobility (e.g. automated on-demand public transport options) over private transport.

### 5.5.3 Performance Requirements

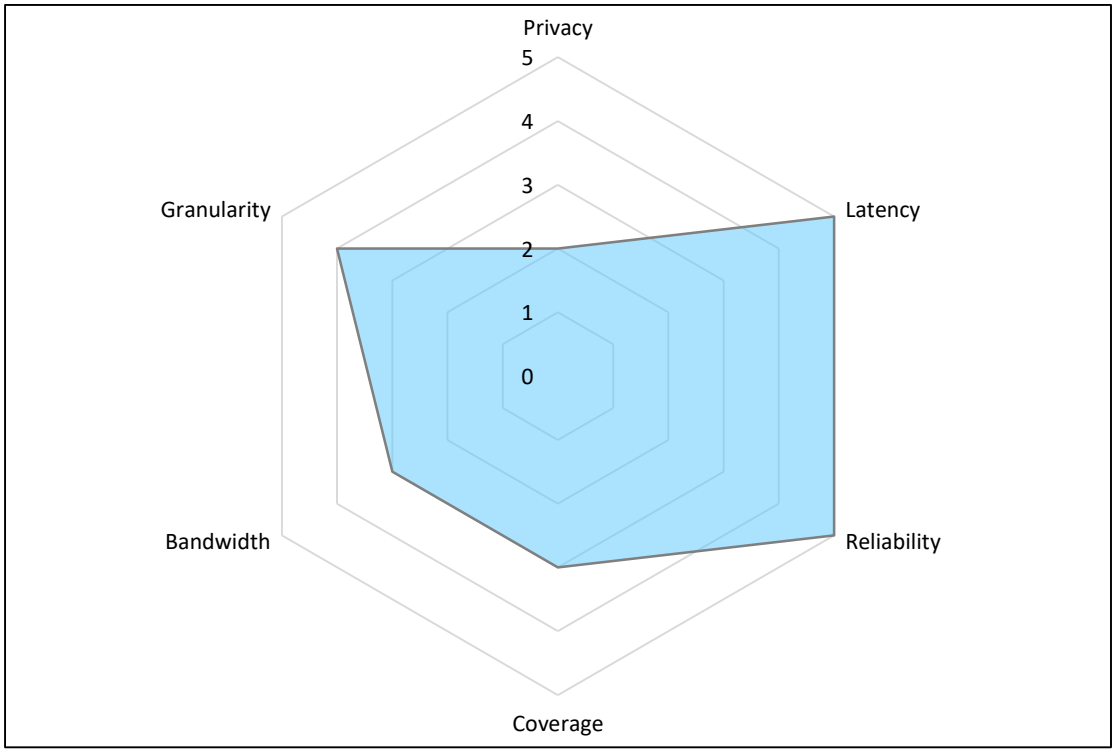


**Figure 12 Market 4 performance requirement ratings.**

Performance requirements are high in this market as the simultaneous coordination of multiple connected vehicles is a high risk activity.

**Table 7 Performance ratings for Market 4.**

| Performance elements | Rating | Description |
|---|---|---|
| Privacy | 2 – Private or sensitive information will not be transferred if services are designed as such. | These services primarily use shared vehicles and fleet vehicles. Where privately owned vehicles are coordinated, restrictions should be in place to ensure that privately identifiable information is not transmitted, which is likely to be the responsibility of the manufacturer and owner[23]. |
| Latency | 5 – Real-time information is critical to the safe operation of vehicles. | Latency needs to be high as the coordination of unmanned vehicle manoeuvres is potential dangerous and needs to be reactive to any change in circumstances. |
| Reliability | 5 – Accurate information is critical to the safe operation of vehicles. | As above, instructing an unmanned vehicle is hazardous. Communication methods must ensure that the information vehicles are receiving is correct. |
| Coverage | 3 – Information services need to be | These services are location specific. |

[23] Tesla's vehicles have a "valet mode" where certain restrictions on information access and driving functions are applied.

