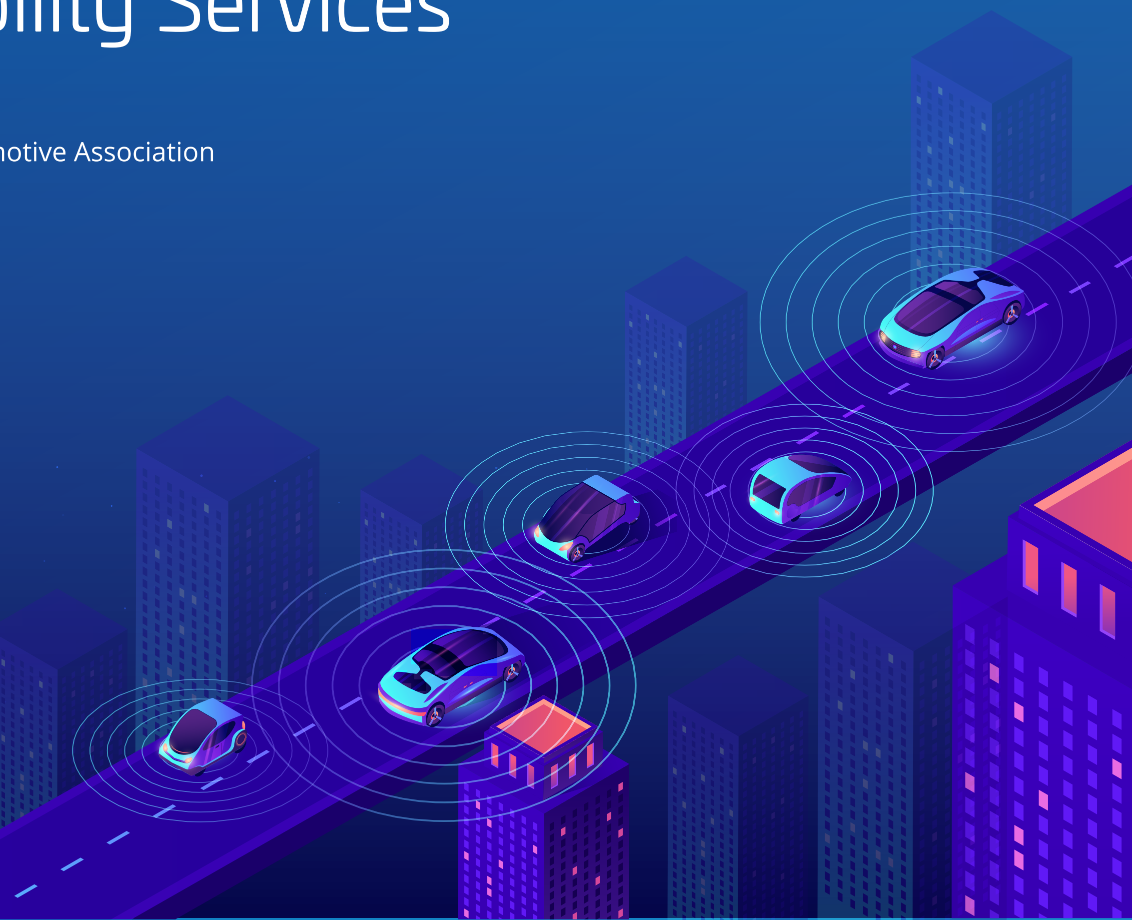
Accelerating 5G Adoption for Connected and Autonomous Mobility Services

5GAA Automotive Association

White Paper



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Executive Summary

The purpose of this white paper is to highlight the wide array of **new business opportunities** that 5G will enable **for the connected mobility ecosystem**.

Our intention is to move the discussion beyond safety and automated driving to other innovative solutions and customer experiences.

1. Introduction

In the second quarter of 2022 connected car sales surpassed non-connected cars for the first time [1] with over 250 million[2]. In 2023, the number of global 5G connections is forecast to reach 2 billion [3], with a fifth of the global vehicle fleet connected to cellular networks [4, 5]. While 4G dominates the connected car market at 90% share, we propose that 5G automotive adoption creates clear value and differentiation with improved customer experiences, data-driven service efficiency, and access to new and innovative business models.

5G is the fifth generation of wireless technology, providing higher speed, lower latency and greater capacity than 4G / Long-Term Evolution (LTE) networks. Through 5G's major technological improvements the automotive industry can enable better quality communications, improve customer experiences and offer new apps and services. The improved performance of 5G provides more efficient vehicle-to-network communication (per-GB) and ultra-low latency services (e.g. edge computing). 5G, together with Cellular Vehicle-to-Everything (C-V2X) developments, offers greater flexibility to access and process vehicle data, improve safety, enable higher levels of automated vehicles, reduce congestion/emissions, and many other innovative customer offerings. Risks are mitigated by considering rapid global deployments and proven 5G technology reliability.

This white paper analyses business and market drivers to assist decision-makers enabling future vehicle models with 5G, focusing on the following areas:

5G coverage and spectrum transition (Section 3)

- 5G radio network coverage. With new spectrum bands globally standardised and harmonised to facilitate deployments, global rollouts of 5G networks have rapidly accelerated. With the rapid adoption of 5G, operators have begun re-farming spectrum from legacy networks (2G and 3G).

5G network evolution (Section 4)

- 5G core networks incorporate new features that enable innovative automotive functions. These enablers are crucial for reliable, flexible connectivity and high-performance data exchange.

Vehicle software trends (Section 5)

- Evolution of software-defined vehicles with cloud resources via 5G. These resources may be public cloud, private network or edge cloud; all cases benefit from 5G with transparent and adaptable network connectivity.

New apps and services (Section 6)

- New apps and services enabled by 5G beyond automated and safety.

Note: C-V2X is a term encapsulating 3GPP V2X technologies: direct (PC5) and mobile network-based (Uu). This paper looks at mobile network use cases. For details on terminology see [6].

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3. 5G coverage and spectrum transition

Deployment of 5G commercial networks began in 2018, and has increased rapidly in 2021 and 2022 with massive investments in 5G network and spectrum deployments. This rapid expansion is an indicator of the success that innovation in 5G has created for markets worldwide.

According to the latest Global Mobile Suppliers Association (GSA) 5G Market Snapshot, June 2022 [7]:

- 493 operators in 150 countries/territories are investing in 5G.
- 214 operators in 85 countries have already launched 3GPP-compliant 5G networks.
- 1,062 commercially available 5G devices, an increase of 90% year on year.

