ENVELOPE

Evaluation and validation of connected mobility in real open systems beyond 5GS

Project deliverable D7.1

# Market and actor-role analysis

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## Legal Disclaimer

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# Project executive summary

ENVELOPE aims to advance and open the reference 5G advanced architecture and transform it into a vertical-oriented one. It proposes a novel open and easy-to-use 5G-advanced architecture to enable a tighter integration of the network and the service information domains by

- exposing network capabilities to verticals,
- providing vertical information to the network; and
- enabling verticals to dynamically request and modify key network aspects,

all performed in an open, transparent, and easy-to-use, semi-automated way.

ENVELOPE will build APIs that act as an intermediate abstraction layer that translates the complicated 5GS interfaces and services into easy to consume services accessible by the vertical domain. The project will deliver an experimentation framework that will facilitate vertical services in accessing a series of innovations developed in the project, namely: edge computing with service continuity support (federation/migration), zero-touch management, multi-connectivity, dynamic slicing and predictive QoS.

ENVELOPE will deliver 3 large scale Beyond 5G (B5G) trial sites in Italy, Netherlands and Greece supporting novel vertical services, with advanced exposure capabilities and new functionalities tailored to the services' needs. Although focused on the Connected and Automation Mobility (CAM) vertical, the developments resulting from the use cases (UC) will be reusable by any vertical. The ENVELOPE architecture will serve as an envelope that can cover, accommodate, and support any type of vertical services. The applicability of ENVELOPE will be demonstrated and validated via the project CAM UCs and via several 3rd parties that will have the opportunity to conduct funded research and test their innovative solutions over ENVELOPE.

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# Deliverable executive summary

This deliverable investigates the business aspects of the ENVELOPE solutions. Towards this direction, three different types of activities are performed: market analysis, definition of ENVELOPE's ecosystem and road-mapping.

The first step in this endeavour is to assess the current status of the market, for each ENVELOPE component, through a market analysis. For each component, the same extensive set of data is provided; among others market size and growth, as well as the factors contributing to the potential growth of the market. Information about market players and competitive products is also included. The fact that all the studies from market research firms forecast significant growth in all the relevant markets is very promising for the potential impact of ENVELOPE.

Ecosystem analysis contextualizes ENVELOPE in a wider ecosystem to understand how it can serve as a unifying solution and its value proposition. Existing and new players are described along with their relationships and revenue streams. The incentives and benefits from the ENVELOPE platform are identified for each role in the ecosystem.

In the framework of the road-mapping activity, the factors affecting market adoption and evolution of ENVELOPE solutions are identified and assessed by experts using the Analytic Hierarchy Process (AHP). A survey is conducted to evaluate the relative importance of these factors and prioritise them. The survey has been correctly completed by 36 experts from several European countries belonging to a variety of different sectors including industry, Small and Medium Enterprises (SMEs), research institutes and academia while having a professional background in telecommunication and Cooperative, Connected and Automated Mobility (CCAM) technologies. The derived results show that the 'Technical Features' criterion is the most important one followed by 'Acceptance / Flexibility'; whilst "Business and Strategy" criterion has the lowest weight. Based on global priorities, the most weighted sub-criterion is that of 'Market growth opportunities' followed by 'Service continuity in cross-domain environments', 'Secure data transfer (Security and Privacy)', 'Scalability' and 'Compliance to standards and specifications'.

# List of abbreviations and acronyms

| Acronym | Meaning |
|---|---|
| **2FA** | Two-Factor Authentication |
| **3GPP** | 3rd Generation Partnership Project |
| **5GAA** | 5G Automotive Association |
| **5GC** | 5G Core |
| **ADAS** | Advanced Driver Assistance Systems |
| **AF** | Application Function |
| **AHP** | Analytical Hierarchy Process |
| **AI** | Artificial Intelligence |
| **AnLF** | Analytics Function |
| **APAC** | Asia-Pacific |
| **API** | Application Programming Interface |
| **APM** | Application Performance Monitoring |
| **AS** | Application Service |
| **ATSSS** | Access Traffic Steering, Switching and Splitting |
| **AUTOSAR** | Automotive Open System Architecture |
| **AV** | Autonomous Vehicle |
| **BSS** | Business Support System |
| **CAM** | Connected and Automated Mobility |
| **CAGR** | Compound Annual Growth Rate |
| **CAPIF** | Common API Framework |
| **CAV** | Connected and Automated Vehicle |
| **CCAM** | Connected, Cooperative and Automated Mobility |

| | |
|---|---|
| **CPaaS** | Connectivity Platform as a Service |
| **CSP** | Communication Service Provider |
| **CV** | Cooperative Vehicle |
| **CVIS** | Cooperative Vehicle Infrastructure Systems |
| **E2E** | End-to-end |
| **EaaS** | Experimentation as a Service |
| **EC** | European Commission |
| **GNSS** | Global Navigation Satellite System |
| **HiL** | Hardware-in-the-Loop |
| **iCORA** | Innovative, Cloud-native, Open, Robust, and Automated |
| **ICT** | Information and Communications Technology |
| **IIoT** | Industrial Internet of Things |
| **IoT** | Internet of Things |
| **IQN** | In-advance QoS Notifications |
| **ISO** | International Organization for Standardization |
| **ITS** | Intelligent Transport Systems |
| **KER** | Key Exploitable Result |
| **MaaS** | Mobility-as-a-Service |
| **MCS** | Multi-Connectivity Support |
| **MiL** | Model-in-the-Loop |
| **ML** | Machine Learning |
| **MTLF** | ML Training Function |
| **MNO** | Mobile Network Operator |
| **MPN** | Mobile Private Networks |

| | |
|---|---|
| **MVP** | Multi-Vendor Platform |
| **NaaS** | Network-as-a-Service |
| **NCAP** | New Car Assessment Program |
| **NEF** | Network Exposure Function |
| **NoW** | Networks on Wheels |
| **MWDAF** | Network Data Analytics Function |
| **OBU** | On Board Unit |
| **OEM** | Original Equipment Manufacturer |
| **OSP** | Open-Source Platform |
| **OSS** | Operating Support System |
| **OTA** | Over The Air |
| **pQoS** | Predictive Quality of Service |
| **QoS** | Quality of Service |
| **ROM** | Reduced Order Model |
| **RSU** | Roadside Unit |
| **RTO** | Research and Technology Organisation |
| **RTA** | Roads and Transport Authority |
| **SDV** | Software Defined Vehicle |
| **SNS JU** | Smart Networks and Services Joint Undertaking |
| **SME** | Small and Medium-sized Enterprises |
| **SiL** | Software-in-the-Loop |
| **SLA** | Service Level Agreement |
| **TaaS** | Testing as a Service |
| **TfL** | Transport for London |

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|---|---|
| **TMC** | Traffic Management Center |
| **TRL** | Technology Readiness Level |
| **URLL** | Ultra-Reliable Low-Latency |
| **URSP** | UE Route Selection Policy |
| **V&V** | Verification and Validation |
| **VRSU** | Virtual Roadside Units |
| **V2V** | Vehicle-to-Everything |
| **WAN** | Wide-Area Network |
| **ZTM** | Zero-Touch Managament |
| **ZTP** | Zero-Touch Provisioning |

# 1 Introduction

## 1.1 Purpose of the deliverable

This deliverable presents the work undertaken in T7.1: Market research and actor-role analysis. The objectives of this deliverable are the following:

- Perform a market analysis by:
  - identifying the size and growth of relevant markets;
  - identifying the drivers, challenges and opportunities for each market;
  - deriving some regional insights;
  - identifying the main players in each market and competitive products (if possible).
- Define the ecosystem that will interact with the ENVELOPE solutions, that is all the involved actors and roles, their relationships and revenue streams as well as potential service delivery options.
- Identify the factors that will affect the market adoption and evolution of ENVELOPE.

Readers will benefit from a deeper understanding of the ENVELOPE solutions potential to address complex CAM needs through tailored, innovative APIs and functionalities. The deliverable concludes by emphasizing ENVELOPE's strategic advantages in promoting cost efficiencies, regulatory compliance, and secure data transfer, making it a compelling tool for more efficient modern telecom and CAM industries. The analysis and roadmap outlined here will provide valuable insights into ENVELOPE's expected impact and evolution, supporting stakeholders in making informed decisions about its integration and long-term value.

## 1.2 Intended audience

The dissemination level of D7.1 is 'public' (PU) and available to members of the consortium, the European Commission (EC) Services and experts outside the project. This deliverable can be used by both ENVELOPE partners and other stakeholders involved in both the telecom and CAM industries, since it provides useful guidelines for ENVELOPE's solutions exploitation. It can also serve as a baseline for both the business modelling activity and the techno-economic analysis that will be performed in the same work package.

## 1.3 Structure of the deliverable and its relationship with other packages/deliverables

This document is structured as follows:

- In Section 2, the results of the analysis for the markets related to the ENVELOPE technical Key Exploitable Results (KERs) is presented.
- In Section 3, the ecosystem around ENVELOPE is presented: the roles and the actors are defined along with their interactions. The main benefits of ENVELOPE for each of the actors are given.
- In Section 4, the results of an online survey regarding the ranking of the factors that will affect the market adoption and evolution of ENVELOPE solutions are discussed.
- In Section 5, the concluding remarks are provided.

# 2 Market Analysis

In this section, the market of each of the ENVELOPE technical Key Exploitable Results (KERs) is presented. For each market component, we perform an analysis of its i) dynamics, ii) regional characteristics, iii) segmentation, and iv) competition. Market dynamics include drivers, challenges and opportunities. Drivers are underlying elements or conditions that significantly affect the direction, speed, and nature of changes within a market environment. Challenges are factors or conditions that create difficulty, uncertainty, or resistance to change within a market, limiting the ability of businesses to compete effectively or achieve sustained growth. Opportunities are external or emerging factors that have the potential to positively impact a market or business, allowing for expansion, differentiation, or value creation. Regional market insights are analytical observations and data-driven findings that reveal how a market functions within a specific geographic region, highlighting local consumer behavior, competitive landscape, regulatory environment, and economic conditions. Moreover, market segmentation is the process of dividing a broad target market into smaller, more manageable subgroups of consumers who share similar characteristics, needs, or behaviors. This allows businesses to tailor their products, services, and marketing strategies more effectively to meet the specific needs of each segment. Finally, competitive landscape refers to the structure and nature of competition within a particular market or industry. It includes an analysis of the key players, their market positions, strategies, strengths and weaknesses.

## 2.1 Predictive Quality of Service (pQoS)

Predictive Quality of Service (pQoS) as a service mechanism delivers in-advance QoS notifications (IQNs) to notify consumers about anticipated QoS changes, by integrating data from mobile network operators and service providers. It combines cross-layer insights from the UE, network, and application layers, and leverages machine learning (ML) for accurate predictions. Thus, it enables proactive reconfigurations, allowing the adjustment of application behaviour, enhancing reliability, optimizing performance, and improving service efficiency.

pQoS is a key innovation in the automotive sector, using AI, ML, and real-time data analytics to anticipate network conditions and increase vehicle performance. This mechanism plays a crucial role in network reliability for connected vehicles by forecasting network performance. This enables adjustments in automotive applications, including autonomous driving and infotainment systems, enhancing user experience and overall operational efficiency. Proposed by the 5G Automotive Association (5GAA) [1], pQoS supports vehicle safety by forecasting network disruptions, enabling proactive adjustments to maintain critical safety functions and minimize accident risks. It also improves vehicle performance by enabling real-time system adaptations by dynamically adjusting application behaviour based on predicted network conditions.

The exploration of pQoS could lay the groundwork for further research, scientific papers, consultancy and pQoS service development.

pQoS can be related with the global automotive predictive technology market (related to the usage of real-time data from sensors and infrastructure to enhance safety, predict risks, and optimize performance) that is experiencing significant growth. According to a report published by Market

Research Future [2], this market is projected to grow from 14.37 USD billion in 2025 to 39.89 USD billion by 2034, reflecting a compound annual growth rate (CAGR) of approximately 12.12% over the forecasted period. This is reflected in Figure 1.

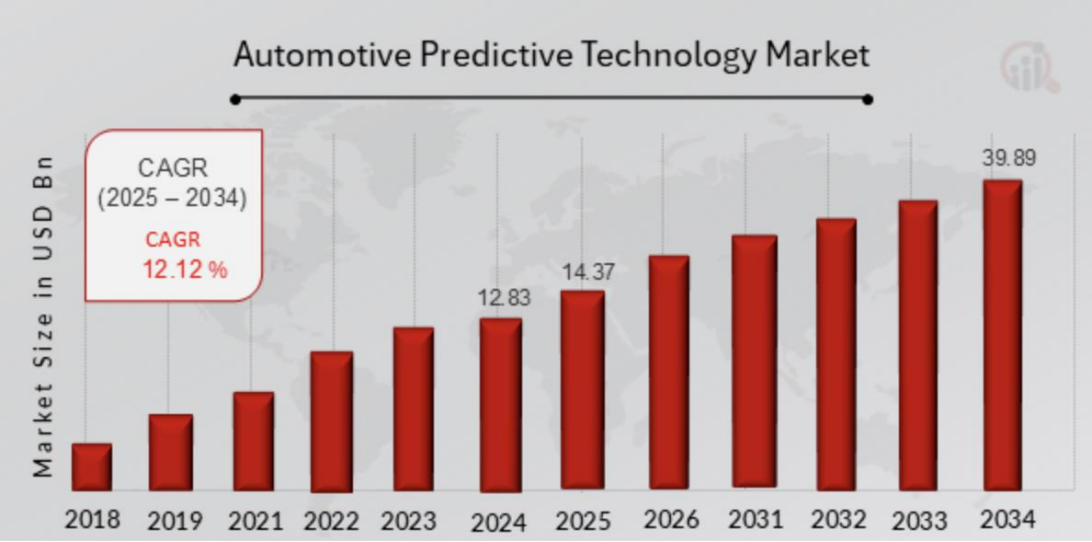


Figure 1: Automotive predictive technology market size in USD Bn. (Source [2])

ENVELOPE is focused on the usage of connectivity data (related to 5G RAN and Core network infrastructure) and application data, gathered through innovative APIs, to drive the training and inference of pQoS, thereby supporting the growth of the predictive technology market.

### 2.1.1 Market dynamics

In the following sub-sections, the drivers, challenges and opportunities around the pQOS specific market are provided.

#### 2.1.1.1 Drivers

- Autonomous vehicle advancement: The progression toward higher autonomy levels necessitates predictable network performance for safety-critical functions.
- 5G infrastructure deployment: The acceleration towards deployment of 5G SA networks across Europe, with the integration of ultra-reliable low-latency communications capabilities, provides the technological foundation for effective pQoS implementation.
- Enhanced road safety: Automotive predictive technologies aim to drastically reduce accidents resulting from human error, making roads safer.
- EU and national initiatives: Governments' regulatory support promoting vehicle safety and emission reductions and substantial funding from the European Commission for related research are driving the advancement of automotive predictive technologies, creating a strong foundation for market growth.

#### 2.1.1.2 Challenges

- Cross-industry standardization: Harmonizing standards between automotive and telecommunications sectors presents ongoing integration challenges.

- Geographic coverage inconsistency: Uneven 5G deployment creates regional disparities in pQoS effectiveness.
- Data collection and management: To achieve high accuracies in QoS predictions it is required to collect and manage significant amount of data from vehicles as well as from the network infrastructure, considering multi-provider scenarios. Highly scalable, flexible and cross-provider data collection and management capabilities have to be implemented to expose accurate AI-driven data analytics.
- Data security: pQoS information exchange, including different data owners such as mobile network operators (MNOs) and original equipment manufacturers (OEMs), faces cybersecurity risks, emphasizing the need for robust measures to protect the security and privacy of data.

#### 2.1.1.3 Opportunities

- AI/ML advancement: Ongoing innovations in machine learning algorithms improve prediction accuracy and response mechanisms.
- AI-as-a-Service: pQoS becomes a key enabler for the implementation of AI-as-a-Service solutions for the automotive sector, as it can exploit heterogeneous data to realize and expose tailored AI services (even beyond pQoS).
- Data monetization: The data generated presents opportunities for data-driven services and valuable insights, creating potential revenue streams through data monetization.
- Edge computing integration: Integrating pQoS with edge computing reduces latency and enables faster response times for critical applications.

### 2.1.2 Regional market insights

The global market of automotive predictive technology is mainly dominated by three regions: Asia-Pacific, Europe and North America [3]. Amongst them, Asia-Pacific has the largest market share which is largely fed by the high sales volume of automotives and the fast technological adoption from countries like China. The powerful manufacturing capacity of the area and the investments in smart mobility solutions continue to drive significant growth of automotive predictive technologies.