| | | |
|---|---|---|
| | available consistently within certain operating areas. | |
| Bandwidth | 3 – Data is of medium size and transmitted over a short period of time. | Though vehicles are continuously connected, only information on the immediate driving directions – relatively small packets of information – is needed. |
| Granularity | 4 – High levels of detail is required, but not entirely performance critical (5-20 cm scale). | Safe driving instructions need accurate positioning data. But vehicles' on-board systems will still be online to ensure that collisions are avoided, so high granularity is not critical. |

## 5.6 Market 5: Connected Travelers

### 5.6.1 Overview

Consumers have an ever-increasing expectation and requirement to be able to access internet enabled services at all times and in all circumstances. This is certainly the case when travelling; individuals are keen to turn this 'dead time' in either productive time or time in which they can be entertained or informed in a variety of ways.

The provision of connectivity for those using public transport is increasing and improving all the time. Passengers are able to browse the web, consume media and communicate with others whilst travelling. Much of the expected benefits of automated vehicles relates the fact that individuals who otherwise would have been drivers all become passengers to some extent.

Whereas the previous four markets discussed here relate to specific information services which enable or improve the capabilities and impact of CAVs, Market 5 relates to the whole breadth of internet-enabled services which will become increasingly desirable to CAV users as their role in controlling the vehicle decreases – or is ultimately removed completely.

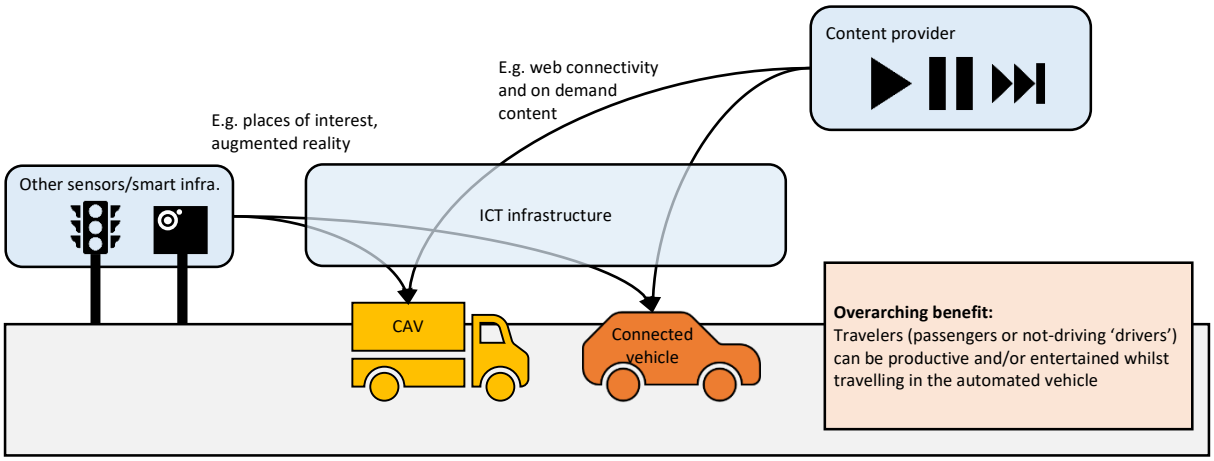


**Figure 13 Diagram summarising the Market 5's structure.**

### 5.6.2 Services

As stated above, this market has a much wider scope that information services for CAVs. The entire range of internet-enabled services are effectively in scope and it is not necessary within the scope of this report to describe and sub-categorise those. This could include, for example, connectivity for use by the passenger to access the web, consume on demand content and communicate (including internet calls).

**Internet-enabled consumer services**

However, the services worth addressing explicitly are those which relate to, and depend on, the context of the particular journey.

5.6.2.1 Enhanced journey information

**Enhanced journey information**

Passengers are supplied with information that is relevant to their journey including:

- Vehicle and journey performance information, including arrival time estimates and refuelling or charging requirements.
- Predictive quality of connectivity for the rest of the route.
- Alerts on any changes to the route or other driving decisions that the CAV operating system or central coordinating system has made.
- Commercial partner content that is location and route specific. For example, advertising upcoming services like rest stops and points of interest.