3.1 Regional notes

Asia

- China, the Ministry of Industry and Information Technology (MIIT) reaffirmed its ambition to build the world's largest and most extensive standalone 5G network by the end of 2025.
- Korea
  - 5G deployment: ~200,000 5G base stations and >20 million 5G subscribers by end of year 2021.
  - C-ITS infrastructure, all highways will be covered by 2027, and nation-wide roads (110,000 km) by 2030.

European Union

The European Union's 5G Action Plan has defined the high-level objective to cover all major road networks with 5G by 2025. Most countries have incorporated additional objectives during spectrum auctions, such as:

- France, all 5G base stations must deliver speeds of at least 240 Mbit/s by 2030.
- Germany, a combination of coverage and quality of service will be implemented. By the end of 2022, speeds of 100 Mbit/s with 10 ms was expected on all German motorways and federal roads, and rail routes with more than 2,000 daily passengers [8]. By 2024, the 100 Mbit/s and 10 ms latency criteria will be extended to all other federal roads and more than 50Mbit/s will be required on secondary roads, seaports, inland waterways core network and all other rail routes.
- Italy, within four years after the 700 MHz FDD auction spectrum is made available [9], operators need to cover collectively the main national roads [10].

North America

North America, especially the USA (330 million population), is considered to have the greatest share of 5G population network coverage of >75% (Statista Research). With a healthy and competitive market, deployment of 5G by multiple operators is expected to rapidly surpass 4G coverage.

3.2 Spectrum bands

5G can utilise multiple spectrum bands with different technical characteristics and business implications. It can be activated on low-frequency bands (<1 GHz), mid-frequency bands (1-7,125 GHz) and high-frequency bands, also denominated as mmWave (>24.25 GHz) spectrum.

All spectrum bands listed in 3GPP TS 38.101 can be used for 5G, and these bands can be combined as described in the same specification. Each mobile network operator (MNO) or communication service provider (CSP) ultimately decides which and when a spectrum band is activated with 5G, hence available spectrum bands may differ between operators and countries. This is due to a combination of technical and business reasons:

- **Low-band provides farther reach**, which is a general rule as frequency band decreases. Hence, low bands are the best spectrum for coverage. However, network capacity and speeds are limited by the bandwidth availability as most available channels in low bands are limited to 20 MHz DL and 20 MHz UL. Additionally, the majority of devices are currently limited by having one common power amplifier for low bands, making the combination of low bands (e.g., 700, 800 MHz) impossible.
- **Mid-band offers the optimal combination of speed, coverage, and capacity**, with the potential of bandwidth channels up to 100 MHz. Mid-band spectrum is critical for the success of 5G and is currently where most MNOs are activating 5G networks.
- **High-band (mmWave) will deliver the ultimate 5G experience** (multi-Gbps speeds, lowest latency), but mostly in hot spot areas due to its limited coverage that requires an economically challenging antenna densification. 5G in mmWave may not be suitable for most moving automotive use cases, but can be beneficial in urban environments and at congested intersections.

Future applicability of automotive use cases will depend on reliable coverage. The automotive industry is today focused on the development of low- and mid-spectrum bands, to get the most out of 5G. The simultaneous use of multiple frequency bands may be a **topic for future study within 5GAA**, such as using dual connectivity and carrier aggregation technologies. This approach may provide a more robust and secure connection, e.g. by combining low- and mid-band spectrum, allowing the user to benefit from both, offering greater coverage in the low band, and improved throughput and capacity, where there is coverage by both low and mid band.

3.3 Spectrum re-farming/sharing

Telecommunications operators use spectrum and more efficient technologies to support the exponential growth of data in their mobile networks and deliver on sustainability and operational objectives. As legacy 2G and 3G networks use highly valuable low- and mid-band spectrum, most operators have decided to switch off legacy networks and are engaged in spectrum re-farming (network sunset) plans to re-allocate resources to 5G, which is considerably more efficient and economical.

Dynamic spectrum sharing (DSS) [41] provides a migration path from 4G LTE to 5G NR by allowing LTE and NR to share the same spectrum. DSS was introduced in 3GPP Release 15 (Rel-15), with further enhancement in Release 16 (Rel-16), allowing 5G device owners to benefit from the already existing footprint of LTE spectrum, while using this for 5G technology too. DSS can be used to boost the network capacity of 5G and 4G network in low-density areas. However, if no further 5G bands are available on the site, 5G performance using DSS does not differentiate from 4G.

Activating DSS on low- and/or mid-band LTE spectrum can help operators roll out 5G in larger areas more quickly, providing acceptable levels of coverage, albeit with limited speeds. DSS is considered an interim for certain markets ahead of 5G deployments in low and mid bands.

The situation of 2G/3G networks sunset and spectrum re-farming is different in every region/country. However, numerous telecommunications operators have publicly announced their plans to switch off legacy 2G and 3G networks. There have been no operator announcements yet on the future of 4G being re-farmed to 5G/6G. Considering previous generations, it is likely 4G and 5G will coexist for a good period of time.

Europe eCall first-generation services (relying on 2G or 3G networks) are a special case and also affects other regions and countries where it is currently operational. It is likely that some 2G networks will be kept active to avoid any impact on eCall services while waiting for the deployment of next-generation eCall (NG eCall), which is expected around 2026.

Examples of announced network sunsets by region:

- Orange France has announced plans to decommission 2G by 2025 and 3G by 2028 [11].
- The UK announced the full sunset of 2G and 3G networks in 2033 [12].
- Top US MNOs completed their decommissioning of 3G by end of 2022 [13].

4. 5G network evolution

The architecture of a 5G network is composed of three main elements: the User Equipment (UE), the Radio Access Network (RAN), and Core Network. The application domain is the end point of the communication to and from the UE, enabled by RAN and Core. Applications can be hosted in-the cloud or with 5G Multi-Access Edge Compute ((MEC), which provides general-purpose, low-latency computing.

In this section, we highlight key features of 5G that enable reliable and powerful data exchange mechanisms. Using these significant features for connected vehicles on-board and off-board communication exchanges, 5G will be a game-changer for architecting future automotive industry services.

4.1 New 5G standards

5G networks are implemented following 3GPP specifications, starting with Rel-15 in 2018, providing a scalable, flexible and powerful architecture. The 5G Core is designed to be cloud native to enable execution in multiple environments and with flexible deployments. The cloud native architecture of 5G with network automation, network slicing and edge computing, are designed for the needs of multiple verticals and to enable an ecosystem for innovation.