Europe follows in the second place, benefited by its strong base of top automotive manufacturers and the increasing emphasis on improving vehicles' safety and performance of automotives through advanced technologies. The region rapidly adopts predictive solutions in new vehicle models supported by favorable regulations and innovation-based policies. North America ranked in third place with the growth of its market to be driven by the presence of significant technological companies and the specific focus on the development of autonomous cars. This collaboration between automotive and technology sectors supports the continuous adoption of predictive systems in the whole region.

### 2.1.3 Market segmentation

Regarding the characteristics of the pQoS mechanism, a market segmentation is considered below. However, it is important to note that pQoS is still in its initial phase of development. The

reason is the restricted access (by MNOs) to real-time network data and analytics, preventing integration of pQoS mechanism with existing mobile infrastructure. The main parts of the possible segmentation are the following:

- By vehicle type: pQoS can be applied to various vehicle types, including passenger cars, commercial fleets, and autonomous vehicles.
- By application: pQoS can support various applications such as autonomous driving, real-time vehicle diagnostics, infotainment and V2X communication.
- By service provisioning models: pQOS has two service provisioning models: a) MNO based in which data aggregation, analysis, training and inference occur within the MNO's infrastructure and b) over-the-top, where these processes are performed by an external third-party outside MNO's network.

### 2.1.4 Market Maturity

The automotive predictive technology market is experiencing rapid growth, driven by technological advancements and rising adoption rates. While certain regions and applications have reached maturity, continuous innovations are expanding the market's potential. The pQoS market, still in its early growth stage, has established core specifications within 3GPP standards (especially Releases 16[1] and 17[2]). However, the practical implementation across vehicles and networks is still evolving.

In particular, while there are several commercial products available in the market that offer advanced connectivity and analytics services for connected vehicles, (e.g., fleet management products such as AWS IoT FleetWise [4] or Bosch CCU [5]) the integration with innovative network data analytics services, like those potentially offered by solutions based on pQoS, are still not available. This is also due to the current lack of network capabilities exposure offered by MNOs towards application providers and verticals, even if recently with the CAMARA and GSMA Open Gateway initiatives this is improving. This represents the technological and market gap that pQoS aims to fill, positioning as key solution to be integrated into mobile network infrastructures to offer added value network data analytics services.

### 2.1.5 Competitive Landscape

#### 2.1.5.1 Main competitors

pQoS is a solution that fits the MNO needs in terms of exposure of their network capabilities and AI-driven analytics towards application providers and verticals in general, while it targets the automotive sector (and in particular car manufacturers or automotive service providers) as end-consumer. For this reason, the main competitors for the pQoS solution are preliminarily identified

[1] https://www.3gpp.org/specifications-technologies/releases/release-16

[2] https://www.3gpp.org/specifications-technologies/releases/release-17

in those technology and service providers that typically engage with MNOs to offer them added-value products and services to exploit their network infrastructure. In particular, competitors can range from telco vendors, such as Ericsson and Nokia, that could leverage on their well-established engagement with MNOs, to hyperscalers, such as AWS, that can leverage on pervasive edge/cloud infrastructure and AI-driven applications portfolio to act as application-to-network bridge for advanced functionalities like pQoS.

Finally, given the nascent stage of the pQoS market where only preliminary assessments are possible, third parties—such as car manufacturers—could also emerge as competitors. They can develop predictive solutions using application-level data and other available information without relying on MNO-owned network data. While their predictions may be less accurate, they avoid costs associated with MNO data usage.

#### 2.1.5.2 Competitive products

At this point in time, also given the current lack of network capabilities exposure offered by mobile network operators (especially in the area of connectivity and QoS insights), the market does not see yet competitive products (i.e. high-Technology Readiness Level (TRL) solutions) offering functionalities similar or comparable with pQoS. However, as stated above in the identification of main competitors, competitive products may soon arise from car manufacturers, technology providers and service providers.

#### 2.1.5.3 Innovations (advantages) compared to existing products/services

The core innovation of pQoS technology lies in its proactive approach to connectivity management. By leveraging machine learning, environmental sensing, and network telemetry, the system can anticipate connectivity issues in advance, providing time for systems to adjust accordingly. This represents a shift from reactive to proactive management, delivering substantial benefits for safety-critical applications. Moreover, the proposed pQoS adopts the 3GPP standards related to network data analytics functionalities [6], aligning with the 5G network data analytics function (NWDAF) APIs, services and functional split into analytics function (AnLF) and ML training function (MTLF). This allows to facilitate the integration within mobile network infrastructures.

The pQoS mechanism introduces several advancements:

- Proactive network management: Enables vehicles to anticipate and adapt to network changes, ensuring uninterrupted connectivity.
- Enhanced safety protocols: Predictive capabilities allow for real-time adjustments to potential hazards, improving overall safety.
- Optimized user experience: By forecasting network conditions, vehicles can adjust infotainment and navigation systems for a seamless experience.

### 2.1.6 Conclusions

The pQoS market is set for substantial growth, tackling key network reliability challenges, especially in the automotive sector. By leveraging machine learning, cross-layer data insights, and real-time

analytics, pQoS enhances vehicle safety, optimizes performance, and ensures seamless connectivity for advanced technologies like autonomous driving, smart infotainment, and driving innovation in intelligent transportation systems.

The market landscape for pQoS aligns with the broader automotive predictive technology sector, which is projected to experience strong growth, driven by advancements in 5G infrastructure, AI/ML innovations, and increasing regulatory support for connected vehicle safety. However, challenges such as cross-industry standardization, geographic disparities in 5G deployment, and data security concerns must be addressed for successful adoption.

## 2.2 Multi-connectivity Support

Multi-Connectivity Support (MCS) is the technological enabler allowing devices or systems to simultaneously leverage and be connected to multiple network connections—such as 5G, LTE, Wi-Fi, and Ethernet—in a seamless and efficient manner. This solution aims to increase reliability, optimize bandwidth usage, and ensure uninterrupted service by dynamically selecting or combining the best connectivity options available. MCS is particularly relevant in high-demand environments, such as industrial IoT, autonomous systems, and remote operations, where latency and reliability are critical.

MCS is expected to offer:

- Network Reliability: By supporting multiple connections, MCS offers communication redundancy and mitigates the impact of a single network's downtime or congestion.
- Reduced Latency & Better Throughput: Combining different networks can lead to higher aggregated bandwidth and lower latency.
- Scalability for Growing IoT Ecosystems: As the number of connected devices increases, MCS ensures networks can handle higher data demands.
- Seamless User Experience: Users can transition between different networks without service interruption.

MCS will be incorporated in ENVELOPE's Greek trial site, where the Connected and Automated Mobility (CAM) applications will be given the choice to trigger multi-connectivity. The in-depth MCS study can serve as a foundation for future research projects and scientific publications.

MCS, despite being in its early growth stage, is a key component of the rapidly expanding Wireless Connectivity Market. According to a report by Straits Research [7], this market was valued at approximately USD 94 billion in 2024 and is projected to grow at a 13.3% CAGR from 2025 to 2033. As per a report by Precedence Research [8], "The global wireless connectivity market size was estimated at USD 103.87 billion in 2024 and is predicted to increase from USD 118.32 billion in 2025 to approximately USD 373.00 billion by 2034, expanding at a CAGR of 13.64% from 2025 to 2034. Figure 2The rising demand for the wireless connectivity by the various end-use industries like automotive, consumer electronics, aerospace, and others that driving the growth of the market." This trend is reflected in Figure 2.

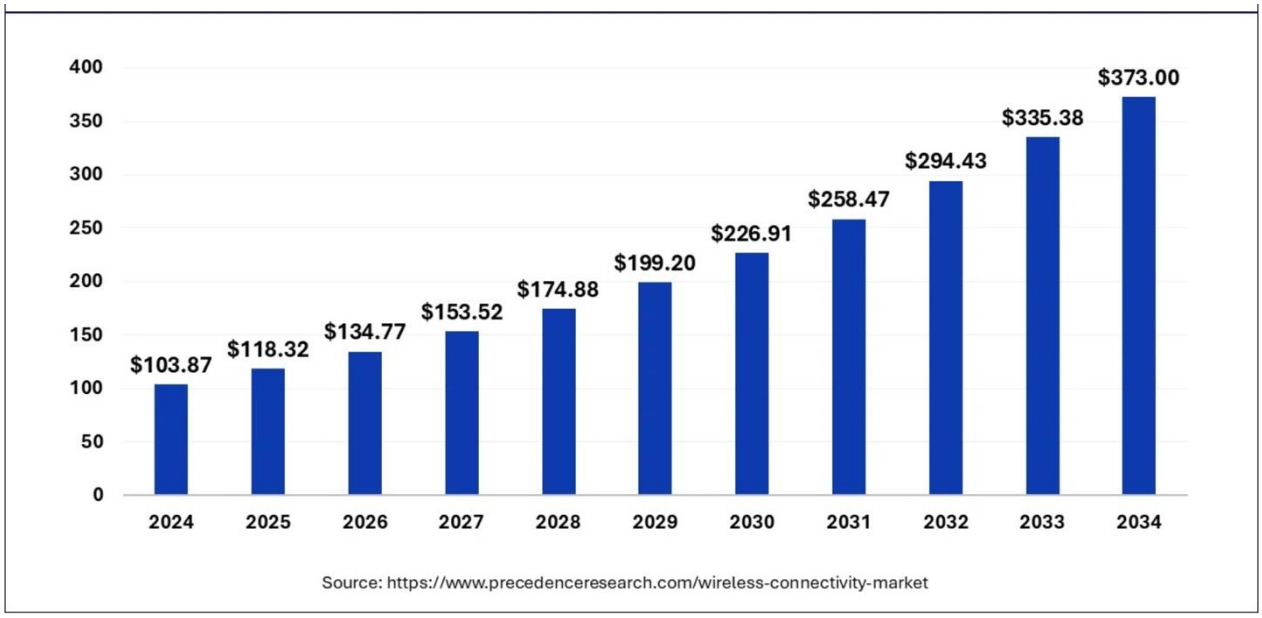


Figure 2: Wireless connectivity market size 2024 to 2034 in USD Billion (source [8])

### 2.2.1 Market Dynamics

In the following paragraphs, the drivers that will boost the growth of the specific market along with the potential challenges and opportunities are presented.

#### 2.2.1.1 Drivers

- Rapid expansion of IoT devices requiring robust and reliable connectivity.
- Growing demand for uninterrupted, high-speed internet in both consumer and enterprise environments.
- Emergence of Industry 4.0, requiring advanced networking solutions for smart factories and automated processes.

#### 2.2.1.2 Challenges

- Complexity of integrating multiple network interfaces and protocols.
- High initial costs for equipment and deployment.
- Regulatory constraints in certain regions concerning spectrum usage and network licensing.

#### 2.2.1.3 Opportunities:

- Development of new vertical-specific solutions (e.g., healthcare, automotive).
- Partnerships between telecommunication providers and technology companies to offer integrated solutions.
- Demand for edge computing and real-time analytics driving multi-connectivity adoption.

### 2.2.2 Regional Market Insights

The wireless connectivity technology market can be categorized by region into Asia Pacific, Europe, North America, and Latin America and Africa [7], [9]. Asia Pacific region leads with a 15% CAGR, driven by affordable electronics, smart technologies, and government smart city initiatives. Rising demand for smartphones, wearables, and advancements in automotive and healthcare sectors further fuel regional market growth and investment opportunities. Europe's wireless technology market is shaped by strict regulations that often drive innovation but may also pose barriers to market entry. A growing emphasis on sustainability is accelerating the adoption of eco-friendly connectivity solutions. North America: North America, with an 11.5% CAGR and a USD 74.5 billion market, drives global growth through technological advancements, innovations, investments, and rising adoption of portable technologies across various applications. In addition, wireless connectivity in Latin America and Africa is still developing but demonstrates strong growth potential. Mobile network operators are increasingly investing in wireless technologies to serve previously underserved communities.

### 2.2.3 Market Segmentation

- By Industry:
  - Manufacturing (Industry 4.0)
  - Transportation & Logistics
  - Healthcare
  - Smart Cities & Public Utilities
  - Consumer Electronics & Wearables
- By Deployment Type:
  - On-Premise (Local enterprise networks)
  - Cloud-Based (Services integrated at the network edge or in the cloud)
- By Connectivity Standard:
  - 5G/LTE
  - Wi-Fi 6/6E/7
  - LPWAN (LoRa, Sigfox, NB-IoT)
  - Satellite/Other specialized networks

### 2.2.4 Market Maturity

Although multi-WAN connectivity has existed for years, widespread multi-access 5G technology is still emerging. Growing use cases in industrial IoT, telecom, and automotive are rapidly pushing adoption forward (Early Growth Stage).

Many companies are developing advanced hardware and software to handle network switching, load balancing, and data analytics in real time (Ongoing R&D).

Industry bodies (e.g., 3GPP, IEEE) are active in defining interoperability standards for multi-connectivity solutions, ensuring a more mature ecosystem in the near future (Standardization Efforts).

## 2.2.5 Competitive Landscape

### 2.2.5.1 Main Competitors

The market for multi-connectivity solutions features several prominent competitors providing robust platforms designed to ensure seamless network performance and reliability. Example competitors are Nokia, Inseego, AT&T, Qualcomm Incorporated, Intel Corporation, NXP, Texas Instruments Inc., STMicroelectronics, Broadcom, Panasonic, Infineon Technologies, Renesas Electronics, MediaTek [9].

### 2.2.5.2 Competitive products

**Nokia Digital Automation Cloud [10]**

Nokia offers an integrated platform combining the strengths of Wi-Fi and private wireless technologies. This solution enhances operational efficiency by ensuring continuous connectivity and flexibility, particularly suited for businesses seeking secure and reliable wireless infrastructure.

**Inseego Cellular Failover Solutions [11]**

Inseego specializes in 5G and 4G LTE cellular failover solutions aimed at minimizing business downtime. Their products ensure consistent connectivity through automated backup cellular connections during wired network failures or unforeseen disruptions like natural disasters.

**AT&T Business Fiber [12]**

AT&T provides a converged device specifically designed for business customers, offering high-speed fiber internet alongside built-in wireless support. This innovative gateway automatically transitions to AT&T's 5G network during fiber outages, reverting seamlessly back to fiber once service is restored, ensuring uninterrupted business operations.

## 2.2.6 Innovations (Advantages) Compared to Existing Products/Services

MCS within ENVELOPE offers several advantages for enhancing multi-connectivity and streamlining network integration. It leverages an MP-QUIC implementation to enable robust multi-path communication. Additionally, it utilizes machine learning-based packet scheduling, which supports ATSSS-like multi-connectivity by dynamically adapting to network conditions across different paths. Furthermore, a simplified network architecture and clearly defined APIs facilitate the activation and exchange of ATSSS rules by vertical applications.

## 2.2.7 Conclusions

Multi-Connectivity Support (MCS) is poised to play an integral role in the evolving connectivity landscape, addressing critical challenges related to reliability, bandwidth, and seamless user experiences. It finds application across a wide range of markets—including industrial manufacturing, transportation, healthcare, and beyond—each of which values high-performing and robust connectivity solutions.

The market for MCS is in a strong growth phase, supported by increased IoT adoption, the rollout of 5G, and the ongoing digital transformation across industries. Main competitors offer various multi-access solutions, but the introduction of advanced AI-driven network management, scalability, and flexible deployment strategies underlines the unique value proposition and future potential of MCS.

As the sector matures, standardization efforts and improved interoperability are likely to further accelerate adoption, while new entrants and partnerships drive product innovation. Early market feedback suggests that organizations are receptive to MCS solutions, especially those aiming to reduce network-related downtime in mission-critical applications. Thus, MCS is strategically positioned to capitalize on rapidly expanding connectivity needs worldwide.

## 2.3 Zero-touch management for CAM

Zero-touch automation of CAM services, known as Zt-CAM, facilitates on the fly onboarding and instantiation of new CAM applications in the vertical domain, which will be easily adaptable to changes in the underlying resources and/or networking and physical infrastructure.

Zt-CAM refers to the use of advanced technologies to automate the management and operation of connected and autonomous vehicles with minimal human intervention. This approach leverages AI, ML, and data-driven algorithms to create self-configuring, self-monitoring, self-healing, and self-optimizing systems.

According to IMARC [13], the global zero-touch provisioning market, which includes CAM, reached USD 3.5 Billion in 2024 and is expected to grow at a compound annual growth rate (CAGR) of 8.86% from 2025 to 2033. As per a report by Market Research Future [14], “Zero-Touch Provisioning Market was valued at USD 3.94 billion in 2024 and is projected to grow from USD 4.37 billion in 2025 to USD 11.31 billion by 2034Figure 3, exhibiting a compound annual growth rate (CAGR) of 10.80% during the forecast period (2025 - 2034)” mainly due to the growing adoption of Internet of Things (IoT) and industrial machines in commercial, consumer, industrial, and infrastructural settings as well as a rise in the deployment of 5G networks at strategic locations. This trend is reflected in Figure 3.