### 5.6.3 Performance Requirements

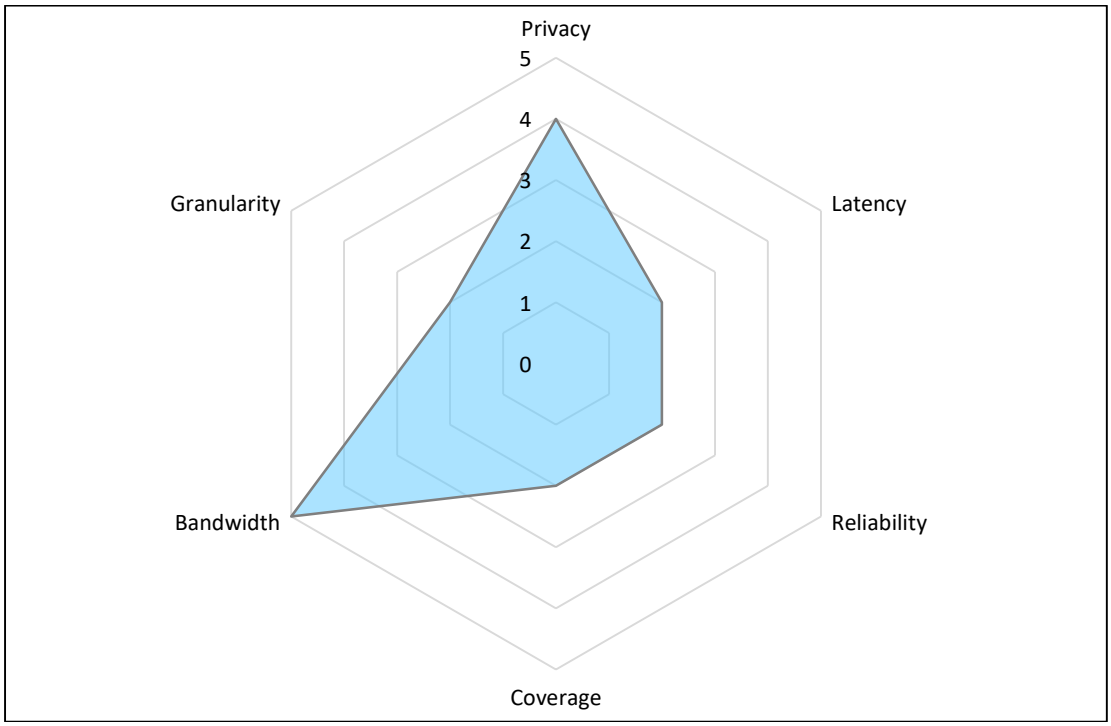


**Figure 14 Market 5 performance requirement ratings.**

These services are not critical to CAV operations, but the perceived value of them is high. Their performance must be sufficient to positively impact the passenger experience.

**Table 8 Performance ratings for Market 5.**

| Performance elements | Rating | Description |
|---|---|---|
| Privacy | 4 – Personally identifiable information is transferred. | Infotainment consumption histories will be personally identifiable (logins and communications) and valuable for profiling and analysis. Privacy and security restrictions must be compliant with regulations. |
| Latency | 2 – Information is not required to be real-time but must be within minutes. | Latency must be sufficient for perceived ease of access but is not a critical requirement. |
| Reliability | 2 – Accurate | As above. |

| | | |
|---|---|---|
| | information is required more than 60% but less than 80% of the time. | |
| Coverage | 2 – Intermittent coverage in only some areas is ok, but not desirable for commercial services. | As above. |
| Bandwidth | 5 – Large data sets will be transferred over a short period of time. | The size of information being transmitted will be large, especially where media is available for streaming. Low bandwidth will affect the consumption experience and detract from the value of this market. |
| Granularity | 2 – Relatively low levels of detail. | Communications and internet connectivity do not require intricate data sets. |

## 5.7 Market 6: Underpinning Communication Services

### 5.7.1 Overview

In operating connected vehicles on public road networks, there is significant opportunity to commercialise the enabling and accompanying data-driven services.

The complexity of effectively and securely communicating with networked devices (including in-situ, cloud computers, MEC and the vehicles themselves) will be addressed by computing services that are either translated from other IT-enabled industries or developed for this sole purpose.