The new air interface of 5G (5G NR) is considerably more efficient and flexible than 4G (LTE) in terms of carrier bandwidth, subcarrier spacing and ratio between downlink and uplink, providing configurable time and/or frequency resources. 5G NR is also designed to operate in a broader spectrum than 4G, which was limited to fewer spectrum bands. As new mmWave bands (24-50 GHz) are made available, bandwidth will increase even further.

5G outperforms 4G in terms of data rates; from 4 to 20 times faster; latency, with values under 10 ms; spectrum efficiency, several times higher user density compared to 4G, and overall reduces energy consumption of transferred data.

The technology evolution of 5G network connectivity currently enables three use case families:

1) Enhanced Mobile Broadband (eMBB) with throughputs beyond 1 Gb/s. This especially benefits automotive use cases, offering higher throughput and lower latency for data exchange, enabling more reliable communication as networks handle a higher density of vehicles.
2) Massive IoT (MIoT) providing the capacity of connecting more than 1 million devices/km^2.
3) Ultra-Reliable Low-Latency Communications (URLLC) offering a latency approaching 10 ms and 99.999% (“5 nines”) reliability. URLLC is intended for scenarios in a limited area where the environment can be controlled and redundancy can be provided, e.g. a confined area, port, airport.

Quality of Service (QoS) mechanisms are also available to increase reliability and are an important part of the 5G toolbox. For example by enabling eMBB, MIoT with QoS the predictability of vehicle data connections can be increased. QoS is further described in the following section.

4.2 Network exposure functionalities

One important functionality available to the automotive industry in 5G is the exposure capability. The 5G system supports Network Exposure interfaces, which allow interaction with a 5G network dynamically. 5G networks 'expose' different Network Services, which can be viewed, configured or modified by authorised applications.

The Network Exposure interfaces follow the HTTP REST Model, which is widely used on the internet. 3GPP has standardised a set of APIs offered by the Network Exposure Function (NEF) – examples of NEF capabilities are described later in this section. Organisations such as GSMA Operator Platform Group (OPG), 5GFF and CAMARA [14] actively collaborate to further align and improve Network Exposure interfaces using feedback from the automotive ecosystem.

Below are some examples of currently available NEFs:

- **QoS with mobile network interaction,** i.e. even a high capacity 5G system could suffer from high load so with QoS an application can dynamically request priority. QoS is available in 4G, but prioritisation was linked to the definition of specific entry points in the network (bearers) for each type of traffic. The 5G solution uses flows to classify and treat the data traffic, providing a more flexible approach. With QoS, the vehicle can get priority and network resources needed for critical events such as public safety operation [15], cybersecurity updates, important communication for ADAS or AD systems, or off-board processing in situations placing a high load on the cellular network. Moreover, the 5G network can potentially predict network conditions and warn applications to adapt if near-term demand/requirements cannot be fulfilled. It is also possible for operators to enable cross-border roaming with QoS to benefit the user experience.
- **Background Data Transfer (BDT),** a 5G network policy control service designed to enable service providers to flexibly deliver large data transfers in a geographical area during off-peak times. BDT is described in ETSI TS 129 554 standard and can benefit OEM software updates ('Over the Air'/OTA). OTA using 5G is further discussed in Section 5.5.

4.3 Network slicing

Network Slicing is the concept of running multiple logical networks as virtually independent business operations over a common physical infrastructure. Compared to one-size-fits-all network architecture, network slicing provides a way to serve different categories of use cases with a diverse set of requirements, in terms of functionality, performance, reliability, management, isolation, etc. Network Slicing provides a scalable, dynamic and tailored service thanks to the virtualisation of network functions deployed in 5G, which is an improvement compared with the more static approach in 4G.

Automotive services will benefit from mobile networks' QoS capabilities. In this direction, basic mechanisms deployed by mobile network operators include 3GPP QoS framework and Network Slicing to ensure network performance for prioritised automotive applications even in congested situations, and Network Exposure API's facilitating the usage of QoS on demand for end users.

It is important to note that all described QoS mechanisms are working on an application level, and not at the device level. So, different applications might make use of different network slices, and some applications might use a Network Exposure API for QoS on demand while others may not. This also addresses the needs of automotive applications with different QoS requirements because they are operated in parallel.

Network Slicing separates network resources to provide a more consistent service. Tools like 3GPP QoS can also be applied for data traffic flows within a network slice. User Route Selection Policy (URSP) provides a foundation to deliver dynamic network slice selection, enabling traffic steering and the separation of services for devices when using network slices. When devices are provided with URSP, they can select between offered network slice(s) – e.g. higher-bandwidth, low-latency, or background data transfer – providing added value for creating dynamic and efficient services.

The network offers the information about available slice types to the device via URSPs, which thus add further details regarding which network slices the device's underlying applications should use when activated. Therefore, the device knows in advance of operating a certain use case which slice types are available, and how to get access to the relevant slice type for the application. Network slice requirements can be discussed with MNOs, and to further improve consistency and scalability, 5GAA is contributing to global standardisation efforts of slice profile characteristics (e.g. with GSMA).

Since 3GPP Rel-15, the 5G network can support isolation/separation between network slice instances and share resource and network functions. Rel-15 capable devices can connect to one or multiple network slices and support roaming scenarios. It is also possible for operators to enable cross-border roaming for Network Slicing to improve user experience. Mobile operators can use Network Slicing to support multiple third parties (e.g. enterprises, service providers, content providers, etc.). Additional building blocks for diverse network slice types beyond eMBB were added in 3GPP Rel-16, enabling more flexible implementation of vertical use cases such as C-V2X. Rel-16 also addresses requirements such as enabling exclusive access to a slice, interworking for slicing between EPC and 5GC, and slice access (authorisation/authentication) via additional user IDs.

Further information on Network Slicing can be found in GSMA technical reports [16].

4.4 Mobile edge computing

MEC with 5G is a key enabler of C-V2X applications requiring ultra-low latency and high reliability. 5GAA has demonstrated MEC in multiple configurations to highlight the value for industry stakeholders and advance technology adoption.

For additional detail on MEC activities within 5GAA please refer to the following reports:

- MEC4AUTO use cases and initial test specifications [17].
- MEC for automotive in multi-operator scenarios [18].