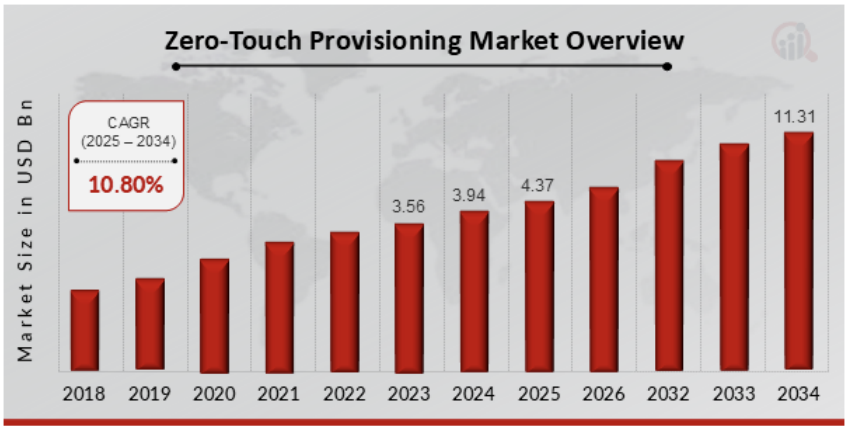


Figure 3: Zero-touch provisioning market (source [14])

### 2.3.1 Market Dynamics

In the following paragraphs, the drivers that will boost the growth of the specific market along with the potential challenges and opportunities are presented.

#### 2.3.1.1 Drivers

- Rise in Need for Eliminating Manual Configuration: The primary aim of ZSM is to establish a comprehensive framework that facilitates complete automation of service and network management in a multi-vendor setting.
- Growth in the Adoption of Cloud Services: Cloud services have become increasingly popular in recent years, as they offer many benefits to organizations, including cost savings, scalability, and flexibility. Cloud services require a different approach to network provisioning, as network devices need to be provisioned and managed in a virtual environment. Zero-touch provisioning makes it easy to provision and manage network devices in a cloud environment, which is essential for organizations that are transitioning to the cloud.
- Increase in Adoption of Industrial Internet of Things (IIoT): The increasing adoption of Industrial Internet of Things (IIoT) is a significant driver for the zero-touch provisioning market.

#### 2.3.1.2 Challenges

- Technical and Organizational Obstacles to a Zero-touch Implementation: The technical complexity of zero-touch provisioning (ZTP) requires the use of standard protocols and APIs to automate the configuration process. Furthermore, organizations with stored organizational structures may face challenges in implementing zero-touch provisioning. Zero-touch provisioning requires close collaboration between IT teams responsible for network operations and those responsible for device management.
- High Implementation Costs: One of the major restraining factors for the adoption of zero-touch provisioning is the high implementation costs associated with it. ZTP requires the deployment of new hardware, software, and network infrastructure to support automated provisioning, configuration, and management of devices. The implementation costs of zero-touch provisioning solutions can be significantly high, particularly for small and medium-sized enterprises (SMEs), with limited budgets. In addition, implementing zero-touch provisioning requires expertise in network infrastructure, protocols, and automation. Organizations need to hire new staff or invest in training existing staff to ensure they have the necessary skills to implement and maintain a zero-touch provisioning solution.

#### 2.3.1.3 Opportunities

Emergence of 5G Networks: The emergence of 5G networks presents a significant opportunity for the zero-touch provisioning market. 5G networks are expected to support a massive increase in connected devices and enable a wide range of new use cases, from smart cities to autonomous vehicles to industrial automation. In addition, zero-touch provisioning can help organizations automate the deployment and management of devices connected to 5G networks, reducing the need for manual intervention and improving operational efficiency.

### 2.3.2 Regional Market Insights

Asia Pacific led the market with a market share of almost 34.0% throughout the forecast period. The growth is attributed to the increasing penetration of network automation solutions, large enterprises and SMEs adopting zero touch provisioning rapidly, and the growing number of connected devices in the region. The growth in the region can be attributed to the rising collaborations, partnerships, smart city infrastructure spending, and new product launches that are significantly contributing to the growth of the Asia Pacific market. India and China have an extensive and distributed customer base driving the demand and creating new regional opportunities. The growth is prominently due to the improving network infrastructure and increasing requirements to reduce CAPEX across the region. Furthermore, the region's untapped potential is generating new investment opportunities for advanced ZTP. The market growth of Europe is driven by the high penetration of zero touch provisioning in the region. North America is expected to develop substantially during the forecast period and expand at a CAGR of 9.2%. The region is equipped with a highly developed infrastructure and owns an extensive research and development base, allowing the region to be the top revenue contributor in the worldwide market during the projected period. A well-established infrastructure has allowed the speedier implementation of modern technologies, such as ZTP.

### 2.3.3 Market Segmentation

- By component:

  It includes platforms and services with a market share 69% and 31% respectively. ZTP solutions offering several benefits such as streamlined deployment and configuration, increased dependability, lower deployment costs, and improved network visibility and management, are credited with the expansion.

- By device type:

  It includes routers, switches, access points, firewalls, IoT devices, and others with the switched dominating the market. The increased use of switched and edge devices by several industries like smart cities, telecoms, etc, is responsible for the huge growth of this segment.

- By network complexity

  It includes multi-vendor environment, complex network architecture, and dynamic network environment, with complex network architecture category dominating the market.

- By enterprise size

  It includes large enterprises and small & medium enterprises, with large enterprises category dominating the market due to the increasing adoption of zero touch provisioning, network virtualization solutions, and network automation.

- By industry

  It includes IT & telecommunications, manufacturing, healthcare, retail, and others, with IT & Telecommunications segment dominating the market. This can be mainly attributed to the increasing number of connected consumer devices.

### 2.3.4 Market Maturity

ZTP market is between early adoption and maturity. The continues evolution of standardized implementation prohibits the market to reach maturity. Despite the increasing adoption by large enterprises and the growing complexity of hybrid IT environments as well as the demand for AI-driven network management, complete maturity has not yet been achieved due to challenges like integration with legacy systems, interoperability, skills gaps etc.

### 2.3.5 Competitive Landscape

#### 2.3.5.1 Main competitors

Main competitors and competitive projects are[15][17]: Accenture, BetterCloud, Cisco, IBM, VMware, Nokia, Ericsson, Huawei, ZTE, Juniper, HPE, Arista, Extreme, Riverbed [15]-[17]. In addition to commercial solutions, several research projects target the implementation of zero-touch automation solutions. In particular, in the context of SNS JU, Hexa-x-ii [18], ADROIT6G [19] and 6G-INTENSE [20], among others, are focusing their efforts in demonstrating AI-driven zero-touch service and network management capabilities.

#### 2.3.5.2 Innovations (Advantages) Compared to Existing Products/Services

Most of the existing products target network equipment. On the other hand, research projects like Hexa-x-ii, ADROIT6G and 6G-INTENSE, among the others, mostly focus on zero-touch automation of several operational actions in network infrastructures aiming at reducing the need of human intervention, validating AI-driven automation mechanisms for improved resource allocation, service provisioning, automated recovery, and energy consumption. In ENVELOPE, the development and implementation of an innovative intent-based and AI-native orchestration framework for advanced Zero-Touch Service Management is targeted, tailored to the CAM needs and characteristics. Unlike conventional solutions, ENVELOPE's solution begins with a deep analysis of CAM-specific service requirements, enabling the intelligent merging and dynamic re-composition of service intents. Business intents are seamlessly translated into context-aware management-plane policies using advanced AI-driven mechanisms, ensuring precise and adaptive service control. Furthermore, our AI-powered closed-control loops deliver fully converged and coordinated automation across CAM applications, mobile networks, and continuum resources,

enabling truly autonomous service lifecycle management with unmatched efficiency and responsiveness.

### 2.3.6 Conclusion

In conclusion, the market analysis and projections indicate a robust growth trajectory for Zero Touch Management in CAM, driven by technological advancements and increasing demand for automated and efficient mobility solutions. Despite facing challenges related to technical and organizational obstacles, as well as high costs, ZTM offers immense opportunities for data monetization, new business models, and enhanced user experiences in the CAM domain.

## 2.4 Advanced digital twins in CCAM

According to [21], new mobility solutions enabled by connected, cooperative and automated mobility (CCAM) will increase the safety, traffic efficiency and accessibility of Europe's Road Transport System.

On the other hand, all new mobility solutions, before deployment shall undergo extensive tests and validation to comply with the existing legislation, standards and user requirements. The developed and deployed CCAM solutions should be safe and reliable on the roads, in all weather and traffic conditions on urban, suburban and countryside roads.

Testing CCAM solutions on the roads, by driving thousands of miles to ensure safety and reliability is not effective and efficient. Therefore, virtual validation helps reduce verification and validation costs and accelerates time-to-market. By using software tools like Simcenter Prescan, advanced digital twins can be developed allowing credible and traceable verification and validation of CCAM solutions.

A digital twin is a virtual representation or digital counterpart of a physical object, system, or process. It involves creating a detailed and dynamic digital model that mirrors the real-world entity, allowing for simulation, monitoring, analysis, and optimization. The increasing prevalence of IoT devices and sensors provides a wealth of real-time data that can be integrated into the solution. This connectivity enables accurate and dynamic representations of physical entities. Digital twin technology is increasingly adopted in various industries (Figure 4), such as manufacturing, healthcare, smart cities, aerospace & defence, and others [22].

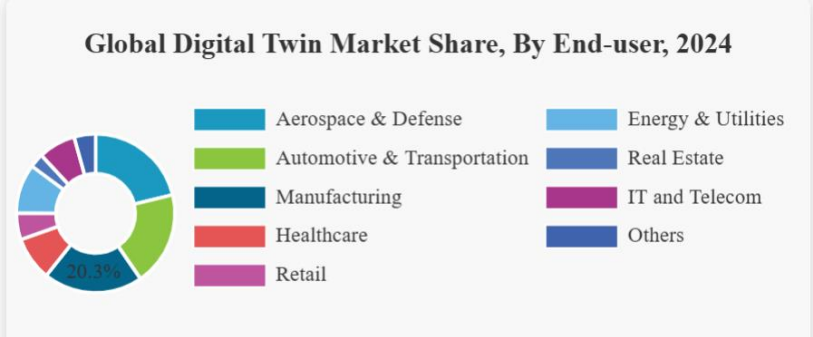


Figure 4: Global digital twin market share in 2024 – source [22]

The global digital twin market size was valued at USD 17.73 billion in 2024 and is projected to grow from USD 24.48 billion in 2025 to USD 259.32 billion by 2032, exhibiting a CAGR of 40.1% during the forecast period [22].

Currently, North America dominated the global market with a share of 38.35% in 2024Figure 5. The growth of the digital twin market is driven by enhanced healthcare applications and advancements in 3D simulation and printing technologies [22]. This trend is reflected in Figure 5.

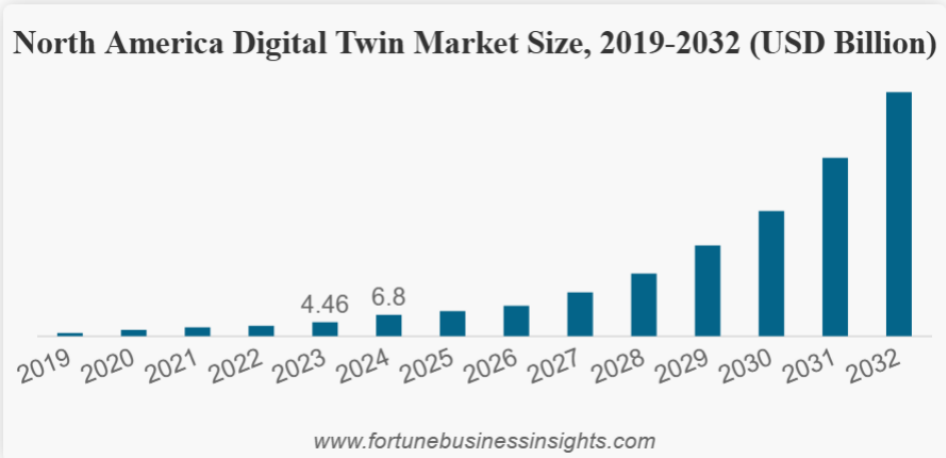


Figure 5: Digital twin market size in North America - source [22]

Furthermore, the U.S. autonomous car market size is estimated to reach $37.56 billion by 2029, growing at a CAGR of 20.5% between 2024 and 2029. However, the widespread implementation of automated vehicles (AVs) in the real world depends on the verification and validation (V&V) for designing, manufacturing and operation [23].

Using data from physical testing and data generated digital twins, engineers can quickly identify on-road edge cases and assess vehicle behavior in all driving scenarios. As the CCAM is an integrated system, its development platform also needs to be tested in realistic virtual scenarios throughout the design process.

By using a comprehensive digital twin during each phase of development and deployment the CCAM solution can be tested and validated effectively and efficiently. This empowers an efficient closed-loop CCAM development lifecycle that spans from design to verification and validation and even through to deployment and in-field maintenance [23].

To perform virtual validation, one needs to create virtual test scenarios that cover all operational design domain (ODD) parameters like weather, traffic signs, and road geometry by incorporating the National Highway Traffic Safety Administration (NHTSA) framework, New Car Assessment Program (NCAP) test protocols, and International Organization for Standardization (ISO) standards [24].

Original equipment manufacturers (OEMs) perform extensive physical testing to test the reliability of their advanced driver assistance systems (ADAS) and CCAM solutions in different environments, and they collect a huge amount of sensor and vehicle data from test drives.

In such a situation, using the collected data, digital twins and virtual scenarios can be created from vehicle recorded logs and the software can be first tested in a virtual environment and then fine-tuned further, reducing the dependency on test drives and the workforce [24].

### 2.4.1 Market dynamics

The market trend towards software defined vehicle (SDV) has changed rules and boundary conditions for mobility business. The architecture of modern cars is changing to keep pace with the market expectations, from domain centric vehicle architecture to vehicle centric architecture and vehicle cloud computing. Related to software engineering, the main trend is decoupling the software from hardware and providing regular updates over the air (OTA).

In terms of development cycles and development process, DevOps (development and operations) are becoming more common in the automotive industry. Where DevOps stands for a set of automated software practices that combine software development (Dev), testing and IT operations (Ops) to shorten the software development life cycle while delivering features, fixes, and updates frequently in alignment with the business' objectives [25].

Furthermore, the software verification and validation (V&V) is also significantly evolving to meet the changing customer expectation, agile development, demand for faster time to market, and pressure to reduce R&D costs. There is a huge focus on front-loading and continuous deployment of software [25].

#### 2.4.1.1 Drivers

- **Standardization:** There is ever increasing demand for standardization of V&V process, methods and tools. Test strategies have to be defined keeping in mind functional safety (ISO 26262), SOTIF and country specific ENCAP regulations [25].
- **Virtualization:** For CCAM and autonomous vehicles, there are certain situations which are very challenging or expensive to validate in field e.g.: miles accumulation for autonomous driving, safety critical scenarios, new road infrastructure supporting CCAM, etc. Virtualized validation using Model-in-the-Loop (MiL), Software-in-the-Loop (SiL), Hardware-in-the-Loop (HiL) are the answers to these challenges [25].
- **Cost saving:** Digital twin technology can enable front-loading of projects, it helps development of the tests in a virtualized environment and later validation in HiL. It saves on validation in expensive lab set-ups and proto vehicles in later phases of the product development.

#### 2.4.1.2 Challenges

However, there are challenges in the introduction of these new technologies.

- Mindset; to convince engineers to test in a virtualized environment and convince project managers to add the extra-activity to build virtual environment.
- How to establish methods for validation, qualification of the virtual toolchain: It requires creation and integration (using for example a middleware) of different models such as: plant model, environment and sensor models from different suppliers and then run the tests seamlessly with a test automation framework.

## 2.4.2 Regional market insights

The CCAM market is highly volatile, with frequent entry and exits from diverse industries. Notable market entrants in the CCAM industry include technological companies like Waymo (Alphabet) and ZooX (Amazon), as well as OEMs like Cruise (General Motors). The lack of autonomous shuttles and the need for funding for public transportation are viewed as important constraints by industry players. Because successful CCAM business models do not yet exist, CCAM providers are cautious to enter the market. The supply gap leads to high purchasing costs for autonomous cars, making it difficult for public transportation operators to adopt them into their fleets. McKinsey predicts (Figure 6 - Figure 8) that by 2035, autonomous driving could generate $300 billion to $400 billion in revenue [26].