Road transport and the processes of ownership, maintenance and use interface with an array of service and industries that will gain value from the increased quantity and quality of data on vehicles and their use that is a direct result of connected vehicle diffusion.

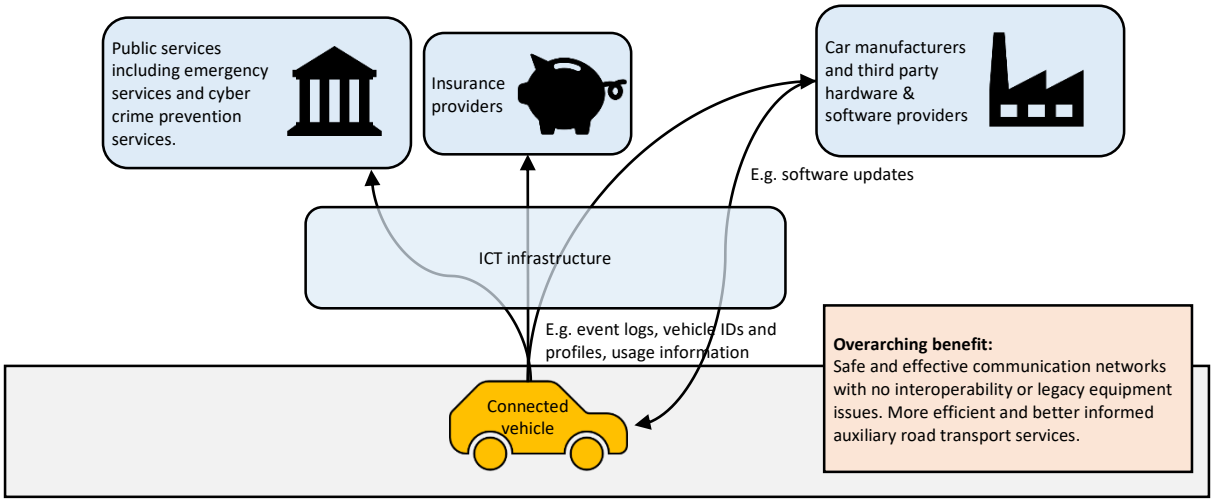


**Figure 15 Diagram summarising Market 6's structure.**

### 5.7.2 Services

#### 5.7.2.1 Secure communication services

**Secure communication services**

Cybersecurity technology providers are working to translate services applied in other industries that require private and secure communication networks to the CAV technology space.

Two such services are:

- Identity and access management (IAM) services: Encryption and device identification services for the protection of connected systems and protection of service infrastructures.
- Security operation centre (SOC) services: A supervision and incident management platform for car manufacturers and other service providers (such as third party software or hardware providers) to use in the monitoring and update of communication security and risk management.

#### 5.7.2.2 Over-the-air software updates

**Over-the-air software updates**

Vehicles with automation capabilities will have a significant amount of on-board software to support this processing. Updates to enable new functionality or fix bugs will be desirable for OEMs to ensure that their products are working safely and effectively.

For example, consortium partner AIRBUS anticipates relying on OTA to reconfigure and to update their own systems embedded in vehicles to keep the security level up to date.

Data to be transferred to the vehicle may include:

1. Specific software and operating system updates, particularly updated security measures.
2. Updates to the vehicle's on-board information sources, including HD maps, road regulations and other intelligent processing capabilities.

Tesla vehicle owners were one of the first to benefit from an over-the-air (OTA) software update service. Users receive notifications via the car's internal display or their mobile app that an update is available. Updates take time to install and the car cannot be driven when its updating, so users are given the option to schedule them in for a time when it is convenient. These updates are conducted over a WiFi connection, which is typical for OTA.[24]

#### 5.7.2.3 Cybercrime prevention services

**Cybercrime prevention services**

The SOC services introduced in Section 5.7.2.1 collects information from vehicles and the networked devices that they are connecting with. One function of the SOC is to collect and analyse the event logs for communication nodes, including any security issues and malicious connections (i.e. if there has been a malicious attempt to connect to a device's architecture).