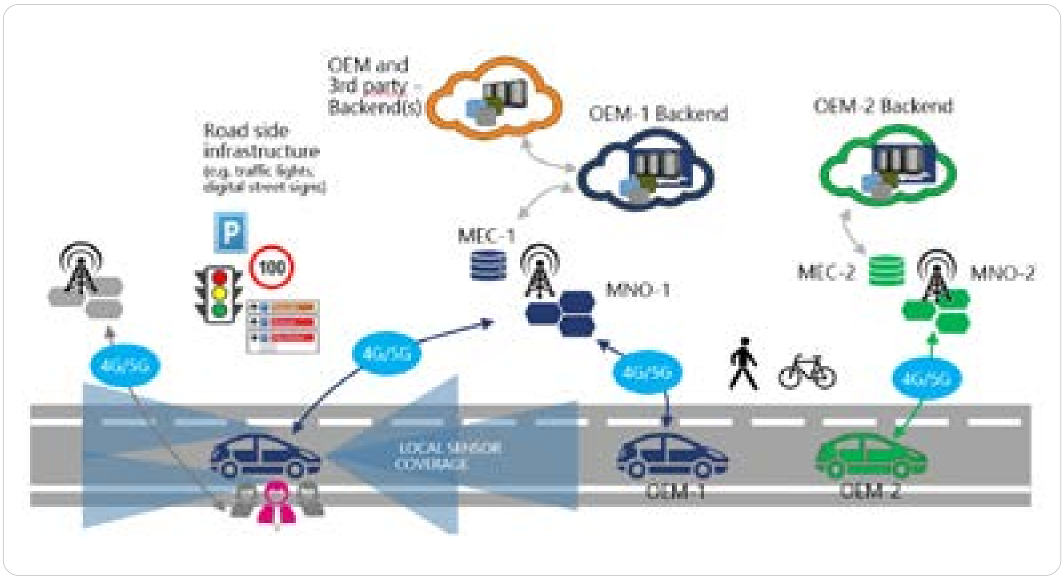

Figure 1 – Edge computing support for automotive scenarios (MEC4AUTO perspective)

4.5 Regional breakout

Regional Breakout (RBO) is a capability of mobile networks based on 5G standards also known as Local Breakout (LBO). RBO enables a consistent user experience while roaming on a visited network, because the user data traffic is directly interconnected to the internet. RBO provides interconnections in a regional setup (e.g. on a city or state level), improving 'visiting' vehicles connectivity performance and benefiting MEC low-latency services.

By using RBO, the visiting user gains better latency and performance since sessions can be terminated locally. The traditional alternative to RBO is Home Routing (HR), where the user's anchor point (IP address) is in the user's home network and all sessions need to be routed from the visited network back to the home network before an application can be reached.

RBO is crucial to 5G improvements, such as coping with the demanding connectivity requirements for a seamless transition between on-board/off-board processing, and to use local edge deployments. As far as possible, RBO helps applications maintain location agnostic status while processing and especially in cross-border situations. The relevance for RBO may depend on the regional roaming conditions (i.e. particularly prevalent in Europe). RBO is a component of 5G networks enabling improved data flows for end users and adding value to roaming partnerships, helping to unleash the full potential at the edge cloud.

Further information can be found in GSMA roaming guidelines [19].

4.6 Precise positioning

Precise positioning is a prerequisite for most automated driving and connected mobility use cases. Using the mobile network infrastructure to provide Global Navigation Satellite System (GNSS) correction services (RTK, PPP, etc.) is a widely known functionality available for the automotive industry. Additional positioning approaches have been unlocked by recent progress in the evolution of 5G.

Especially in areas of poor GNSS coverage (e.g. tunnels, underground parking, urban canyons), additional positioning services/assistance from the mobile network are required to support autonomous driving and C-V2X safety applications.

Within 5GAA, positioning requirements [42] were derived for various use cases [45, 46, 47]. Based on these, three sets of accurate positioning requirements for automotive scenarios were derived and captured in 5G standards [43]. These are summarised below with relevance for end users:

- Set 1: 10-50 m with 68-95% confidence.
- Set 2: 1-3 m with 95-99% confidence – relevant for example with cooperate manoeuvres.
- Set: 0.1-0.5 m with 95-99% confidence – relevant for example to protect vulnerable road users.

These values may not apply to all networks, especially Sets 2 and 3 require specific deployment for absolute positions but they are equally applicable for absolute and relative positioning.

In addition to pure 5G positioning capabilities, 5G also supports a positioning protocol to enable sensor fusion. In turn, the 5G positioning framework serves as a supplemental methodology for GNSS and GNSS correction, and as a sensor data and GNSS correction service conveyor.

5. Vehicle software trends

The digitisation of vehicles is a tremendous megatrend in the automotive industry, as OEMs further explore and embrace developments in electrical/electronic vehicle architecture, feature modularity, and remote software updates. Future vehicle architectures move complexity from hardware to software, enabling cost reductions and customer experience benefits, both key for future differentiation and value creation. As a result of advances in vehicle software, value chain roles and market players are repositioning in what many expect to produce the largest business model transformation in more than a century. The shift toward the 'car of the future' is happening and 5G connectivity is key for this evolution.

This unprecedented combination of state-of-the-art technologies that include sensors, software control functions, cloud/edge computing, and machine learning is already transforming the vehicle into a software-defined digital chassis, enabling continuous provision of new services, features and personalised experiences to drivers and passengers. The future connected car will be able to optimise its own operations and maintenance as well as anticipate the convenience and comfort of its passengers by leveraging on-board sensor data with cloud data sets computed thanks to always-connected advanced mobile connectivity.

With the vehicle software evolution, analysts believe new vehicles will create vast amounts of data with significant impacts on connectivity planning:

- Accenture estimates raw data produced by a vehicle can reach 40 TB/day [20], which can be interpreted as an upper-bound applicable to a subset of the deployed future vehicle fleet.
- McKinsey estimates that by providing end-to-end access – exchanging over the network – to 1-2 TB of raw data per car each day to 'enable continuous product and service improvements' [21] OEMs can better differentiate themselves and monetise connected vehicle data. This may be interpreted as a threshold for unlocking connected-car data monetisation opportunities.

Although today, only a small percentage of the data produced by a car is exchanged with applications via the network, with the greater efficiencies of 5G networks and edge computing, OEMs have a new tool to innovate and create new business value. We will see the emergence of different visions with important implications in terms of opportunities to improve the user experience, future business models for connected and autonomous mobility, and the potential challenges to consider and mitigate.