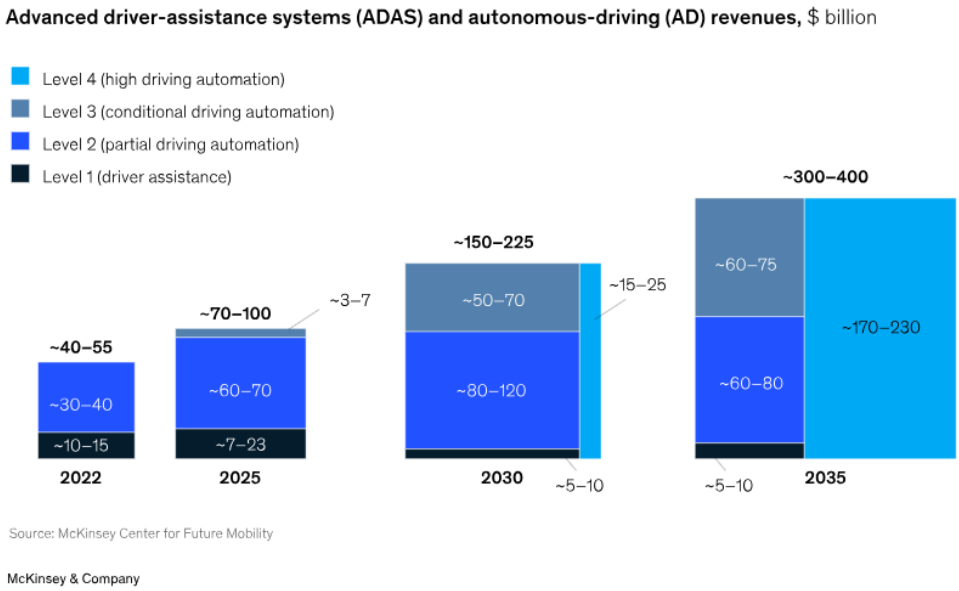


Figure 6: ADAS and AD forecasted revenues – source [26]

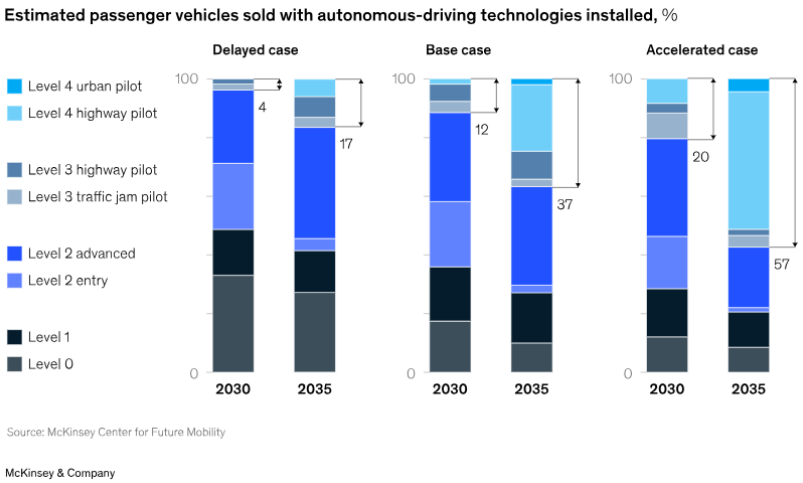


Figure 7: Autonomous-driving technologies development in the coming years – source [26]

Notable industrial collaborations include those between software vendor Mobileye and OEM Schaeffler, shuttle provider HOLON and middleman Beep, and Mobileye and Goggo Network, which provides autonomous software for its shuttles. The 2016 Amsterdam Declaration defined important principles for European collaboration in the development of CCAM, as well as a structured conversation involving stakeholders from both the corporate and governmental sector – see Fig. 6. The most recent high-level dialogue on Connected and Automated Driving, held in Ghent in June 2024, emphasized the importance of ongoing collaboration among local, national, and international players to harmonize research, standardization, and regulatory efforts and achieve the goal of large-scale deployment in Europe [21], [27].

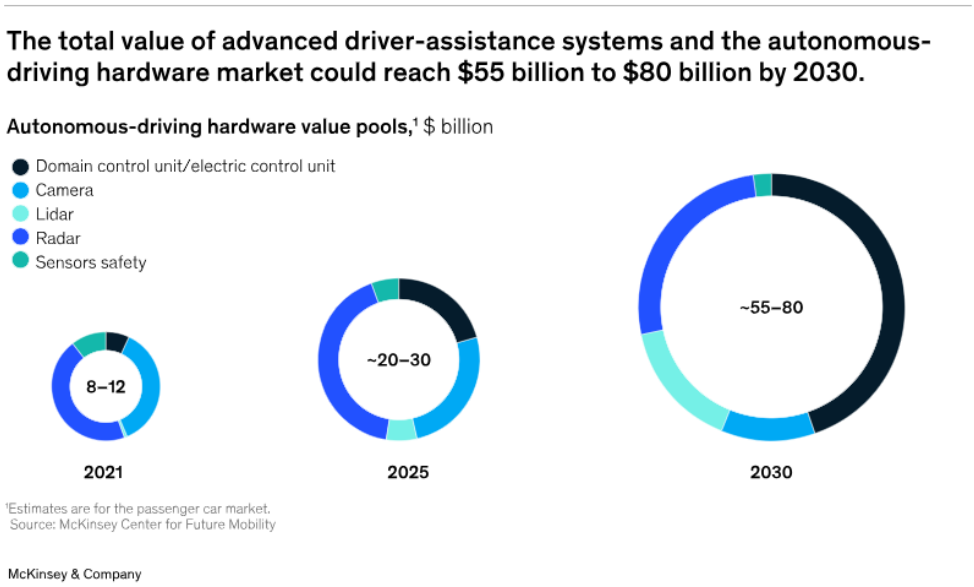


Figure 8: Autonomous-driving hardware value – source [26]

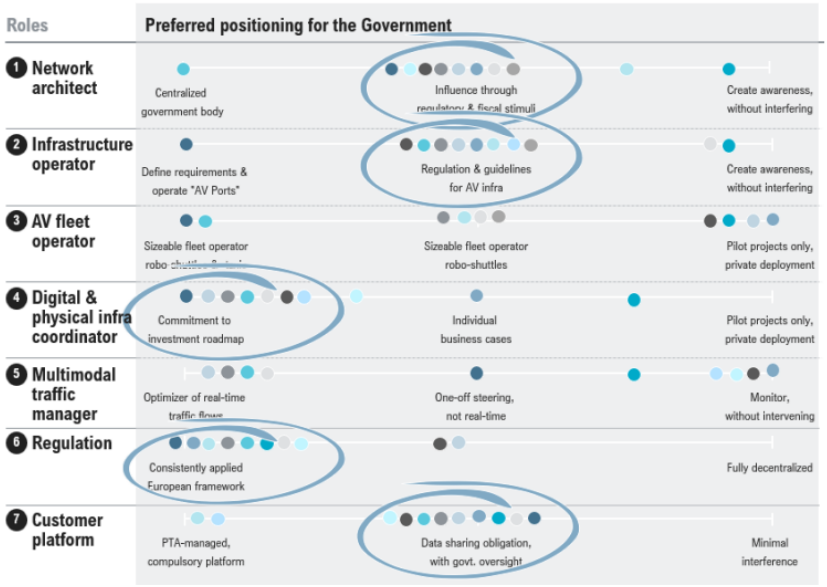


Figure 9: CCAM market and preferred role of the government – source [27]

The European Commission aims to propose draft legislation in 2025 that would allow insurers, leasing companies and repair shops fair access to valuable vehicle data, according to its auto industry action plan. The data covers everything from driving patterns to fuel usage and tire wear, and analysts believe the connected auto business will be worth hundreds of billions of euros by the end of the decade. The current disagreement over access stems from the fact that EU law does not clearly define data ownership [28].

The attitude towards connected vehicles seems to be positive, taking into account the strong users' willingness to pay for connected car services [29]. In the AV area, a recent study found that more than half of surveyed Europeans (53.3%) would consider buying an AV, whereas the numbers in the US and Japan are slightly lower (50% and 41%, respectively) [30]. In a poll of 1,500 users from Germany, Japan, and the US[31] it was revealed that 75% of users are willing to pay for such services, with the average sum being around 190 euros per month. The categories with the highest percentage of willingness to pay are "Communication" (e.g. social networks), "Productivity" (e.g. work) and "Basic requirements" (e.g. sleep), while on the other side the lowest percentage one is related to "Entertainment" (e.g. games) services [31].

### 2.4.3 Market Maturity

Toyota Motor, along with Nippon Telegraph and Telephone (NTT), intend to invest a total of 500 billion yen ($3.27 billion) by 2030 on an infrastructure and software platform that use artificial intelligence to prevent road accidents. The automaker and telecommunications provider stated in a joint statement on 30 October 2024 that they intend to create a mobility AI platform that leverages massive amounts of data to enable driver assist technologies, with the goal of having a system available by 2028.

Toyota and NTT first collaborated in 2017 to research technology for 5G-connected cars, and they later formed a capital partnership as part of a smart city initiative in 2020. NTT announced in November 2023 that it wanted to test driverless vehicle technology with Toyota as early as 2025 and invest in a US firm researching self-driving systems. Toyota launched an autonomous driving technology unit in 2021 to invest in and improve mobility using artificial intelligence. Toyota's Woven business is also working on an automotive software platform, Arene, as well as a testing location for mobility-related technologies and services in Shizuoka prefecture, west of Tokyo [32].

In Europe, concerted efforts are being made to build a robust CCAM ecosystem. The CCAM Association, which represents over 200 stakeholders, issued a strategic vision in February 2025 to boost Europe's global competitiveness in automated mobility under the upcoming Tenth Framework Programme (FP10). This strategy focuses on accelerating innovation, large-scale deployment of Level 4 automation use-cases, and maintaining technical sovereignty. Furthermore, the European Commission has been aggressively supporting CCAM with significant financing. Horizon Europe has allocated around €500 million to projects that develop and deploy highly automated and connected driving systems [33].

virtual Roadside Units (vRSUs) are positioned as a less expensive and more scalable alternative to traditional Roadside Units (RSUs) as a tool for cooperative mobility. However, they complement rather than compete, with each excelling in certain use cases. Optimal Vehicle-to-Everything (V2X) systems combine both types to provide cost-effective yet robust deployments. ABI Research, a

worldwide technology intelligence group, projects that vRSUs will span 120,000 signalized junctions globally by 2030, expanding at a 66% CAGR from 2024 [34].

While cost and scalability drive this expansion, addressing technological and business model alignment issues is crucial for realizing this growth.

Despite these advancements, challenges remain. The European Commission's staff working document from July 2024 [35] highlights the need for continued progress in operational, technological, societal, and economic aspects of CCAM. Addressing issues such as data security, interoperability, and public acceptance is crucial for the widespread adoption of CCAM solutions.

## 2.4.4 Competitive landscape

### 2.4.4.1 Main competitors

- Bosch is participating in Cooperative Vehicle Infrastructure Systems (CVIS), and its products and solutions compete with Siemens Mobility. The company's emphasis on innovation and recent achievements in this field distinguish it as a significant competitor. Bosch has developed a universal connectivity device that can communicate utilizing all of the world's most prevalent transmission technologies. This unit provides seamless vehicle-to-everything (V2X) connectivity, allowing vehicles to successfully interact with their surroundings [36].
- Bosch offers digital twin solutions that create virtual representations of physical industrial assets. These solutions enable real-time data monitoring, analysis, and optimization to enhance efficiency and productivity [37].
- Ansys supports the safety by design and validation approaches. Ansys offers extensive and detailed simulation capabilities for driverless vehicles and advanced driver support systems. The software can be used to create high-fidelity, physics-based sensor models for ISO26262 and Automotive Open System Architecture (AUTOSAR) compliant embedded software and human-machine interface development. Ansys' products include autonomous sensor development, system development and validation, and software development, which help engineers solve problems in record time and at a low cost by automatically generating code, demonstrating safety standards compliance, and reducing the number of real-world miles required to prove efficacy [38].

  Ansys Twin Builder allows you to easily create a digital twin, or a connected clone of an in-service asset. This enables improved lifecycle management and accurate predictive maintenance, resulting in cost savings that help preserve a competitive advantage. Ansys unveils Ansys TwinAI, a new addition to Ansys Digital Twin’s product line that seamlessly merges the accuracy of physics models with insights from real-world data powered by cutting-edge AI approaches. Ansys TwinAI now supports Reduced Order Models (ROMs) and combines Ansys Design Language with new UI/UX enhancements [39].

- dSPACE delivers complete vehicle connectivity solutions that enable a variety of communication technologies, accelerating the development of connected cars. Their services include rapid prototyping systems and hardware-in-the-loop (HiL) testing, which help with the development and validation of vehicle-to-everything (V2X) applications. These

tools enable automobiles to interact with their surroundings, which improves road safety and efficiency [40].
dSPACE's sensor-realistic simulation for digital twins includes high-resolution graphics, including realistic lighting and weather effects, as well as high-quality 3-D assets built by dSPACE, such as autos, e-scooters, and people. Realistic camera, lidar, and radar models, as well as Linux and Docker compatibility, are included, as are APIs for integrating third-party sensor models [41].

- AVL has a solid track record of customer projects up to L2+ and is assisting commercial vehicle customers in their transition to autonomous fleets driving 24/7 on highways. AVL's new Mobility and Sensor Test Center in Roding, Germany, is a one-of-a-kind indoor laboratory for verifying and validating sensors for driver assistance systems. The 1600 square meter test area allows for the testing of safety-relevant functions under harsh weather conditions, independent of real-world outdoor settings, ensuring vehicle safety in semi-autonomous operation [42].

  AVL is working in a digital twin simulation to speed the development of fuel cell electric vehicles. Using the AVL CRUISE™ M methodology to create digital twin fuel cells and vehicle simulations allows AVL to prioritize development tasks, reducing testbed time and prototype vehicle numbers in a safe and cost-effective environment [43].

#### 2.4.4.2 Competitive products

- AVL – AVL Cruise - Simulation software is used to model, simulate, and optimize vehicle powertrains, facilitating the development of autonomous and connected vehicle technologies [43], [44].
- NVIDIA – VVIDIA Drive Sim - AI-powered simulation platform that creates realistic virtual settings for testing autonomous vehicles and ADAS by combining high-performance computation with realistic graphics [45].
- ANSYS – ANSYS VRXPERIENCE - provides solutions for autonomous vehicle simulation, with a focus on virtual testing and validation of ADAS and autonomous driving systems through realistic surroundings and physics-based simulations [46].
- dSPACE – dSPACE AutomationDesk & SCALEXIO - A testing and simulation platform for ADAS and autonomous vehicle systems that includes HIL testing, sensor modeling, and scenario simulation [47].
- IPG Automotive – CarMaker - A simulation software for testing and certifying ADAS and autonomous driving systems in a virtual environment, which includes sensor simulation and real-world scenario testing [48].

#### 2.4.4.3 Innovations (advantages) compared to existing products/services

The currently developed solutions by ENVELOPE are highly competitive and, in many aspects, have similarities with the solutions developed by the competitors. One of the innovative advantages, which shall be highlighted is the use of advanced communication networks 5G/6G in digital twins. The communication network is an essential part of the digital twin, but often we observe that high fidelity simulation models alone are classified as digital twin. More details about the Siemens solution/innovations can be found in the references [49]-[54].

### 2.4.5 Conclusions

Information about the CCAM and AV market in terms of size, dynamics, segmentation and maturity as well as about the digital twins used in CCAM and AV development (design and testing) is provided. We observe that the CCAM market is a very segmented one, and successful CCAM deployment requires closed cooperation of the stakeholders, which in Europe is strongly supported by legislative actions and public funding. The use of digital twins in CCAM – is an emerging technology – and the relevant software tool providers are already present with dedicated tools and solutions.

## 2.5 Network Openness for Connected Automated Mobility

Network Openness is a fundamental feature of the new generation mobile networks and has been introduced together with the Service-Based Architecture as part of the 5G Core Network (5GC) specification already from Release 15[3], in 2020. Through the specification of the Network Exposure Function (NEF), the secure interaction of the network functions with external entities, such as vertical applications and third-party providers, is allowed. NEF interactions include (i) network data exposure, such as location information, QoS (Quality of Service) and subscriber data, and (ii) event data exposure, such as events or triggers for location updates or network status changes, as well as (iii) control exposure, by allowing external applications to request a network, or resource allocation change.