Crime prevention services will see commercial value both in the provision of event monitoring data for their reactive processes and in any other threat or vulnerability intelligence services that can facilitate their proactive processes. Arrangements like this has already been operating in

[24] Tesla, Software Updates, accessed December 2018

communications-enabled industries such as banking and utilities and are expected to translate across to connected road transport.

#### 5.7.2.4 Other road fleet management services

As the concentration of connected vehicles increases, various existing services that support the safety and organisation of road fleets will develop or translate across industries to utilise the new wealth of data resources available to them. The provision of this data is a commercial opportunity for entities that have ownership over it.

**Other services for road fleet management and support**

Example services include:

- Insurance market services
  By providing insurance providers with data on road transport use and driver behaviours with a higher degree of granularity and the intricate profiling of road users, their calculation of risk rates will be more accurate. As such, providers will be willing to engage with a transaction for this data – which is generated by the communications network that enables connected vehicle use.
- Emergency services
  As with insurance markets, greater detail on road transport use will support the efficiency and application of emergency services.

### 5.7.3 Performance Requirements

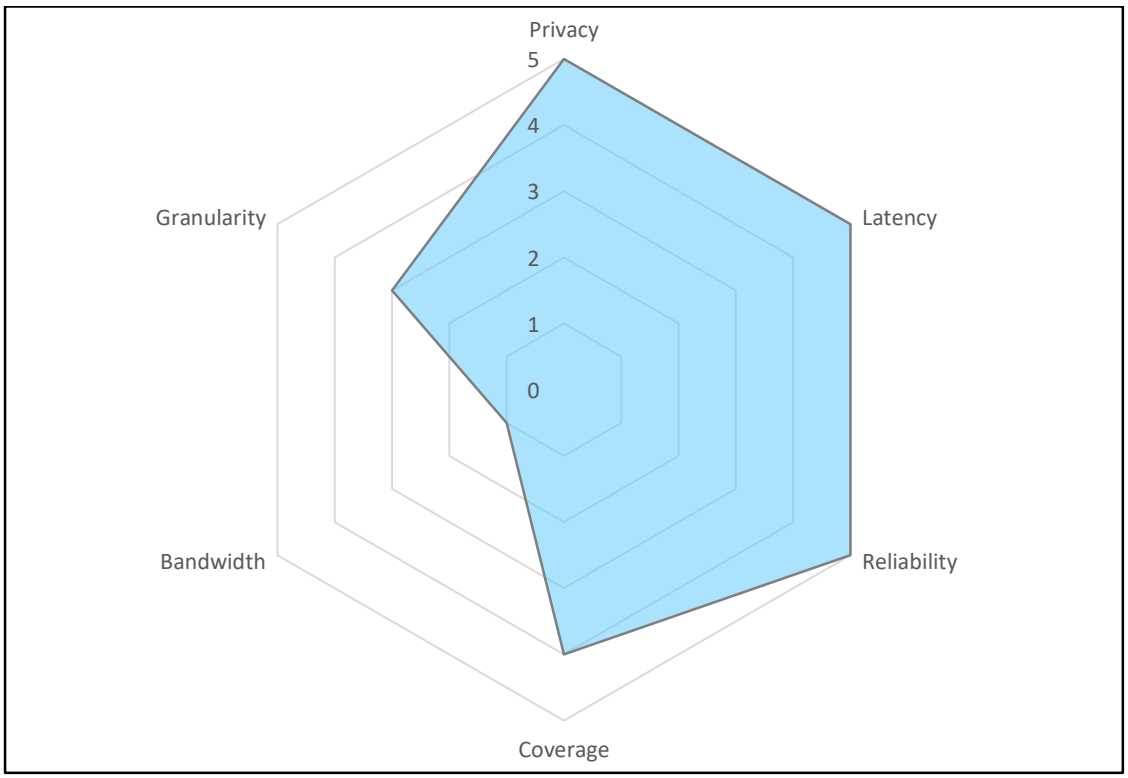


**Figure 16 Market 6 performance requirements ratings.**

Privacy is rated high in this sub-sector. These services are responsible for the anonymisation of personal information and support all services, including those that transfer sensitive information, so are at a significant risk from attempts to breach security.