5.1 Opportunities to improve the user experience with new features

Software will be a key component and enabler of future Autonomous Vehicles (AV). Advances in software enable the latest advancements in automation, sensing, mapping and positioning techniques, and unlock innovation in and with the vehicle, such as the 'intelligent cockpit' (that includes infotainment), digital businesses and new mobility services. Software will allow connectivity, computing and features to enable both sharing and customisation. The global automotive trend is to build standardised hardware to maximise benefits of scale and create differentiation through software. As with similar digital transitions in other industries, we anticipate the majority of future vehicle innovations will be software-related.

The software inside the vehicle will play a strategic role, enabling truly innovative services in terms of user experience that will improve the satisfaction of car ownership (e.g. predictive maintenance), while maintaining a strong connection with the brand and the product. The value of the opportunity will be captured along the multi-year digital life cycle of the vehicle, introducing new recurring revenues. Over-the-Air (OTA) updates will install and update software-based features into vehicles, even those already on the road.

In the Autonomous Driving (AD) field, advances in software provide benefits in terms of asset management (sensors and network), flexibility, scalability, and security. Merging local 'perception' – provided by on-board sensors – of vehicles with information provided by other vehicles' sensors and by the roadside infrastructure (e.g. about obstacles, road surface conditions, and planned manoeuvres) will improve awareness of the surroundings and the overall safety, autonomy and efficiency of the system. This vision will start by enabling autonomous driving functionalities.

Consumer preferences are expected to change as businesses and consumers move toward flexible modes of working and socialising. The combination of local (in-vehicle), edge and cloud computing have the potential to greatly facilitate the delivery and operation of a comprehensive set of applications and services such as:

- **User-centric mobility services**: insurance (pay-as-you-drive), MaaS, payments (parking, tolls, energy), EV services (charging/reservation/battery sharing), navigation/telematics.
- **User-centric non mobility services**: infotainment and integration with existing and emerging ecosystems in the smart home/office environments (via personal assistants), advertising, gaming, videoconferencing, e-commerce/app-stores.
- **Vehicle-centric**: maintenance, fleet management, OTA updates, remote diagnosis/optimisation; safety, time-saving (e.g. smart navigation) and infotainment are seen as major opportunities in all markets.
- **In all cases**, future connected vehicles must manage, store and compute large amounts of data.

We are just starting a transition toward new mobility experiences that leverage customised information based on location, user profile and preferences. In that context, implementing security and privacy compliance will also create additional opportunities. Also in regards to societal transformation and the way vehicles will be owned in the future, OEMs may go into the fleet management business where they can offer transportation services to people who choose not to own a car. These software trends are foreseen to transform vehicles further, as described in Section 6.

5.2 Opportunities to create new business models

The rise of the software-defined vehicle heralds an age of electric, automated and connected driving, with a completely new user experience. The combination of these elements with 5G will offer unprecedented levels of safety and convenience while reducing the sector's carbon footprint. By implementing the right combination of sensors, network and computing resources that perform in all environmental and road conditions, these services can be offered via various business models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS), and Network as a Service (NaaS). In addition to different models of subscription services in the vehicle, we will see new business opportunities in data monetisation, carsharing, insurance and adjacent markets such as aerial transportation and robotics.

On average, automated driving will free up to one hour per day for drivers, unlocking new connectivity-related business models in media and content. Additionally, reducing time spent in traffic (140 hours/year [20]) also lowers the industry's environmental impact. Mobility-as-a-Service (MaaS) opportunities such as carsharing can increase utilisation of vehicles and produce income for its owner, e.g. Turo, Lyft Rentals, and Uber Rent.

According to forecasts by Stellantis [31], by 2030 per-vehicle level connectivity has been estimated at delivering between USD 50-100 per month in additional subscription revenues (e.g. Autonomous Driving as a Service). Moreover, the provision of improved or additional functionalities with OTA is a way the automotive industry is seeking to better monetise the installed base over a vehicle's lifetime – building a deeper customer relationship and generating additional monetisation opportunities at the same time.

The connected-vehicle value proposition counts on the implementation of new digital services and requires technical and connectivity infrastructure both inside and outside the vehicle, split into safety-critical and non-safety-critical functions. Globally, governments have increased investments in infrastructure, but that will not make a drastic difference unless ecosystem partners work together to deliver this vision with 5G.

Large ecosystems are emerging to manage this complexity and share development costs and risks. The environment is still heterogeneous and fragmented. Strategic partnerships and new collaboration models will be crucial to accelerate development and adoption. The role of 5GAA, for instance, can be key to managing this increase in complexity and capturing economies of scale, especially in a connected and autonomous driving scenario.

In this context, software and hardware are evolving in parallel with different life cycles, as vehicle architectures gradually become more simplified and centralised in terms of computing power. Future automotive architectures, leveraging digital service platforms and applications, will be designed around powerful processors, playing a similar role to the previous generation of vehicles that were designed around powertrain performance. This evolution will make it possible to add new/complex features faster and more cost-effectively. Greater standardisation of software and hardware will push down costs. This may lead to commoditisation of vehicle hardware elements, with software and semiconductor components dominating the Bill of Materials (BoM) and capturing a higher share of value.

In addition to improved performance, a software-driven, cloud-connected, centralised architecture will reduce vehicle BoM cost and power consumption. The proportion of electronics in the BoM are predicted by Roland Berger, a management consultancy, to more than double for a premium connected car with electric drivetrain from USD 3,145 in 2019 to USD 7,030 in 2025, compared to a car with an internal combustion engine [32]. Just the market for embedded software in vehicles is forecast to reach USD 35 billion by 2030. This is very relevant, as computing and power requirements of automated systems >L2 are significantly higher than those of L0 to L2.

The automotive industry is leveraging advances in edge and cloud computing to consolidate traditional Electronic Control Units (ECUs) into centralised domains and cloud platforms connected by mobile technologies. This will reduce hardware complexity and costs but also increase software complexity. At the same time, with the traditional long life cycles of the automotive industry, automakers will have to design ‘swappable hardware’ to accommodate future updates and retrofit with OAT updates.

The automotive industry is moving from an era of manual driving to Advanced Driver Assistance Systems (ADAS) and eventually to AD. This shift requires the combination Artificial Intelligence (AI), HD maps, sensors and computing power. Processor performance must also be considered when designing software-based applications. Connected car platforms and operating systems aim to offer users additional value-adding services, both inside and outside the car. In the future, services based on C-V2X communications will be an essential component of these platforms.

5.3 Challenges and risks

The convergence of connected vehicles, AI, and 5G networks will create greater business opportunities but also challenges. With the introduction of new services, the complexity of the ecosystem will inevitably increase.