However, this exposure is implemented through a well-defined set of standardized Application Programming Interfaces (APIs) at the network level and assumes a deep knowledge of the telecom network that is not obvious for the application developers [55]. The need for a 'service exposure' abstraction layer, to hide the complexity of interacting with the Network including the Operating Support Systems (OSS)/Business Support Systems (BSS), has led to the formulation of the CAMARA Alliance [56] that together with the GSMA Open Gateway [57] initiative bring together all Communication Service Providers (CSP) and other players, such as aggregators and developer platforms, to formulate simplified service APIs that can be commonly available across telco networks and countries. Yet, the main challenge with those ambitious approaches is that they try to support a broad variety of verticals while no open implementation exists to support the practical validation of the concepts presented. This is the gap bridged by ENVELOPE, that prioritizes the specification and development of network openness and service exposure APIs, tailored to the demands of the automotive industry and the Connected Automated Mobility (CAM) applications (such as Application Function (AF) traffic influence, Application Service (AS) session with Quality of Service (QoS), and Event Reporting) and aims to provide tangible results, including practical validations through open calls. As such, ENVELOPE offers a unique value proposition in 5G for CAM domain, empowering CAM developers and vehicle Original Equipment Manufacturers

[3] https://www.3gpp.org/specifications-technologies/releases/release-15

(OEMs) with advanced 5G capabilities to develop new enhanced applications and services, realizing 'programmable networks' that can differentiate operations intelligently and on demand, considering mobility aspects and stringent QoS Service Level Agreement (SLAs).

ENVELOPE aspires that the Network Openness developments shall be driving new revenue opportunities for the entire ecosystem, benefiting developers, service providers and enterprises and as such of immediate interest for all partners of the project. It is considered that new business and cooperation models between the Mobile Network Operators (MNOs) and third parties will be defined, allowing for the monetization of network data and control. Already SME project partners contributing to the respective developments (e.g. NWX) are considering the commercialization path for these developments, while consortium's research institutes (e.g. ICCS) leverage the competence built and the involvement with standardization (e.g. ETSI) and community (Linux-foundation, open source) development activities. The validation activities on the open/programmable 5GC systems of the ENVELOPE trial sites as well as the results/feedback from the open callers' experimentation, are expected to drive the action plan of the MNOs of the project (e.g. OTE) on prioritizing the early adoption of the network exposure functions to support the automotive verticals.

ENVELOPE through its network openness capabilities paves the way to the development of intelligent network-aware CAM applications, that according to industry associations [59] are beneficial for our society in various ways. Firstly, for safety, as highly automated vehicles exchanging information will realise a collective artificial intelligence that can overcome the capabilities of humans to drastically reduce the number of accidents. Secondly, for traffic efficiency as exchanging information of manoeuvre intentions and real-time monitoring of real-traffic conditions for optimal traffic efficiency are just a couple of examples of the potential of CAM to improve the capacity and efficiency of roads. Thirdly, for passenger comfort as vehicles driving in a highly automated manner will transform the passenger experience, allowing for a more relaxed and fruitful traveling time on-road. Overall, reduction of environmental impact of road traffic is a final goal that can be boosted thanks to CAM. In this context, it becomes clear that the automotive industry through the development of advanced CAM applications exploiting programmable, open networks are the main target market for the ENVELOPE openness exposure capabilities. In line with this approach, GSMA as part of its strategic pillar to support industries by facilitating collaboration, developing use cases of new technology and accelerating growth through a standardized approach, has identified Automotive and Mobility for Connected Vehicles market as the area with the biggest impact on the safety and well-being of citizens. Indicatively in past reports it was expected that by 2025, connected cars could save 11,000 lives and lead to 260,000 fewer accidents every year, while avoiding 400,000 tons of $CO_2$ emissions and saving 280 million hours of driving [64]. This report also highlights that the connected vehicle services will be worth US$ 81 billion by 2030, making the connected vehicle market one of the highest growth areas in the IoT and providing an immense revenue opportunity for mobile operators, automotive manufacturers, and companies in the wider ecosystem.

To this end, GSMA is working to accelerate the growth of the connected vehicle market by agreeing a common approach to security, regulatory and infrastructure solutions, understanding that only a standardized and collaborative approach of the industry can unlock the full potential of a secure market, with the Open Gateway becoming the flagship initiative to achieve this. The MNOs interest in the GSMA Open Gateway initiative is rising, and by June 2024 around 75% of the global mobile market share representation was achieved, according to the GSMA report [62]. This report stresses

that the geographic spread of operators continues to tilt towards China and Asia (in total and relative to their mobile subscriber base), while operators in Africa have been slower to adopt. It also highlights that 2025 is set to be about monetization and proof points from commercial deployments.

The 5G Automotive Association (5GAA) [58] is a global, cross-industry organization of companies from the automotive, technology, and telecommunications industries, working together to develop end-to-end solutions for future mobility and transportation services and has conducted many studies on the timelines of advanced CAM applications, as depicted in Figure 10. These timelines set the targets for the readiness of the underlying technologies, accounting also for ENVELOPE's network openness.

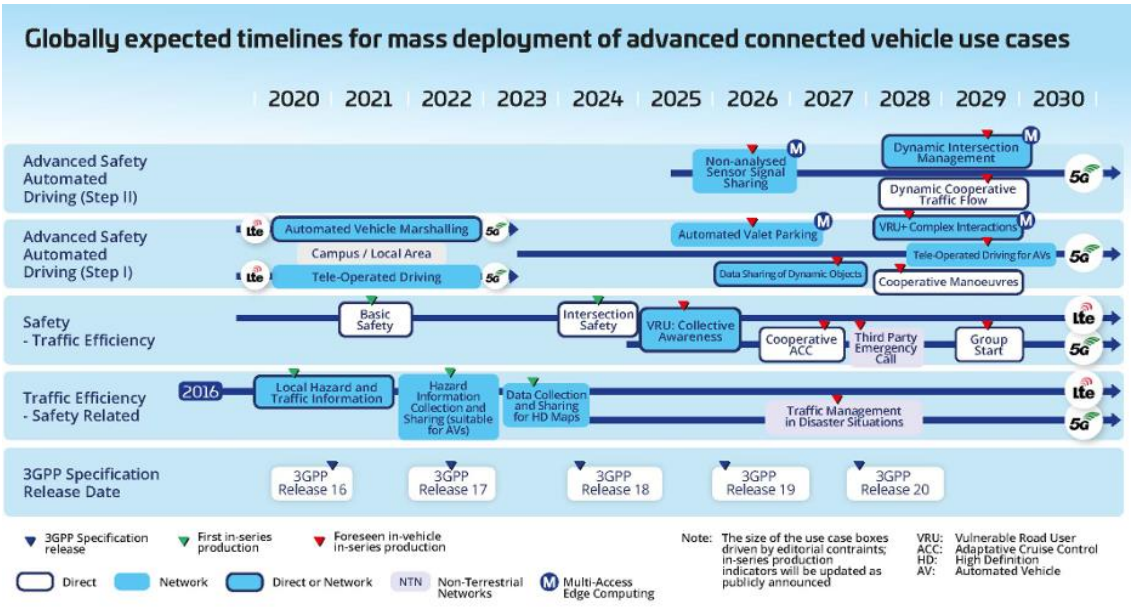


Figure 10: Globally expected timelines for mass deployment of advanced connected vehicle use cases [60]

## 2.5.1 Market Dynamics

In order to appropriately support the enhanced CAM application adoption timelines, prioritisation of the network openness and exposure capabilities tailored to V2X (Vehicle to Everywhere) becomes of strategic importance and raises a unique exploitation opportunity for the ENVELOPE developments.

According to Straits Research, "the global telecom API market size was valued at USD 265.33 billion in 2024 and is expected to grow from USD 319.45 billion in 2025 to reach USD 1410.64 billion by 2033, growing at a CAGR of 20.4% during the forecast period (2025-2033)." With 5G rollouts accelerating, 5G network openness (for service innovation, integration, and agility) is expected to significantly expand the market over the next years.

The relevant market dynamics are analysed in the paragraphs that follow.

#### 2.5.1.1 Drivers

The number of cellular-connected vehicles on the road has now reached more than 300 million globally (December 2024). Two-thirds of new cars sold in the world's leading automotive markets are now connected, and several automakers have already released 5G cellular network-connected cars relying on the 3GPP Release 15 specifications of 2019 [6]. At the same time, industry initiatives such as GSMA Open Gateway and Open Linux Foundation CAMARA project have brought together key stakeholders and have paved the way for the exposure of unified, interoperable, simplified service exposure APIs that can facilitate the development of more intelligent CAM applications. The target market size as well as the stakeholders' committed interest unveil unique market opportunities for the ENVELOPE CAM-focused network openness developments that according to Figure 10 need to produce tangible results by 2030.

#### 2.5.1.2 Challenges

Reflecting on the "5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe" [61] that investigates key topics for developing the 5G CAM ecosystem in Europe by adding the network openness dimension, the following challenges should be highlighted (i) the need for appropriate cooperation models among involved stakeholders; (ii) stabilising the technology roadmap; (iii) cybersecurity; (iv) regulation; (v) data access and sharing; and (vi) coordination of deployment.

#### 2.5.1.3 Opportunities

ENVELOPE network openness technology is validating unique solutions responding to CAM applications demands for which existing systems do not provide adequate support. Starting from position accuracy, using the service from mobile networks to receive 3GPP standardized Global Navigation Satellite System (GNSS) correction data is a well identified service. Further evaluating 5G NR precise positioning to enhance accuracy in areas of poor GNSS coverage (e.g. tunnels, underground parking, urban canyons) or provide high position accuracy (e.g. 20 cm accuracy to locate a vehicle in the centre of a designated lane) that in many scenarios GNSS cannot provide (e.g. 2 m accuracy), become important features to support autonomous driving and V2X (basic) safety and local hazards applications [64]. Additionally, by exploiting QoS related APIs, ENVELOPE exhibits differentiated network performance for prioritized automotive applications even in congested situations, facilitating the usage of QoS-on-demand by the end users.

### 2.5.2 Regional Market Insights

According to GSMA [63], the Asia-Pacific (APAC) region shows significant progress in advancing telecommunications network API exposure. With over 50% of global operator participation in GSMA's Open Gateway initiative, APAC leads in launching APIs for fraud prevention, authentication, and network optimization. The region's unique characteristics, high mobile penetration, young tech ecosystems, and diverse economies, drive API adoption and innovation. Prominent case studies from Indonesia, China, and Sri Lanka showcase real-world applications, reflecting the potential for APIs to transform industries and accelerate digital transformation.

However, and as shown in Figure 11, beyond the GSMA community, the general developers' community understanding for the concept and benefits of Network APIs is still limited and underlines the continued need for market outreach.

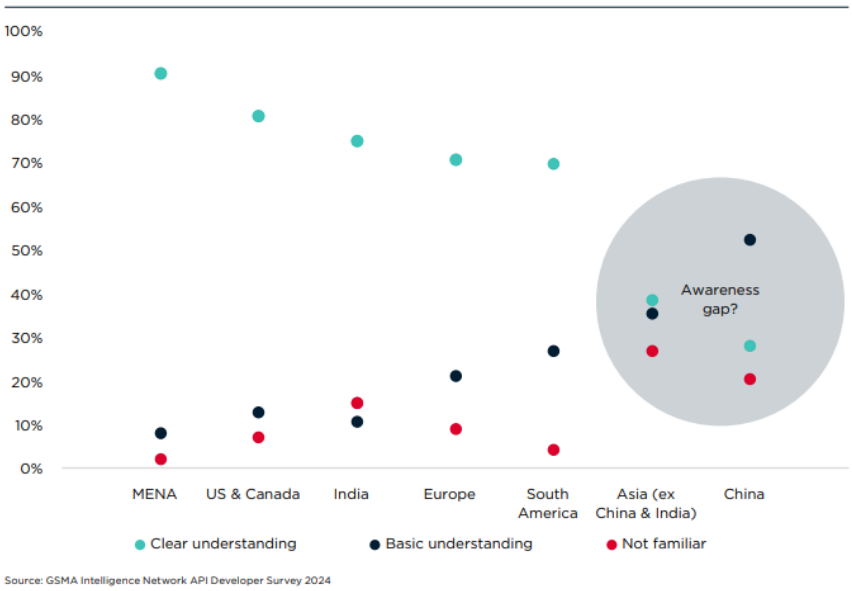


Figure 11: Network APIs concept and benefits understanding by Developers

Efforts should emphasize collaboration among developers, operators, and channel partners, with a focus on enhancing security, quality of service, and monetisation opportunities.

Regarding the expected adoption of CAM applications in the regional market, an interesting timeline is provided in Figure 12 for Europe and Figure 13 for US respectively.

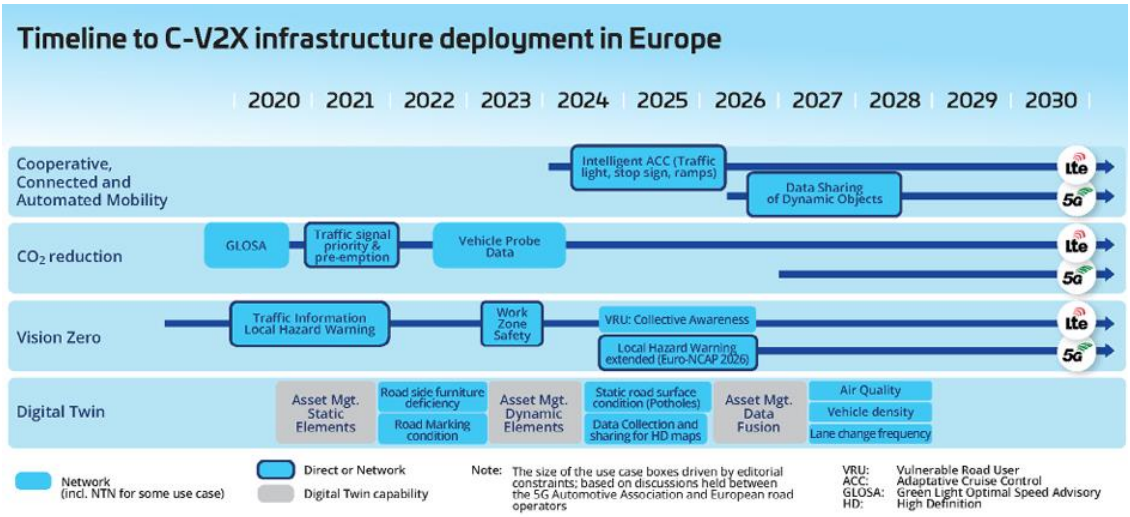


Figure 12: Timeline to C-V2X infrastructure deployment in Europe [60]

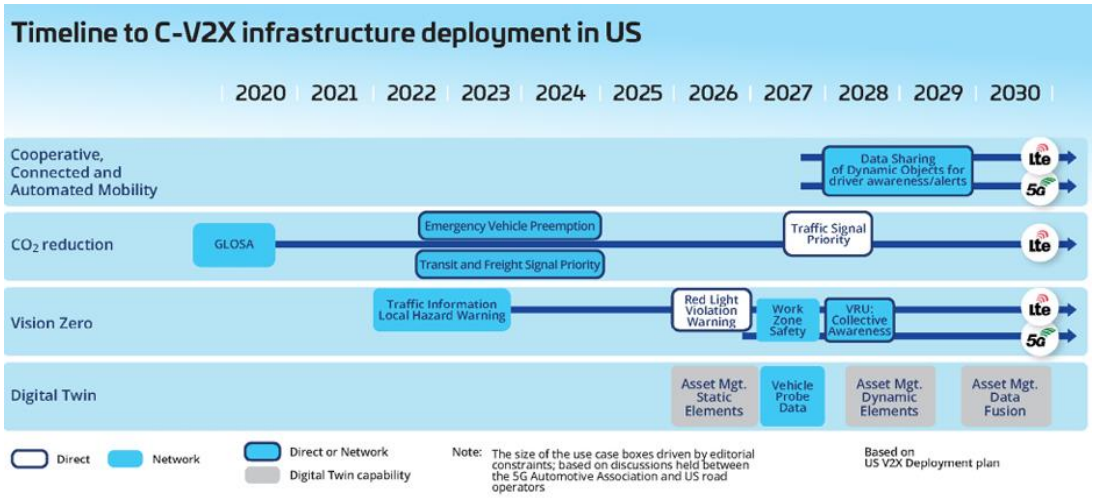


Figure 13: Timeline to C-V2X infrastructure deployment in US [60]

### 2.5.3 Market Segmentation

According to the GSMA Intelligence Report [62], the key players that need to cooperate to drive the market adoption for network openness are:

- Mobile Operators: To expose the network APIs.
- Network Vendors: To provide platforms that expose interoperable network APIs with tools to facilitate developers in building new use cases.
- Hyperscalers: To collaborate with operators and seamlessly expose the cloud infrastructure and services APIs.
- Connectivity Platform as a Service (CPaaS) Companies: To extend their existing CPaaS platforms (currently offering voice, messaging, video communication APIs) with the enhanced APIs.
- System Integrators: To exploit the exposed APIs and bridge the technology gaps that delay the exposure adoption.
- Industry Groups: To collaborate towards achieving an interoperable and all-encompassing API framework incorporating all aspects including OSS and BSS functions.