In terms of performance, latency must be as high as possible and bandwidth as low as possible. The

current technology state-of-the-art assumes that supporting services such as IAM will be sharing bandwidth with the communications that they are enabling. As such, they will need to be as quick as any safety-critical process that they are supporting, and as small as possible, so as to not impact on the size of the operating signals being sent on the same channel.

**Table 9 Performance ratings for Market 6.**

| Performance elements | Rating | Description |
|---|---|---|
| Privacy | 5 – Private user information is intrinsic to some of these services and there is a significant risk of security breaches. | Cybersecurity and other secure signal management services will have high privacy requirements as they are dealing directly with user data. |
| Latency | 5 – Information services are in real-time and are safety-critical and need to be delivered within timescales of less than 100ms to be effective. | Supporting systems will be used to enable safety-critical and other real-time communication operations, so need to be as fast as possible in order not to hinder them. |
| Reliability | 5 – Information must be accurate more than 99% of the time for these services to be effective. | Accuracy of the information used in supporting services is critical to their effective use, particularly in encryption and other communication support services. |
| Coverage | 4 – Services aren't required everywhere but must be available consistently. | These services must be available where they are needed; in connected vehicle operating areas. |
| Bandwidth | 1 – Information transferred will be small. | Encryption and other security signals must not detriment the size and speed of operating signals. |
| Granularity | 3 – Data sets are on a scale of 10m. | Information sets are to be as small as possible to enable the performance requirements above, whilst still retaining enough detail to be valuable. |

### 5.7.4 Market Structures

Table 10 below illustrates five simplified market structure scenarios. This framework was used to consider the fundamental structure that is likely to apply across the CAV information services. The market structures for the 6 service sectors summarised above are not covered in any more detail in this document, as Task 9.5 will address this later in the ICT4CART programme.

**Table 10 The service provision scenarios explored in the workshop.**

| | | Services are paid for by | |
|---|---|---|---|
| | | Public provision | Users/private sector |
| Infrastructure is paid for by | Public investment | Scenario 1 | Scenario 3 |
| | Private investment | Scenario 4 | Scenario 2 |
| Scenario 5: some combination of the above. | | | |

The application of these scenarios is largely dependent on four factors:

1. Existing markets from which these services have emerged (or are emerging);
2. The ownership and operational responsibility of the environment within which the services are deployed, as well as the geographic scale of the environment;
3. The type of value generated by the services (see Figure 4 above);
4. The performance demands of the services.

#### 5.7.4.1 Scenario 1

**Most likely applies to:** Intelligent Management services.

In Scenario 1, the national, regional or local government invests in the ICT infrastructure required to support widescale roll-out of CAVs. This investment includes the upfront investment for design and installation as well as ongoing maintenance and upgrade costs. The government would also fund the provision of all information services provided to CAVs and others. All of these information services are free for any and all users.

This scenario is already in use for various safety-related public services. For example, the transmission of traffic information over cellular networks. Services that align with public-mobility policies are the most likely to be implemented using this model; policies which are currently dominated by safety-related developments.

This scenario provides all users with services for free and on a standardised basis. This accessibility and focus results in this scenario being the best in supporting the direct realisation of the societal benefits of connected vehicles.

This scenario is likely to occur in distinct use cases where the levels of investment required can result in distinct business benefits for the public authority, such as on toll roads or revenue-generating parking infrastructure. For instance, Italian highways are already deploying ITS-G5 infrastructure.

It is uncertain at this stage as to whether the environmental and societal benefits would be sufficient to drive investment in other applications of connectivity infrastructure that would not necessarily generate direct monetary income for the public sector.