The challenge for all companies working in this emerging ecosystem is how to effectively combine all these new technologies to improve customer experience while maintaining the high-volume, high-quality, low-cost, consistent and compliant production paradigm that has characterised the auto industry for over a century.

5G networks are expected to support multiple use cases that will tackle new market segments. Hence, 5G is expected to face demands that may have conflicting requirements. Heterogeneous services with diversified requirements will need to be simultaneously supported (e.g. high-bandwidth infotainment services and diagnostics).

The final decision on the 'placement' of data and computing must consider multiple factors, e.g. security, latency, computing power requirements, regulatory considerations, and application energy costs. In multi-stakeholder (multi-OEM/ multi-MNO) environments that require combining in-vehicle and third-party data, the importance of these factors increases.

This multiplicity of use cases is characterised by heterogeneous service and connectivity requirements. Support for connected vehicle use cases will also require standards and federation of the 5G edge, especially in roaming or cross-border scenarios. To guarantee a consistent roaming user experience, a basic set of functionalities covering the main requirements, such as data interfaces (e.g. exchange of raw/processed sensor data, mobility and authentication/ authorization), will need to be agreed between OEMs, mobile operators and third-party companies.

6. Apps and services

In this section we present customer-centric innovations beyond automated driving and safety which can be uniquely enhanced or enabled by 5G. The examples highlighted were sourced by surveying vehicle OEMs and Tier-1 technology suppliers within 5GAA, and include perspectives from respected research groups. These examples and opportunities are presented for those considering investing in 5G modem vehicle integration, R&D and business potential. These examples are intended to be representative rather than an exhaustive list.

6.1 In-vehicle entertainment

In-vehicle entertainment has always played an important role in improving the overall atmosphere for drivers and passengers. As premium-tier media services evolve to high-bandwidth formats, such as 4K/8K video and XR/Metaverse, 4G networks will not be sufficient. Expanded use of 4G network in this way can lead to a bottleneck for mid-tier customers wanting upgraded entertainment, who may then select aftermarket (over-the-top) solutions.

Opportunity

Adding 5G connectivity immediately presents a variety of benefits for entertainment services:

- Unequalled content access to highest-quality media formats [23].
- 5G networks are less congested and users will experience fewer interruptions.
- Enables XR/Metaverse innovations such as Audi Holoride [24]; sub-20 ms latency may improve visual connection.
- Multimedia-interface software updates will complete faster, improving engagement.

6.2 E-commerce and app stores

Drivers and passengers accessing in-vehicle apps and services expect an effortless experience thanks to years of interacting with smartphones. OEMs seek to reflect the seamless smartphone experience and preserve brand identity while delivering (new) commercial offerings such as payments. This enables a deeper vehicle-owner relationship and greater owner flexibility in service selection.

Opportunity

In vehicle e-commerce systems are increasingly adopting extensible operating systems such as Android which provide access to an ecosystem of application developers and services, including the ability to customise app store experiences [25]. 5G enables higher performances for a better app experience and for OEMs provides technical enablers to simplify e-commerce store management including in terms of app communication flow separation (Section 4.3), security, resource allocation, and even billing [26].

- 5G/Edge can prove useful in extending service and capability (multi-player) and offering multiple virtual environments unlimited by the device storage capacity.
- Opportunity for OEMs to monetise/leverage vehicle data and possibly backhaul connection by splitting traditional telematics and new connection to approved service platforms.

6.3 Data orchestration

Accessing telematics sensor data for connected vehicle services has been limited by 4G throughput, scalability, cost and other factors. In Section 4 we summarised analysts' views on connected vehicle data production which has dramatically increased. This trend is driven by EVs and other vehicles becoming more software-defined and having the ability to access sensor data (e.g. camera, LiDAR, GPS/GNSS, and V2X messages). Since most of this data currently stays on-vehicle, data-driven solutions such as remote diagnostics and other C-ITS innovations are restricted. As regulations and privacy requirements for connected vehicles are being defined, data orchestration platforms may become a key value creator for optimising compliance management.

Opportunity

5G higher bandwidth and network efficiencies introduces scope for business models that are no longer linked to the volume but to the type of service. Moreover, vehicle software and MEC may enable 'compute' calculations to be performed closer to the car and in near real time using digital twins and AI/ML – creating a more agile and decentralised approach for providing services to consumer and enterprise fleets.

The development of 5G-oriented data orchestration platforms can support a number of benefits:

- Enhance sensor fusion with cloud/MEC resources to increase signal quality and data modelling.
- Adjacent market innovations, e.g. financial, warranty, insurance.
- Model customer satisfaction with higher accuracy.
- Predictive maintenance [27].
- EV charging network intelligence [28].

6.4 HD maps

High Definition (HD) Maps provide accurate and detailed (cm-level) information about precise positions of traffic lights, signs, barriers, lanes, and possibly dynamic road-user positions. Helping automated driving systems address lateral and longitudinal control, they apply contextual awareness to the surrounding environment and process local road rules to enable safer and proactive driving decisions.

HD Maps are a strong complement to real-time vehicle computing of on-board sensor data (e.g. cameras, radar, LiDAR), which is not enough to master the dynamic road and traffic complexity.-

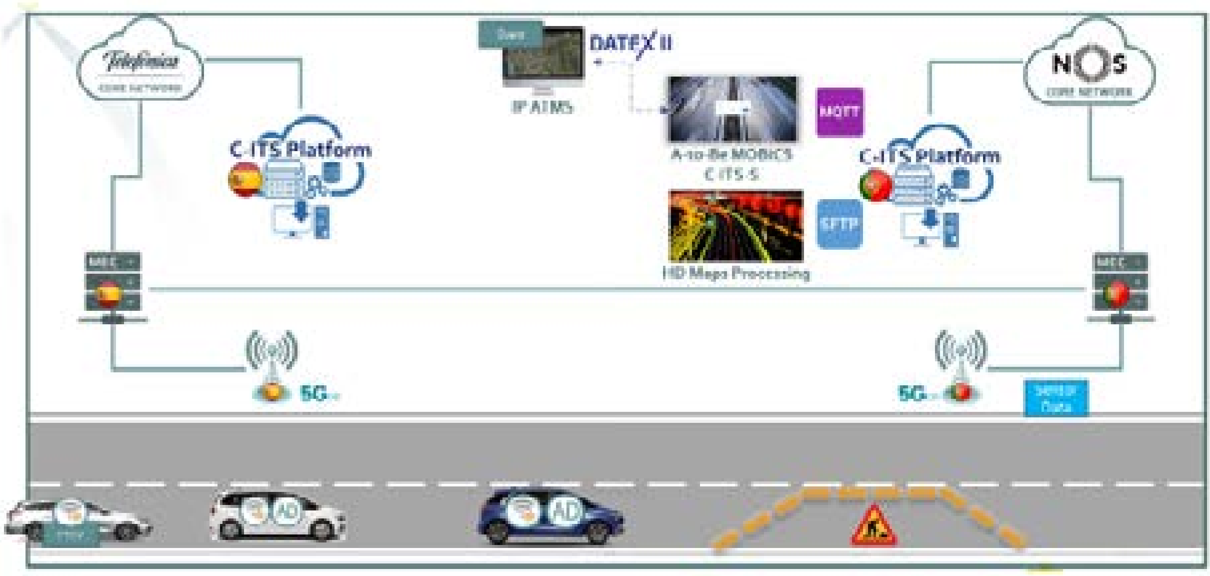

Figure 2 – HD Maps in the 5G-MOBIX Project [26]