Considering the automotive industry that drives the demand for enhanced CAM applications necessitating network openness, 5GAA [65] denotes the important role of:

- Road Users (car drivers, truck drivers, pedestrians)
- Infrastructure owners and operators (road operators, cities)
- Vehicle OEMs (car, truck, motorbike manufacturers)
- Application service providers (navigation, information services, and fleet management)
- MNOs
- Field Equipment Manufacturers (roadside units, traffic light controllers, sensors, etc.)
- Technology providers

It is obvious that the market segmentation considering the number and diversity of the stakeholders involved becomes a key consideration and emphasizes the need for the appropriate collaboration

model and practical facilitation to be offered by both regulatory authorities and industry associations.

### 2.5.4 Market Maturity

Considering the developments reported by GSMA [62] and 5GAA [65] the 5G Network APIs is a slowly emerging market, there is a growing demand, and few offerings are already available. Operators currently make 25–35% of their revenues from B2B customers. According to [62], enterprises expect to spend 10–15% of their revenues on digital transformation between 2024 and 2027 and while more enterprises rate 5G as their number 1 investment priority (21%) than any other category, however, the Network APIs garner a far lower share; around 15% of enterprises put it in their top five (see Figure 14). Furthermore, it must be noted that the unique selling points (USPs) for the APIs are prioritised to be security, latency, QoS and billing applied horizontally to multiple enterprise product lines (included and not limited to CAM).

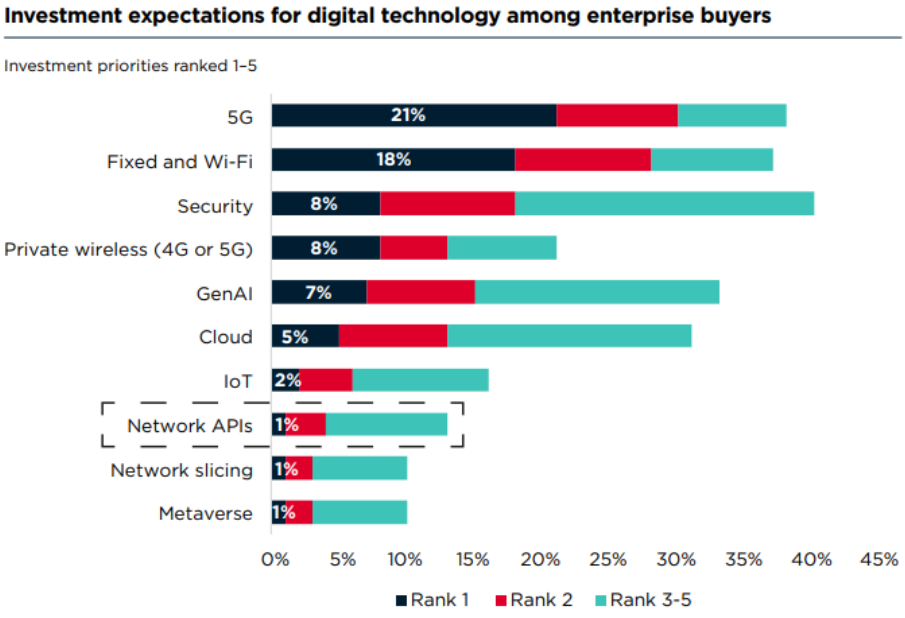


Figure 14: Investment expectations for digital technology – prioritization [65]

### 2.5.5 Competitive Landscape

#### 2.5.5.1 Main Competitors

The Network Exposure API market is considered competitive, with offerings ranging from telecom giants like AT&T, Vodafone, Telecom and Telefonica to cloud providers like AWS, Google Cloud, and Microsoft Azure. Specialized API management platforms such as Apigee, MuleSoft, and Kong also play a significant role in helping telecom operators expose their network capabilities securely. It is noteworthy that targeted telecom-related propositions come from CPaaS providers.

### 2.5.5.2 Competitive products

An indicative list of competitive offerings contains:

AT&T API Marketplace: AT&T offers a comprehensive platform with a wide range of APIs that include capabilities like messaging, location, and network monitoring, making it a strong competitor in this space. AT&T is focused on opening up 5G network capabilities to allow developers to create new services.

Telefonica (Open Gateway): Telefonica's Open Gateway initiative is designed to expose key network capabilities via APIs. This includes services like edge computing, 5G network slicing, and IoT connectivity. Their platform provides access to low-latency network features that are valuable for a wide range of industries.

Deutche Telecom and Vonage: As noted by Claudia Nemat, Board Member for Technology and Innovation Deutsche Telekom, together with Vonage and Ericsson, “we are the first to expose network APIs in a one-stop shop portal. APIs are a key strategic focus for Deutsche Telekom as underlined by our status as a founding member of the CAMARA alliance, which aims to make standardized APIs available internationally”.

Vodafone: Vodafone offers API solutions through its Vodafone Business APIs platform. They expose key functionalities such as messaging, location-based services, and IoT data, with a special focus on 5G network exposure.

Syniverse: Syniverse is a leading player in telecom API solutions, providing telecom operators with a wide range of exposed services, including messaging APIs, location-based services, and roaming services. Their solutions help telecoms expose network features while maintaining security and reliability.

Twilio: While primarily known for communications APIs, Twilio also supports telecom network exposure through its APIs, particularly in messaging and voice communications. With the rise of 5G, they are expanding into additional network capabilities for developers.

Sinch and Aduna: Sinch’s network APIs enable businesses to embed scalable, secure communications directly into their digital services, supporting critical functions like two-factor authentication (2FA), identify verification, and fraud prevention. Launched in September 2024, Aduna is focused on simplifying and accelerating the adoption of network APIs, offering seamless access to mobile network capabilities such as authentication and security. With key developer platform partners like Vonage and Google Cloud, Aduna’s collaboration with Sinch will drive further innovation, scale, and operational efficiency for enterprises relying on secure digital infrastructure.

### 2.5.5.3 Innovations (Advantages) Compared to Existing Products/Services

ENVELOPE Network Openness activities build on standardised solutions developed by standardisation bodies (3GPP) and industry best practices (GSMA OP, CAMARA) and prioritise on the detailed specifications of the interfaces mandated by the automotive industry (CAM use cases). ENVELOPE develops end-to-end interoperable prototype systems validated in real-field testbeds exploiting the capabilities offered by existing B5G systems. While few of the competitive solutions listed above are working with CAMARA (such as Vonage and Sinch), there has not been sufficient evidence for the prioritisation on CAM application requirements that ENVELOPE is

promising, or the validation on open-source product developments, including beyond SoTA technologies.

### 2.5.6 Market Feedback

Looking ahead, the automotive industry is highly optimistic about the long-term prospects of 5G network openness. It is expected to provide more robust support for connected car ecosystems, fostering innovation in areas like autonomous vehicles, electric vehicles, and shared mobility. Telecom operators and car manufacturers are increasingly working together to develop tailored 5G services for vehicles. Automakers, especially in the luxury vehicle segment (e.g., Mercedes-Benz, BMW, and Audi), are collaborating with telecom giants such as AT&T, Verizon, Vodafone, and China Mobile to deploy 5G-powered connectivity in vehicles. The expectation is that 5G network openness will help create a standardized approach for delivering in-vehicle infotainment, advanced driver assistance systems (ADAS), and smart mobility solutions. However, complexity in standardisation and the level of coordination needed across stakeholders including OEMs, policymakers, MNOs and other players has led to delays in the deployment of several advanced safety and cooperative automated driving use cases. 5GAA sees the need for increased cooperation within the stakeholder ecosystem to make a significant impact on safety, efficiency, and sustainability. Investment in data exchange and services infrastructure complementing the digitalisation of road infrastructure is a prerequisite to ensure data availability and quality [60].

Similarly, from the GSMA perspective [62], and as already depicted in Figure 11 developer knowledge of network APIs (mostly mobile) is healthy in most regions, including those where 5G deployments are most prevalent – the US, Europe and Middle East. However, in China, only around a third of developers claim a clear understanding of network APIs and this is somewhat counterintuitive considering China's advanced position in 5G, and 5G sales to B2B segments.

### 2.5.7 Conclusions

Through the specification of the Network Exposure Function (NEF), the secure interaction of the network functions with external entities, such as vertical applications and third-party providers, is allowed. However, this exposure is implemented through a well-defined set of standardized Application Programming Interfaces (APIs) at the network level and assumes a deep knowledge of the telecom network that is not obvious for the application developers. ENVELOPE prioritizes the specification and development of simplified network openness through service exposure APIs tailored to the demands of the automotive industry and the Connected Automated Mobility (CAM) and offers a unique value proposition in the 5G for CAM domain, empowering CAM developers and vehicle Original Equipment Manufacturers (OEMs) with advanced 5G capabilities to develop new enhanced applications and services.

By 2025, connected cars are expected to save 11,000 lives annually, reduce 260,000 accidents, and cut 400,000 tons of CO2 emissions. The global number of cellular-connected vehicles has surpassed 300 million, with the market projected to reach $81 billion by 2030. Strategic network openness and V2X support are vital for the sector's growth. Meanwhile, the global telecom API market is set to rise from $319.45 billion in 2025 to $1.41 trillion by 2033. 5G rollout and network exposure APIs present major new revenue opportunities, especially for B2B telecom services.

The Network Exposure API market is highly competitive, featuring telecom leaders, cloud providers, and API platforms like Apigee and MuleSoft. CPaaS companies such as Vonage and Twilio offer telecom APIs, with some collaborating with CAMARA. ENVELOPE focuses on standardized, interoperable solutions aligned with automotive industry needs, validated through real-world testbeds. Unlike many competitors, ENVELOPE emphasizes CAM application requirements and open-source, beyond-state-of-the-art technologies. This targeted approach differentiates it within the evolving B5G ecosystem.

## 2.6 Interoperable, Secure, Trustworthy and Specification-compliant API Management

This is related to Common API Framework (CAPIF). CAPIF is a standardized framework developed by 3GPP (3rd Generation Partnership Project). The goal of CAPIF is to simplify and unify the way APIs are exposed, discovered, and managed across telecommunications networks, particularly in 5G and future networks. It provides a centralized interface for onboarding, discovering, accessing, and monitoring APIs offered by network functions and services, enabling better interoperability, security, and efficiency.

CAPIF will serve as a centralized API exposure and management point in 5G network. CAPIF provides a unified, secure framework for managing 5G APIs (Northbound APIs), supporting service discovery, auditing, and onboarding of external entities. Hosted in a trusted domain, CAPIF allows multiple MNOs to collaborate securely. CAMARA adopts CAPIF as a suitable standard for managing API interactions. CAPIF ensures:

- Secure onboarding of API providers and consumers
- API discovery
- Access control and authorization
- Logging, auditing, and performance monitoring of APIs

The proposed solution is aiming to address the following problems:

- **Fragmentation:** In a multi-vendor and multi-domain 5G environment, each network function or service may expose its APIs in different ways. This leads to inconsistent interfaces and documentation and increased complexity for application developers.
- **Lack of Unified API Discovery and Cataloging:** Developers need to explore APIs from different sources (vendors, network domains), each with its own portal or access method.
- **Lack of Observability and Monitoring for API Usage:** Without a unified framework, tracking how APIs are used is complex.

The rapid adoption of 5G technology across EU member states has significantly increased the demand for telecom APIs. According to the European Commission, as of 2023, approximately 81% of EU households had access to 5G coverage, facilitating the expansion of API use in sectors like healthcare, logistics, and smart cities [70].

The increasing number of large enterprises in the EU is a key driver for the NaaS market. As of 2024, there were over 43,504 large enterprises in the non-financial business economy, highlighting a growing demand for scalable and flexible networking solutions [71].

Globally, according to Grand View Research, the Telecom API market was valued at USD 214.64 billion in 2023. It is expected to expand at a CAGR of 21.3%, reaching approximately USD 827.45 billion by 2030 [72]. For the Network-as-a-Service (NaaS) Market, in 2021 the global NaaS market size was valued at USD 6.67 billion [73]. From 2022 to 2030 it is expected to reach USD 81.82 billion, growing at a CAGR of 32.9%

### 2.6.1 Market Dynamics

#### 2.6.1.1 Drivers

- Explosion of 5G use cases which need specific network capabilities. CAPIF simplifies the exposure of these capabilities through APIs.
- CAPIF enables standard exposure of APIs across different vendors and network domains, helping telcos and simplify third-party onboarding.
- CAPIF supports the demand for real-time network programmability and monitoring by abstracting complex network functions into developer-friendly APIs.
- By exposing network capabilities through standardized APIs, CAPIF enables operators to monetize their infrastructure, e.g., charging for priority traffic.

#### 2.6.1.2 Challenges

- Opening network interfaces to third-party developers raises security challenges.
- Existing API ecosystem which is vendor-specific, making it difficult to standardize.

#### 2.6.1.3 Opportunities

- Open APIs: CAPIF aligns with the Open APIs movement by offering consistent, discoverable, and secure API exposure.
- Network-as-a-service (NaaS): CAPIF is a key enabler of NaaS, where network capabilities are offered to enterprise customers.
- Telecom-cloud collaboration: CAPIF provides a telco-native way to expose network services to cloud developers and integrate across domains.

### 2.6.2 Regional Market Insights

- **Europe:** Strong support from EU-funded projects and standardization bodies like ETSI and 3GPP.
- **North America:** Major telecom operators are investing in API exposure platforms.
- **Asia-Pacific:** Rapid growth in 5G deployments driving interest in CAPIF-aligned architecture.

### 2.6.3 Market Segmentation:

- By User:
  - Third-Party Developers: This segment comprises external developers and independent software vendors who integrate APIs into their own products or build innovative services on top of existing platforms. Their demand drives the need for secure, well-documented, and easily consumable APIs to accelerate development cycles and enable interoperability across ecosystems.
  - Application Developers: Focused on creating user-facing applications, this group relies heavily on APIs to access backend services, data, and platform functionalities. As mobile, web, and cross-platform app usage grows, the need for efficient API management becomes critical to ensure seamless functionality and performance.
- By Application:
  - Internet of Things (IoT): APIs are foundational to managing and integrating diverse IoT devices, enabling real-time data exchange, remote control, and edge analytics. This segment demands scalable, lightweight, and secure APIs capable of supporting high device density and frequent interactions.
  - Edge Computing: Edge deployments rely on APIs for orchestrating localized computing resources and enabling fast, reliable data processing closer to the source. APIs facilitate coordination between edge nodes and central systems, enhancing performance in latency-sensitive applications such as autonomous vehicles and industrial automation.
- By Network Type:
  - 5G Networks: With 5G's promise of ultra-low latency and massive device connectivity, API management plays a critical role in exposing network capabilities, enabling dynamic service provisioning, and supporting real-time applications such as AR/VR and connected mobility.
  - Private Networks: Enterprises deploying private LTE or 5G networks use APIs for configuring network functions, integrating vertical-specific applications, and ensuring secure communication within localized environments. These use cases often require fine-grained access controls and compliance-aware API architectures.

### 2.6.4 Market Maturity

Still in early adoption phase particularly in telecom domain. On the other hand, from a research perspective, more and more EU-funded projects adopted it and use it to explore its capabilities. CAPIF is part of the broader Open APIs endeavor gaining space in new generation networks such as 5G and 6G. As APIs become monetized assets in telecom, frameworks like CAPIF will gain increased relevance.

### 2.6.5 Competitive landscape

#### 2.6.5.1 Main Competitors

The main competitor is Ericsson.

#### 2.6.5.2 Competitive Products

The main competitive product is Ericsson Network Exposure Layer. This exposes 5G capabilities to third-party developers.

#### 2.6.5.3 Innovations (Advantages) Compared to Existing Products/Services

ENVELOPE's system, built on the CAPIF framework, delivers clear advantages over competing solutions by adhering to a standardized, vendor-neutral approach defined by 3GPP. This ensures seamless interoperability across diverse network domains, eliminating the fragmentation often seen with proprietary interfaces. ENVELOPE's implementation includes built-in security features such as robust access control, comprehensive auditing, and automated service discovery, enabling secure and transparent API exposure at scale. Furthermore, its support for multi-domain and multi-vendor API integration positions it as an ideal choice for complex, heterogeneous network environments, where agility, compliance, and cross-ecosystem collaboration are critical.