**Table 11 Advantages and disadvantages of Scenario 1.**

| Advantages of this scenario | Disadvantages of this scenario |
|---|---|
| • Control in being able to align services with public mobility policies and in being able to regulate them.<br>• The possibility to mandate compliance resulting in faster market penetration.<br>• Greater impact in policy areas, as services can be designed to impact on one specific area such as journey times or road safety.<br>• The payment channels for services are already established, such as taxes and tolls.<br>• Users have greater trust levels for public authorities in the handling of personal data. | • Concerns over the raising of tax rates and public perception of the value of these services.<br>• Timescales and poor management as public authorities manage the implementation of infrastructure and services whilst still maintaining other operations.<br>• The delivery is not driven by the market and may not be suitable for the users. |

#### 5.7.4.2 Scenario 2

**Most likely applies to:** Informed Journeys

In Scenario 2, the national, regional or local governments invests in the ICT infrastructure required to support widescale roll-out of CAVs. This investment includes the upfront investment for design and installation as well as ongoing maintenance and upgrade costs. Where it differs from Scenario 1 is that ongoing information services to CAVs and others are then provided by private bodies on a commercial basis such that the actual payee could vary (e.g. OEMs, Fleet Operators, end-users), as could the potential transaction models (e.g. monthly access fee, pay as you go, on a service by service basis).

This model is relatively unlikely to be used, due to concerns over competition law and conflicts of interest. However, there are cases where it is likely to be implemented where services that users pay for regardless of who operates them could be outsourced by public authorities; public transport, for example, some cities manage their parking infrastructure in this way.

As with Scenario 1, public bodies investing in infrastructure of this scale was highlighted as being an unlikely route. For example, in Austria, national spending of toll revenue is planned across all development programmes, and money will only be spent on connectivity where it can be easily built into the spending plan. Otherwise, it may be the case that connected vehicle could be charged higher toll rates. This would only be feasible where users see value in the services that are being provided in exchange for this additional charge; but this would result in more focussed, market-driven infrastructure and service delivery.

**Table 12 Advantages and disadvantages of Scenario 2.**

| Advantages of this scenario | Disadvantages of this scenario |
|---|---|
| • Higher quality of services as commercial competition in the service market is greater.<br>• Public infrastructure provision reduces the risk in investment for private innovators.<br>• Public provision of infrastructure will ensure standards are maintained – ensuring harmonised deployment, national roaming and interoperability. | • Limiting the access to services to only those who can pay. |

#### 5.7.4.3 Scenario 3

**Most likely applies to:** Underpinning Communication services

In Scenario 3, the private sector invests in (and subsequently owns) the ICT infrastructure required to support widescale roll-out of CAVs. This includes the upfront investment for design and installation as well as ongoing maintenance and upgrade costs. Governments then fund the provision of all information services provided to CAVs. All these information services are free for any and all users.

This scenario would be the least likely to be realised in the delivery of connected vehicle services. The public sector is unlikely to provide services for free, unless it was to directly enable specific public benefits such as safety improvements. It could however be used in closed networks, such as university or business campuses.

**Table 13 Advantages and disadvantages of Scenario 3.**

| Advantages of this scenario | Disadvantages of this scenario |
|---|---|
| • As private infrastructure providers have a smaller obligation for interoperability and delivery standards, state-of-the-art technology can be provided.<br>• Any public-private partnership in technology can further the delivery of it and the ensuing benefits. | • Tax spending is benefiting private investors (infrastructure owners) and not the public or governing bodies.<br>• Higher initial investment risk from the perspective of the private investor. |

#### 5.7.4.4 Scenario 4

**Most likely applies to:** Connected Travellers

In Scenario 4, the private sector invests in (and subsequently owns) the ICT infrastructure required to support widescale roll-out of CAVs. This includes the upfront investment for design and installation as well as ongoing maintenance and upgrade costs. Ongoing information services to CAVs and others are then provided by private bodies on a commercial basis such that the actual payee could vary (e.g. OEMs, Fleet Operators, end-users), as could the potential transaction models (e.g. monthly access fee, pay as you go, on a service by service basis).

Though this service distribution model is unlikely to take off in areas where there is currently a low user base, some connectivity services that are already operating in a similar model will translate across to the CAV service market; that is, connectivity for entertainment. Other services that offer distinct value to end users and are valued by them in "comfort" areas such as infotainment, safety and the individual's driving experience, will be the most profitable areas. Market demand will see these services being some of the first to be developed. Third-party innovator supply models, using privately-owned platforms that replicate "app stores" for vehicles, were judged to be a likely format for this market structure by the consortium. Apple and Android already have platforms, called CarPlay and Android Auto, on the market.