Opportunity

HD Maps enhance trust and can help enable automated driving adoption. 5G helps improve the HD Map concept by allowing real-time dynamic map layers to connect and aggregate sensor data from multiple vehicles. 5G enables lower Time-To-Reflect-Reality (TTRR) for HD Maps so they can be a reliable and accurate data source for automotive applications.

Uploading and aggregating vehicle sensor data to the 5G edge/cloud also enables business model opportunities for automakers seeking sustainable cloud-based methods for HD Map services.

OMDIA describes the opportunity presented by HD Maps: "One of the main ways to create HD Maps is by effectively turning vehicles into mapping agents. Cameras, LiDAR, radar, and other vehicle sensors fitted on vehicles can help provide a 360° view of roadways and their surroundings. […] Eventually, it is likely that consumers will have to consent to allow their vehicle and its cameras and sensors to contribute to HD maps, possibly in exchange for reduced tariffs associated with receiving data." [26]

Potential HD Maps use cases and benefits with 5G:

- **HD sensor data sharing for map maintenance** (combining vehicle sensor data with other data sources) will evolve from updates at regular intervals towards near real-time publication (a live map), and hence near real-time upload of events can be expected.
- **HD Map tile downloads** will enable moving vehicles to validate if having a sufficient fresh HD Map at hand for the route ahead, if not it will download tiles with relevant data/layers.
- **HD Map awareness of V2X messages** is essential for cooperative usage of V2X messages, e.g. when receiving a V2X message from an object ahead, the vehicle wants to know if it is on collision course or not, and a HD Map provides valuable 'context' such as vehicle lane/segment.
- **Use of HD Maps to provide additional road context** will emerge as fixed V2X actors/entities (i.e. traffic signals, dynamic speed signs and other roadside infrastructure) increasingly benefit from real-time information. HD Maps can host such content including precise object localisation. This may need industry harmonisation/standardisation.
- **HD Maps used to provide accurate location in V2X messages** as an alternative to GNSS; the HD Map can localise objects and accurately position vehicles on the road. This type of map-based odometry can provide an important accuracy check/indicator for V2X messages. This would also need industry harmonisation/standardisation.

6.5 5G OTA updates

Vehicle software advancement (Section 5) is a major trend in the automotive industry. New software components demand updates for a variety of reasons beyond standard bug fixes and cybersecurity threats, e.g. AI/ML model deployment (for ADAS, energy management, AI-powered assistant, etc.), map cartography, EV battery management algorithm refresh, or other on-board feature updates. Given the wide variety of scenarios it is clear updates will become more frequent and the process for doing them more efficient, thus improving the customer experience. Between 2020 and 2021, Tesla has carried out more than 35% of their recall updates based on OTA [30]. Stellantis, for example, predicts roughly 400 million OTA transactions annually by the year 2030 for its vehicles [31].

Opportunity

For a mobility product such as a vehicle, the best end-user experience for refreshing software components is through a wireless OTA firmware approach, and with 5G this will be greatly improved, minimising interruptions to vehicle and transportation. 5G not only provides better performance (Section 1), but also new features (Section 4) such as Network Slicing which can be used to deploy critical upgrades (cybersecurity correction or recall campaign). Updates can be treated by the network depending on the ‘slice’ parameters, linking service levels (SLA) to a business model. This takes the current connectivity paradigm beyond being based purely on large data exchanges.

Updating vehicle software remotely substantially reduces the need for costly maintenance recalls, with more than 15 million vehicles ~~were~~ recalled for Electronic Component defects in the US in 2019 (Stout, 2020), and around 70% of vehicles affected by software-related defects. This is why OEMs and suppliers increasingly employ OTA software updates and recalibrations to remedy defects previously requiring the repair or replacement of vehicle components in a workshop/garage. Moreover, the recent introduction of Cybersecurity Regulation UNECE WP.29/R155 and ISO23434 have made OTA mandatory for security and high-priority safety patching.

Background Data Transfer with 5G (Section 4.2) allows vehicles to utilise the network more efficiently; helping to lower tariffs for OTA and map updates, as non-urgent downloads can be performed off-peak. The OEMs and/or final users are more willing to pay for an urgent cybersecurity update or new driving feature compared to a non-critical SW update (e.g. map update) without a strict time requirement. Today, such updates are handled by repair shops, delivered over WiFi, or transferred by the customer using a USB. With BDT and OTA, there is a win-win approach for the ecosystem: OEMs reduce costs, the user experience improves, and it creates new revenue opportunities for MNOs.

6.6 AI-powered on-board virtual services

Interacting with smart vehicles through a conversational interface optimises safety and comfort, allowing the driver to maintain visual connection with the road environment. Virtual Personal Assistant (VPA) services use conversational AI models to integrate data across digital platforms (vehicle, smartphone, connected home). Automatic Speech Recognition (ASR) machine-language models vary in size and will have to evaluate trade-offs between using local capabilities versus relying on a 5G network/cloud alternative, to create the best user experience. Enabling VPAs to take advantage of new data sets such as C-V2X messages, and high-bandwidth sensor data is an ongoing challenge and opportunity for service providers seeking to innovate beyond providing timely and accurate driver guidance.

Developments in VPA technology open up new possibilities for advanced solutions across domains. Virtual assistants can be used to power home or office devices and perform complex tasks, such as checking on the status of devices, shutting and opening doors, turning on the lights and air-conditioning, reading news, finding restaurants, sending emails and messages, opening applications, playing songs, etc.

The virtual assistant applications can improve customer engagement and experience as they can provide a more efficient way of handling administrative tasks with reduced human effort, while creating new monetisation opportunities.