### 2.6.6 Conclusions

CAPIF fills a critical gap by standardizing how network APIs are exposed and consumed. Its integration of discovery, onboarding and security provides a clear and solid solution to the increasing complexity in 5G service delivery.

As networks become programmable and developers demand faster integration, CAPIF's role will be increasingly vital. While still in its development phase, its alignment with global standards and integration in more projects shows a widespread adoption and a great future.

## 2.7 Monitoring Platform

The Monitoring Platform Module logs, retrieves and visualizes relevant metrics coming from the network, computing infrastructure or vertical service. The Monitoring Platform gathers metrics interacting with other components and the applications deployed on top of several modules. The Monitoring Platform features a graphical interface, powered by Grafana, to display the collected monitoring data. It targets both the experimenters' needs and the trial site evaluation needs.

The ENVELOPE Monitoring Platform addresses several key challenges in CCAM and Intelligent Transport Systems (ITS) testbed environments: (i) the fragmentation of monitoring tools across different infrastructures, (ii) the difficulty in aggregating heterogeneous metrics from vehicles, roadside units (RSUs), the network and computing systems, and (iii) the lack of a unified, real-time visualization layer for stakeholders. It enables consistent monitoring of KPIs related to network,

infrastructure, and application performance, which are critical for validating the safety and reliability of cooperative driving scenarios.

Additionally, it solves the problem of trial reproducibility and transparency. By systematically logging data and offering a centralized view, the platform ensures that test results can be audited, compared, and re-evaluated over time, which is crucial for standards development and regulatory compliance.

The potential market includes research institutions, mobility testbeds, smart city initiatives, and CCAM technology developers across Europe and globally. According to European Commission figures, the CCAM market is projected to reach €62 billion by 2030, with a strong focus on infrastructure-assisted technologies and validation environments. The Monitoring Platform targets a niche within this, with the exact size depending on adoption rates among living labs and pilot sites.

The growth of digital twin test environments and the deployment of AI-based vehicle and infrastructure solutions further increases the demand for robust, interoperable monitoring tools like this platform.

### 2.7.1 Market dynamics

This segment is driven by EU-funded CCAM initiatives, national ITS programs, and increasing private investment in mobility-as-a-service (MaaS). The shift toward data-driven safety validation and regulatory scrutiny on automated driving also pushes the need for traceable, standardized monitoring systems. Stakeholders require platforms that can bridge experimental, pre-commercial, and operational phases, and the ENVELOPE Monitoring Platform is built with that interoperability in mind.

Moreover, the adoption of 5G, C-V2X, and edge computing architectures has increased the need for modular and real-time capable monitoring layers. Platforms must support dynamic environments with diverse data sources, a need that ENVELOPE directly meets.

### 2.7.2 Regional market insights

Europe represents the most mature market for such platforms due to strong regulatory research, and funding support. Countries like The Netherlands, Greece, and Italy - all active in the ENVELOPE project - are leading the deployment of 5G corridors and living labs. As such, early adoption of the platform is most likely in these regions, particularly in public-private test environments.

Beyond Europe, interest is growing in regions like South Korea, Japan, and parts of North America, where integrated CCAM validation is becoming a strategic priority. These regions may follow European precedents, making the platform exportable or adaptable through future standards.

### 2.7.3 Market segmentation

The market can be segmented as follows:

- Public test sites and living labs (government-backed mobility corridors),
- Industry R&D teams (automotive OEMs, telecom operators),
- Research and academia (universities, EU H2020/HEU consortia),
- Infrastructure operators (municipalities, road authorities),
- Third-party validators and certifiers (e.g., TNO, TÜV).

The Monitoring Platform is best positioned for the research & pre-deployment phase but has potential to scale into regulatory validation use cases, especially if integrated with standards-based APIs.

### 2.7.4 Market maturity

The market for mobility monitoring platforms is still emerging and fragmented. While tools like Grafana, Prometheus, or custom-built dashboards are in use, there is no unified product specifically tailored for CCAM testbed environments that offers vertical service integration, real-time edge-to-cloud data aggregation, and standardized KPIs.

This positions ENVELOPE's platform in a first-mover category within the experimentation-as-a-service (EaaS) ecosystem. As EU regulations on CCAM trials become stricter, the demand for structured monitoring platforms will mature quickly.

### 2.7.5 Competitive landscape

#### 2.7.5.1 Main competitors

Two competitor classes have been identified:

- Direct competitors: Commercial network monitoring solutions (e.g., dPACE, Spirent or Datadog) with advanced analytics capabilities. They offer partial tools but no open platforms.
- Academic/Research Tools: Custom-built platforms in other European projects. Normally not available outside the project consortia.

#### 2.7.5.2 Competitive products

**1. dSPACE – Sensor Simulation Monitoring & Data Logging Tools**

dSPACE [74] offers a comprehensive suite of tools for monitoring and simulating sensor environments, especially in the context of autonomous driving system validation. While highly precise and suitable for lab or HiL/SiL testing, their tools are not optimized for large-scale, real-world CCAM trial environments.

**2. Spirent – TTworkbench and TestCenter IQ**

Spirent [75] provides network testing and monitoring tools like TestCenter IQ and TTworkbench, which offer KPI analysis, latency/jitter visualization, and protocol tracing. Though used in automotive V2X projects, these are commercial tools tailored to telecom validation and lack direct support for CCAM vertical services or experiment lifecycle management.

**3. Datadog**

Datadog [76] is a monitoring and analytics platform for cloud applications, servers, databases, tools, and services. It offers infrastructure monitoring, Application Performance Monitoring (APM), log management, security monitoring, and more, with extensive integrations and visualization. If experimenters come from an enterprise background or require a very broad set of monitoring capabilities (including deep APM) beyond what the ENVELOPE platform might offer, Datadog could be an alternative. However, it might be too costly or complex for typical EaaS scenarios focused on specific experiments.

**4. Dynatrace**

Dynatrace [77] is an AI-powered observability platform that provides infrastructure monitoring, APM, digital experience management, and business analytics. It focuses heavily on automation and AI-driven problem detection. Similar to Datadog, Dynatrace offers a very comprehensive (and often premium) solution. Its AI capabilities for automated anomaly detection could be attractive, but its fit depends on the complexity and budget of the experiments.

**5. New Relic One**

New Relic One [78] is an observability platform that allows users to see all their telemetry data - metrics, events, logs, and traces - in one place. It provides tools for full-stack observability, from infrastructure to application and end-user experience.

#### 2.7.5.3 Innovations (advantages) compared to existing products/services

The ENVELOPE Monitoring Platform stands out by combining:

- Modular and extensible architecture.
- Real-time, multi-layer metric collection (network, compute, application).
- Seamless integration with EaaS and CAM trial infrastructures.
- User-friendly visualization via Grafana.
- Option to export data into a dataset that complies with SNS JU's Common Metadata Template.
- Developed and tested in real 5G-CAM project contexts.
- Strong alignment with industry and research needs.

### 2.7.6 Conclusions

The ENVELOPE Monitoring Platform fills an important gap in the CCAM ecosystem by offering a purpose-built, extensible, and standards-aligned solution for real-time monitoring and post-test analysis. It supports the experimental workflows of test sites while following the recommendations from the SNS JU Test, Measurement and KPIs Validation Working Group. With the ongoing digitalization of transport and expansion of cooperative mobility services, this platform can become a reference solution in the European CCAM landscape, and a potential export to global markets.

## 2.8 Experimentation as a service module

The ENVELOPE project foresees providing an Experimentation as a Service (EaaS) module that has to be used by the experimenter to interact with the ENVELOPE Platform to manage all the aspects related to the experimentation. The ENVELOPE Portal is the single point of access of the experimenter towards the ENVELOPE Platform that is deployed in each trial site. The experimenter must first authenticate at the ENVELOPE Portal to access the interfaces towards the ENVELOPE Platform. The interfaces will allow the experimenter to deal with the corresponding back-end modules using a graphical interaction where possible.

The proposed module can be included in the testing as a service market. According to Grand View Research [79], “the global testing as a service market size was estimated at USD 4.54 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of 14.0% from 2024 to 2030. The increasing complexity of software development, involving functionalities and dependencies, necessitates comprehensive testing approaches, driving the demand for Testing as a Service (TaaS). The industry's shift towards agile and DevOps methodologies for faster development requires efficient testing solutions, making TaaS well-suited with its on-demand scalability and expertise.” As per a report by Precedence Research [80], “the global testing as a service market size was valued at USD 4.63 billion in 2023 and is anticipated to reach around USD 17.21 billion by 2033, growing at a CAGR of 14.03% from 2024 to 2033. The rising complexity of software development, involving functionalities and dependencies, necessitates comprehensive testing approaches, driving the demand for testing as a service.”

### 2.8.1 Market Dynamics

The drivers, challenges and opportunities around the Testing as a Service market are shown below.

#### 2.8.1.1 Drivers

- TaaS aligns well with Agile and DevOps, which focus on rapid development cycles.
- TaaS enhances speed, product quality, and time-to-market through flexible and efficient testing.
- It provides access to skilled testers and automation tools, simplifying the testing process.
- Companies using TaaS can concentrate more on innovation and faster product launches.

#### 2.8.1.2 Challenges

- TaaS market may struggle to meet the unique needs of specific industries.
- Industries like healthcare and aerospace require specialized testing due to strict regulations.
- TaaS providers often offer general solutions that may not align with these specific demands.
- Lack of industry-specific expertise can limit the effectiveness of TaaS.
- Organizations in highly regulated sectors may find it difficult to use generic TaaS offerings.

#### 2.8.1.3 Opportunities

- Industries like healthcare, manufacturing, and government are beginning to adopt TaaS to improve software reliability, security, and compliance.
- As these sectors become more software-reliant, the demand for tailored testing services is growing.
- TaaS providers have an opportunity to offer industry-specific solutions and become trusted partners.
- AI and ML are transforming software testing through features like intelligent test case generation and self-healing scripts.
- Test automation offers benefits such as higher efficiency, broader test coverage, and faster feedback.
- Around 40% of organizations are already using AI in software testing.
- The growing adoption of automation is creating new opportunities for testers and TaaS providers.

### 2.8.2 Regional Market Insights

The U.S. TaaS market was valued at USD 1.30 billion in 2023 [80]. It is projected to reach USD 4.82 billion by 2033, growing at a CAGR of 14.10%. An analysis of the U.S. market showed that North America led the market in 2023 with a 39.2% share due to a strong software development industry. On the other hand, Asia Pacific is expected to grow significantly over the next years. Increased cloud computing adoption in Asia Pacific boosts TaaS demand. Moreover, Government support in countries like China and Japan further drives market growth.

### 2.8.3 Market segmentation

The market segmentation is as follows:

- By test type: the functionality segment has generated more than 28% of market share in 2023. However, the security segment is expected to grow the fastest during the forecast period.
- By deployment type: the public segment held a significant share of the market in 2023 while the private segment is poised to grow at a significant rate during the forecast period.
- By end use: In 2023, the IT & telecommunication segment led the market. During the forecast period, the healthcare segment is expected to grow the fastest.

### 2.8.4 Market maturity

The market does not yet exist, and it is not yet clear that the product has potential to create a new market

## 2.8.5 Competitive landscape

### 2.8.5.1 Main competitors

At research level there are some projects that are also working (or have worked) on experimentation as a service modules. Some examples are recapped hereafter: iCORA platform, 5G-VINNI, 5G EVE, 5Genesis and 6G-SANDBOX.

### 2.8.5.2 Competitive products

**i-CORA platform**

i-CORA (Innovative, Cloud-native, Open, Robust, and Automated) is a large scale multivendor, cloud native experimentation and testing platform for new 5G services for European operators, service providers, and enterprises. i-CORA has been built by multiple vendors to support the research and innovation demands from EU projects, vertical use cases, and mobile operators' business areas. The i-CORA platform serves EU projects such as 5G- SOLUTIONS, FUDGE-5G, 5G-HEART, 5GMediaHUB1, FIDAL2, COMMECT4, IMAGINE-B5G, and 5G-EMERGE5. It consists of four parts: a main multi-vendor platform (MVP) offering an E2E public 5G network; a set of Mobile Private Networks (MPNs); a set of Networks on Wheels (NOWs); and an Open-Source Platform (OSP).

**5G-VINNI**

The 5G-VINNI moving experimentation facility site concentrates on the research, development, experimentation, validation and demonstration of customized solutions for satellite integration into 5G, with focus on satellite backhauling solutions.

**5G EVE**

5G EVE is the European 5G validation platform for extensive trials. It is one of three 5G PPP infrastructure projects started on 1st July 2018. The goal is to implement and test advanced 5G infrastructures in Europe.

**5Genesis**

The "Genesis of 5G" has entered the crucial phase of experimentation, and currently faces the challenge to validate the 5G network KPIs and verify the 5G technologies with an end-to-end approach. Towards this objective, a key challenge is to integrate all the highly diverse results and technologies from EU, global as well as internal (corporate) R&D projects, to "glue together" the 5G picture and unveil the potential of a truly full-stack, end-to-end 5G platform, able to meet the defined KPI targets. In this context, the main goal of 5GENESIS will be to validate 5G KPIs for various 5G use cases, in both controlled set-ups and large-scale events. This will be achieved by bringing together results from a considerable number of EU projects as well as the partners' internal R&D activities in order to realise an integrated End-to-end 5G Facility.

**6G-SANDBOX**

The 6G-SANDBOX project[4] brings a complete and modular facility for the European experimentation ecosystem (in line and under the directions set by SNS JU), which is expected to support, for the next decade, technology and research validation processes needed in the pathway towards 6G.

**5G-IANA**

The 5G-IANA project[5] provided an open 5G experimentation platform to enable the development, deployment and testing of Automotive related 5G application.

**VITAL-5G**

The VITAL-5G project[6] proposes a 3rd party experimentation that provides a centralized access point for all the experimentation services offered by the system to the various actors that interact with VITAL-5G.

**5GASP**

The 5GASP project[7] introduced a fully automated and self-service experimentation and certification platform for SMEs.

#### 2.8.5.3 Innovations (advantages) compared to existing products/services

A specific technical comparison between the identified comparable solutions has not been performed at the moment. However, the innovative aspects of the ENVELOPE EaaS module are related to its ease of use and to the fact that it facilitates users' interaction. Moreover, it is not a whole platform and can be adapted to specific cases and uses. Finally, if released as an open-source solution, a wider adoption among the developers' community can be envisaged in the short and mid-term.

### 2.8.6 Conclusions

The Experimentation as a Service (EaaS) module has been conceived to be used by the experimenter to interact with the ENVELOPE Platform to manage all the aspects related to the experimentation. Examples of similar solutions have been found at research level, however there is no evidence of similar solutions already in the market. Even if the short and mid-term scientific exploitation is the most feasible, potential commercial exploitation can be foreseen in the mid and long term: this module can be offered (or eventually adapted / integrated in other existing platforms) to organizations and R&D departments that need to make experiments using a simple and accessible interface that facilitates the experimenter action.

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[4] https://6g-sandbox.eu
[5] https://www.5g-iana.eu
[6] https://www.vital5g.eu
[7] https://www.5gasp.eu

# 3 ENVELOPE Ecosystem

ENVELOPE fully understands the challenges of CAM and tries to address them with a special focus on the dynamic interaction between the different service and network layers. ENVELOPE acknowledges the need for advanced vertical capabilities such as low latency computing, intelligent traffic management and real-time reconfiguration of the network. By integrating predictive QoS and AI driven orchestration models, ENVELOPE allows CAM services to be dynamically adapted to the changing network conditions, vehicles behavior and to mobility patterns, ensuring thus the continuity and reliability even in highly volatile environments.

ENVELOPE also recognizes that existing 5G and cloud architectures are not sufficient to allow the control and transparency for vertical sectors like CAM. In response, it offers open and reconfigurable APIs supporting the on-demand customization of services across different domains. Through the advanced NEF and PCF services, the selective multi-connectivity and the dynamic updates of UE Route Selection Policy (URSP), vertical sectors can influence the way that resources are allocated as well as how network slices are managed in near real-time. This capability is crucial for the development of safety-critical applications like tele-operated driving and the response to urgent situations where network responsiveness and context awareness are of paramount importance.

To support such innovation, ENVELOPE brings together a diverse ecosystem of interested stakeholders, including mobile network operators, application providers, edge data centers providers, telecom and tier-1 providers, vehicle manufacturers as well as Traffic Management Center (TMC) and road infrastructure operators. This cross-sectoral collaboration is mandatory in order to achieve scalable, interoperable and sustainable CAM applications. As the complexity of the interactions between vehicles and networks is increasing, ENVELOPE sets a plan for future-proof service aware B5G infrastructures that can support the next generation of connected and automated transport systems.