**Table 14 Advantages and disadvantages of Scenario 4.**

| Advantages of this scenario | Disadvantages of this scenario |
|---|---|
| • Faster timescales than scenarios involving public funding, as knowledge development and exchange is unhindered by procurement or grant management.<br>• Innovative, effective and competitively priced services are enabled by market competition.<br>• Fewer barriers to entering the services market resulting in a higher quantity of offerings, making them suitable for a wider range of users.<br>• Private investors see a direct financial return.<br>• Standards will develop quickly as private investors will want to enter the market as soon as possible. | • Slower penetration rate as the investment risks are higher when services are for an undeveloped market.<br>• Specifications may develop in a fragmented manner whilst the market develops.<br>• Services will not be accessible to all if they are designed for specific use cases and for paying users.<br>• By extension, only profitable services in profitable areas will be developed and provided. |

#### 5.7.4.5 Scenario 5

**Most likely applies to:** Automated Driving services

Scenario 5 is where the provision of services and infrastructure is a mixture of private and public responsibilities.

A version of Scenario 5 is perceived to be a highly likely scenario, as the model is representative of the R&D work that is currently being undertaken by private industries with funding from the European Commission and taxes.

The table below summarises a likely future structure for Scenario 5, devised during the workshop.

**Table 15 Example scenario 5 structure.**

| | Public | Private |
|---|---|---|
| Investment | Public invest in sensors and other connected devices on the road network. | Private invest in telecommunications infrastructure |
| Services | Some public services that support traffic management, safety and other public interest benefits. | • User pays for individual services.<br>• Fleet managers pay for certain services.<br>• Private advertising is a revenue stream.<br>• OEM or other business pays for collecting certain types of data. |

**Table 16 Advantages and disadvantages of Scenario 5.**

| Advantages of this scenario | Disadvantages of this scenario |
|---|---|
| • The risk of development is shared across the industry, and public sector involvement ensures that regulation and safety requirements are up-to-date.<br>• This scenario is already the case in the developments happening today.<br>• Business growth is supported.<br>• This scenario offers more flexibility in services, by balancing the long development cycles of public-provision and better access to market for private companies increasing competition. | • Involvement of multiple entities may result in fragmented supply.<br>• Early regulations are needed to ensure that market flexibility is ensured whilst concerns over competition laws are addressed.<br>• Coordination is needed as public policy and market needs are both strategically addressed. |

# 6 Conclusions and Recommendations

This document has described research undertaken into the expected market needs for ICT infrastructure for CAVs. What CAVs need from connectivity is a key question in this developing market place and is influencing investment and design decisions across various global industries, such as telecommunications, automotive and intelligent transport systems.

In some areas, there is a degree of clarity and consensus around this question. However, this research has found that despite its importance to industry and governments throughout the world, there is a lack of a holistic, user-focussed, shared understanding about what CAVs and other users will actually need the supporting ICT infrastructure to provide for them.

By focussing on the discrete information services that CAVs could (or do) utilise rather than the technology that will enable them and by organising those services into a clear service-based framework, the findings of this research offers a helpful contribution to the CAV industry knowledge base. It can offer the basis for better dialogue and collaboration between the different parties, from local and national governments through to large established industries that need to work together in new ways. Furthermore, it can enable that collaboration to be centred around what generates value for users, and society at large.

On the basis of this report, we would offer the following recommendations for consideration in the wider ICT4CART project:

1. The framework for categorising information services and their required performance levels used in this research should be fed into the Systems Requirements being developed in Task 2.3;
2. The market structures should be further explored for each of the markets set out here and inform the completion of Task 9.5 and the delivery of a report on the business models that can be used to commercialise the solutions developed in ICT4CART;
3. A market sizing analysis should be carried out as part of the Cost Analysis to be completed in WP8. This should take a bottom-up, value-based approach to estimating the potential for these services;
4. The opportunities for innovation within each market should be further explored and fed into WP5.

# 7 References

The following resources have been referred to at various points in the document, and are compiled again here for ease of reference:

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