Opportunity

5G networks can provide enhancements which directly support the success of AI-powered services:

- Lower latency for accessing cloud data sources and inference engines which power VPAs. BMW has introduced an Intelligent Personal Assistant (IPA) as part of the iDrive 8 system, which is considered to communicate more naturally to users. iDrive is an integrated solution, hosted on-board the vehicle and 5G is used to ensure that the system is always up to date [33].
- Higher throughput for updating local data quickly, e.g. ASR ML-models.
- Edge cloud/MEC for optimising training and inference time [34].
- Federated and distributed learning (note that a privacy-preserving AI architecture is being studied in 3GPP Rel-18 and optimisations are expected in an upcoming 5G release) [44].

6.7 Live sensor signal sharing

As vehicles are increasingly fitted with cameras and other sensors, there is an opportunity to maximise value by sharing data insights in both real-time and non-real-time scenarios, such as:

- Automated driving and assistance e.g. live video sharing [35, 36].
- Parking and accident/insurance claims.

- Remote vehicle monitoring to reduce and prevent vandalism or theft.
- Communicating public services and road status in the event of incidents so vehicles, first responders, road operators and authorities, etc. are better able to determine tactics as they approach the site.

Opportunity

Modern vehicles generate and use a vast amount of data. In-vehicle sensors can deliver real-time intelligence about the vehicle itself and its immediate surroundings. This information can generate substantial value if applied to use cases outside of the vehicle.

Using 5G to distribute video streams while safeguarding data privacy is a significant way to enable business model innovation by taking advantage of the greater network efficiencies. Storing and analysing sensor data that can be used by third parties will be an essential component of future vehicle services. Some examples are described below:

- Tesla streams live video from its vehicles through its Sentry Mode service, enabling drivers to view their immediate surroundings on a smartphone app [37].
- Veoneer (with Ericsson and Volvo) have demonstrated how on-board cameras on a vehicle involved in a simulated incident share video to an approaching emergency vehicle, enabling first responders to plan their response [38].

6.8 WiFi hotspot

Vehicle passengers like to use personal devices principally for infotainment applications which have various data requirements, from high-volume (high-quality movies) to low-latency (gaming). Many infotainment devices, such as those for gaming, do not have embedded cellular modems and can only use Wi-Fi connectivity. The in-vehicle Wi-Fi hotspot is connected via a cellular network with internet.

Opportunity

5G's coverage and performance have improved such that users connected to the vehicle Wi-Fi hotspots can expect a much better experience with higher throughput and lower latency, creating value opportunities. Similarly, terminals not supporting 5G can then connect to the vehicle Wi-Fi hotspot and benefit from the 5G performance to connect to the internet.

7. Conclusion

At the end of 2022, operators in 85 countries have deployed 5G [7], enabling society to benefit from the massive connectivity, higher throughput, lower latency, and improved energy efficiency (Section 3). Through deployments of newly allocated spectrum (with coverage obligations), and in some cases re-farmed legacy spectrum, it is clear 5G is already a global success and the future of mobile connectivity.

Lessons from the past indicate that a new cellular 'generation' occurs roughly every decade and may be operational for more than 20 years. With an average vehicle lifespan beyond ten years, 5G already offers the best connectivity option for automotive transformation and future business innovation. Millions of connected vehicles will use 5G as the most trusted wireless alternative to communicate securely and reliably in real time. Latencies of milliseconds for a massive number of concurrent users in the same area can be enabled for traditional as well as mission-critical services.

A major advantage of 5G, thanks for its cryptographic-based security, is that identity and integrity are embedded in all vehicle communications, thus better enabling a trusted V2X experience and facilitating secure communications between vehicles and infrastructure. Based on a secure network foundation, 5G further offers communications integrity and confidentiality with strong privacy protection. In the digital transformation of the automotive sector, this added security will help ensure reliable car-to-cloud communications, lowering the risk of adopting new business models and enabling economic development.

By integrating 5G connectivity in upcoming vehicles now, OEMs can leverage new network functionalities and APIs (Section 4) such as edge computing, network slicing, regional breakout and precise positioning. These high-performance data-exchange APIs enable seamless user experiences between the car (on-board) and the outside (off-board) worlds.

Across the vehicle lifecycle, 5G offers the connectivity needed for value creation in alignment with software-defined vehicle trends (Section 5). The integration of software-defined vehicles within a 5G ecosystem will enable OEMs access to innovative service delivery platforms for improving the user experience and for new business models (Section 5.1, 5.2).

Without 5G, OEMs risk missing out on opportunities to move features from the car to the cloud, create subscription services, or deliver software and AI/ML model updates efficiently. Many additional apps and services (Section 6) – beyond safety and automated driving – benefit from 5G such as in-vehicle entertainment, e-commerce, data orchestration, HD Maps and more.

A new industry paradigm connecting software-defined vehicles to cloud/edge resources has been established and, as 5G is adopted at scale by OEMs, user experiences will be greatly improved, creating new revenue opportunities and more agile service delivery.

Annex A: Industry example – CARIAD

CARIAD is the software technology innovation centre of the Volkswagen Group [39]. By 2030, it aims to connect up to 40 million vehicles globally to its own Automotive Cloud. As an example of the trend, **R&D investments by VW's Automotive Division increased to EUR 4.4 billion in Q1 2022** (8.5% over revenues) due to significant development activities on electrification and digital technologies. By leveraging Volkswagen Group's global fleet size and making use of its data, CARIAD will develop and continuously improve the quality and coverage of the software-based services around three key priorities [40]:

- OTA upgrades.
- High-end software platform featuring an infotainment system based on Android, as well as an ADAS in around 2023.
- Unified software platform for all VW brands in around 2025; the Group plans to roll out a Level 4 system in the middle of the decade.

At a press conference, CARIAD presented one of its recent innovations, the 'Rainbow' project. This initiative aims to adjust the digital experience of the vehicle to match the outfits (clothing) of passengers, such as by changing the desktop theme, the colour of the ambient light, as well as the greetings and music.

This is a good example of an agile (reducing the development cycle of new applications), integrated (across all the brands of the group) and data-driven approach (to enable AI and simulations) that is developed around core software capabilities.

5GAA bridges the automotive and telecommunication industries in order to address society's connected mobility and road safety needs with applications such as automated driving, ubiquitous access to services and integration into intelligent transportation and traffic management. For more information such as a complete mission statement and a list of members please see http:/5gaa.org/

5GAA Automotive Association