This section outlines the relationships and interactions among various roles within the ENVELOPE ecosystem. This initial step is crucial for gaining a comprehensive understanding of the ecosystem and its characteristics. It will prove instrumental in exploring associated business models concerning ENVELOPE in the subsequent phases of the project.

Initially, the various roles of actors participating in the ecosystem are presented. The section concludes by presenting the initial reference model around ENVELOPE. The following definitions are used in the following sections:

- **Actor:** an entity that participates in the business model. It can provide or consume services.
- **Role:** the functionality of each actor that participates in the business model. An actor can take one or more of the roles, while a role can be undertaken by several actors.
- **Relationship:** the interaction between two roles in the model.

## 3.1 Actors and Roles

In this new era, CAM involves a number of actors cross-collaborating in the value chain. These actors include not only traditional ones like vehicle manufacturers and road operators, but also actors from other industries like Information and Communications Technology (ICT).

Many actors are entering the market following different approaches, either collaborating or competing with traditional actors. Given the rapid growth of both CAM and telecoms, these actors are actively positioning themselves in the value chain, assessing all opportunities to deliver enhanced value and maximize profit potential.

Considering the ENVELOPE architecture and use cases (UCs), the proposed solution plays a central role in the ecosystem, adopting the proposed tools. The subsequent paragraphs (Table 1) describe the key actors and roles in this dynamic landscape.

Table 1: Actors and their Roles with examples, of ENVELOPE ecosystem

| Actor | Role | Example |
|---|---|---|
| **ENVELOPE** | ENVELOPE is developing and offering APIs and specialized functionalities like NWDAF to MNOs and Telecom Operators. | Can be an independent entity or part of the MNOs or telecom vendors. |
| **Mobile Network Operators (MNOs)** | Provide 5G/B5G connectivity and advanced network capabilities (e.g., slicing, NEF, PCF, PQoS). They host and manage UPFs, EDC/MEC and participate in cross-domain orchestration. MNOs expose capabilities via open APIs and support URSP provisioning. | Orange, Deutsche Telekom / Cosmote,Telefonica, Verizon, AT&T, etc. |
| **Telecom Vendors** | Develop and provide infrastructure and network components (e.g., core network elements, NEF/PCF modules, orchestration frameworks, RAN). They also provide components like 5G modems to vehicle manufacturers. | Ericsson, Nokia, Athonet. |
| **Tier-1 Suppliers** | Develop critical automotive systems (e.g., OBUs, sensor platforms) and integrate them with communication modules. They collaborate with OEMs and ensure compatibility with networked features. | Bosch, Continental, Links |
| **Road Operators** | Deploy, operate and maintain road infrastructure and provide real-time data (e.g., topology, construction, road conditions). Facilitate sensor deployment and integration into systems (e.g. Digital Twin) for improved road awareness. | Government transportation agencies such as the Department of Transportation in the USA, Transport for London (TfL) in the UK, and the Roads and Transport Authority (RTA) in Dubai. |

| | | |
|---|---|---|
| **Traffic Management Centre (TMC) Operators** | They oversee the real-time monitoring and control of traffic flow. TMC operators play a central role in optimizing road network efficiency, ensuring safety, and supporting the integration of AVs. They are responsible for managing intelligent traffic management systems, coordinating responses to incidents, and facilitating communication between vehicles and infrastructure. These operators utilize advanced technologies and data analytics to make informed decisions, adapt traffic signal timings, and implement dynamic strategies to minimize congestion. They can also interact with MEC-based Digital Twin services for real-time event reconstruction and coordination. | Regional transportation agencies, city TMCs, and private entities specializing in traffic control and monitoring, such as Siemens Mobility, Kapsch TrafficCom, and Iteris. This role can also be played by road infrastructure operators. |
| **Original Equipment Manufacturers (OEMs)** | Produce connected vehicles (CAVs) and integrate OBUs. Collaborate with MNOs and Tier-1s for service deployment, vehicle-to-network interface support, and URSP adaptation. | Tesla, Waymo, and traditional automakers such as BMW, Ford, General Motors, Stellantis, etc. |
| **CAM Application Developers and Providers (SMEs)** | Create and deploy CAM vertical applications (e.g., tele-operation, traffic prediction, emergency management) that utilize exposed 5GS capabilities (e.g., PQoS, NEF APIs). | Bosch, Waymo, Aurora Innovation, Aptiv, Mobileye (Intel),<br>Cruise (GM Cruise) owned by General Motors, Baidu Apollo, NVIDIA, TomTom, AutonomouStuff (Acquired by Hexagon), Renovo |
| **End Users** | CAV and Conventional Vehicle Users, Vulnerable Road Users (VRUs). They directly or indirectly receive CAM services and their benefits | Vehicle owners, drivers, passengers or pedestrians, freight and logistics, or providers of public services. |
| **Public Entities / City Councils** | Define regulatory frameworks, enable pilot deployments in urban areas, and ensure public safety. They may provide access to traffic infrastructure | Commune di Torino |

| | | |
|---|---|---|
| | and act as end-users of safety/efficiency applications. | |
| **Research and Technology Organisations (RTOs)** | Drive innovation in several domains. Lead standardization-aligned research, experimentation, and provide validation methodologies. | National Center of Scientific Research Demokritos, ATHINA |

## Incentives and benefits for the different roles to participate in ENVELOPE ecosystem

This section discusses the anticipated developments and benefits for the different roles of the ecosystem stemming from the introduction of ENVELOPE.

### 3.1.1 ICT infrastructure providers: Mobile network operators (including EDC/MEC providers) and telecom vendors

ICT infrastructure providers are expected to gain significant benefits as enablers of CAM. Engagement with the ENVELOPE can assist ICT infrastructure providers in discerning emerging market and business challenges, recognizing potential opportunities, and promptly identifying novel business models. Furthermore, this interaction enables ICT infrastructure providers to venture into the lucrative automotive market, expand their portfolio of applications and premium, tailored connectivity services (e.g., for teleoperation or emergency vehicles), leading to differentiation from competitors. In addition, new revenue streams can be generated mainly through the exposure of network slicing and customization services. In addition, ICT infrastructure providers can experience an increase in the consumption of their edge and cloud services due to the need for local data processing and decision-making. Finally, ICT infrastructure providers are expecting an enhanced operational efficiency via AI-powered zero-touch orchestration and predictive QoS, reducing manual intervention and improving SLA management.

### 3.1.2 Road operators/TMC operators and Public Authorities

Road operators and TMC operators stand to gain valuable insights from the data shared by CVs, enabling the implementation of innovative strategies and tactics for effective and optimized traffic management. This optimization not only enhances CAM services, including emergency services, but also improves overall traffic flow and road capacity. The ability to interact with CAVs and VRUs empowers road operators to regulate demand by establishing guidelines for vehicle behaviour. Real-time situational awareness and decision-making for road segments or intersections can also be achieved through the Digital Twin support at MEC level.

Moreover, the utilization of their infrastructure during the UCs provides them with valuable insights into necessary upgrades. This may include the introduction of new equipment with enhanced capabilities. Collaborating with big players in the industry becomes crucial, as they can articulate their expectations and requirements for future automotive applications, guiding the creation of innovative solutions.

### 3.1.3 CAM Application Developers and Providers (SMEs)

The advanced connectivity and APIs exposed from MNOs, the availability of a high volume of data from different sources as well as the need to combine different wireless communication systems allows CAM application developers and providers to develop advanced services and applications focused on the special needs of CAM vertical. These factors also contribute to the establishment and growth of dedicated development teams, specifically focused on crafting ENVELOPE solutions, expansions, and interfaces.

### 3.1.4 Vehicle Manufacturers (OEMs) and Tier 1 Suppliers

The automotive industry is expected to enhance the capabilities of connected and automated vehicles to meet the evolving needs of next generation mobility. New strategies for data generation and sharing will be developed, enabling vehicles to share information. Vehicles will incorporate new functionalities to improve road safety and traffic efficiency. Furthermore, active involvement in ENVELOPE UCs empowers them to comprehend the essential requirements for deploying novel services. This understanding enables the adaptation of both hardware and software in their vehicles, ensuring preparedness for the market entry of these applications. This includes for example the ability to deploy CAM-specific logic on On-Board Units (OBUs) that communicate directly with the 5GS, unlocking low-latency applications like collision avoidance and platooning. In addition, ENVELOPE can lead to improved integration of vehicle data (e.g., location, status, planned route) into the network for real-time service optimization as well as the integration of advanced communication features (e.g., ATSSS, URSP, MEC migration), characterizing next generation vehicles.

### 3.1.5 Research and Technology Organisations (RTOs)

For the Research and Technology Organisations community, ENVELOPE offers a valuable opportunity to work and become familiar with B5G technologies through the provided cutting-edge tools and data sets. In such an environment, RTOs can innovate across multiple domains, like AI-driven networking, zero-touch orchestration, and vehicular communications. Within ENVELOPE, RTOs can also collaborate with well-known companies in the field, gaining knowledge from the co-design of proposed solutions and tools. Moreover, RTOs are able to validate future 6G enablers such as intent-based orchestration frameworks and predictive service management, helping reduce the gap between theoretical developments and industry-ready solutions.

### 3.1.6 End users

End Users are expected to gain significant benefits from the introduction of ENVELOPE. In detail, the following benefits are anticipated:

- **Enhanced Safety and Reliability**

- Lower latency and higher reliability in communications (enabled by MEC, multi-connectivity, and dynamic QoS) means that critical services like collision avoidance, emergency braking, or hazard alerts work faster and more reliably.
- With selective traffic duplication, only the most important safety data is sent redundantly, improving the robustness of time-sensitive CAM services.

- **Better Mobility Experience**
  - Services such as real-time route optimization, platooning, safe teleoperation, or traffic flow coordination can dynamically adapt to network and environmental conditions, making the driving experience smoother, more efficient, and less stressful.
  - Digital Twins hosted at the edge offer accurate, localized road and traffic information, improving situational awareness and decision-making for automated or semi-automated vehicles.
- **Seamless and Consistent Service**
  - With ENVELOPE's support for service continuity in roaming and cross-operator orchestration, users benefit from consistent performance, even when moving across regions served by different network operators.
  - Personalized connectivity (via URSP and PCC) allows vehicles or user devices to automatically adjust network configurations to meet specific service preferences (e.g., low-latency for gaming or media streaming, high-reliability for navigation).
- **Increased Trust and Transparency**
  - Through APIs and predictive QoS, services become more responsive and adaptive to network conditions, leading to fewer disruptions or unexplained slowdowns.
  - Proactive quality notifications (IQNs) enable apps and services to inform users about anticipated performance changes, empowering them to make informed decisions (e.g., re-routing or adjusting driving behavior).

## 3.2 ENVELOPE Reference Model

The next phase involves delineating the relationships among stakeholders in the ENVELOPE environment. The associated reference model encompasses a diverse array of actors and a complex value network. Figure 15 illustrates ENVELOPE reference model, outlining all participating actors, relationship interfaces, and revenue streams.

Definitions:

- The direction of arrows in the model signifies the flow of services.
- Revenue flow is considered to move in the opposite direction. In certain instances, there is bidirectional revenue sharing between two roles.
- The rectangle with a dotted line symbolizes an actor, which may assume one or more roles. The rectangular boxes within the dotted-line rectangles depict these roles.

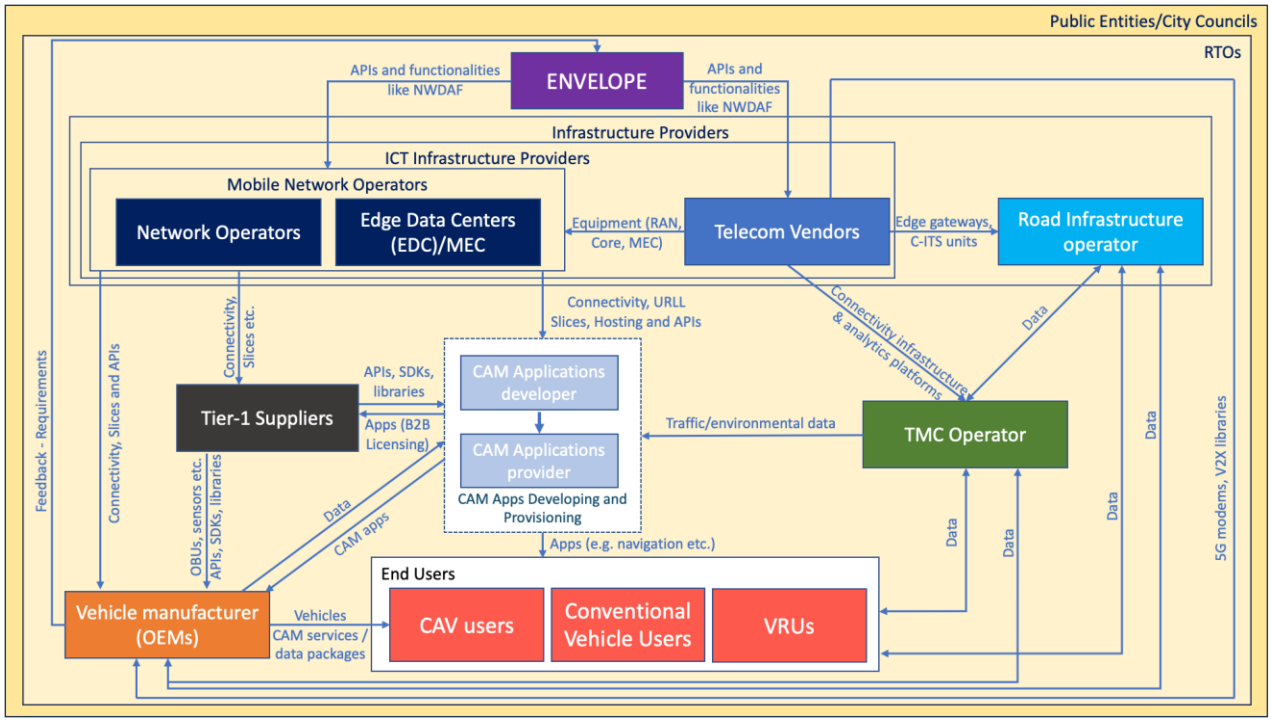


Figure 15: ENVELOPE reference model

The business relationships within the reference model are outlined as follows:

- **ENVELOPE:**
  - **Description:** Represents the relationship between actors for the provisioning of APIs and functionalities like NWDAF.
  - **Participants:** ENVELOPE provides APIs and functionalities to MNOs and telecom vendors.
- **MNOs:**
  - **Description:** A broad term encompassing various resources (connectivity, computational resources, slices, APIs etc.) provided by network operators and EDC/MEC providers.
  - **Participants:**
    - MNOs provide connectivity, slices and APIs to OEMs
    - MNOs provide connectivity and slices to Tier-1 suppliers
    - MNOs provide connectivity, Ultra-Reliable Low-Latency (URLL) Slices, hosting and APIs to CAM application developers and providers.
- **Telecom Vendors:**
  - **Description:** A broad term encompassing various components and platforms provided by telecom vendors.
  - **Participants:**
    - Telecom vendors provide Equipment (RAN, Core, MEC, etc) to MNOs

- Telecom vendors provide Edge gateways, C-ITS units to Road Infrastructure Operators
- Telecom vendors provide 5G modems, V2X libraries, etc, to OEMs
- Telecom vendors provide connectivity infrastructure & analytics platforms to TMC operators.

- **Tier-1 suppliers:**
  - **Description:** A broad term encompassing various automotive systems, APIs, SDKs and libraries.
  - **Participants:**
    - Tier-1 suppliers provide OBUs, sensors, APIs, SDKs, libraries to OEMs
    - Tier-1 suppliers provide APIs, SDKs, libraries to CAM application developers and providers.
- **Road Infrastructure Operators:**
  - **Description:** Represents the relationship between actors for the exchange of data.
  - **Participants:** Road Infrastructure Operators provide data (including alerts) to TMT operators, end users and OEMs.
- **TMC Operators:**
  - **Description:** Represents the relationship between actors for the exchange of data.
  - **Participants:** TMC Operators provide data (including alerts) to road infrastructure operators, CAM applications developers and providers, end users and OEMs.
- **CAM applications developers and providers:**
  - **Description:** Represents the relationship between actors for the provisioning of applications.
  - **Participants:** CAM applications developers and providers deliver applications to Tier-1 suppliers, OEMs and end users.
- **OEMs:**
  - **Description:** Represents the relationship between actors for the provisioning of vehicles data and feedback provided by the vehicle manufacturer to end users.
  - **Participants:** Vehicle manufacturers provide
    - Vehicles, CAM services / data packages to end users.
    - Feedback – Requirement for ENVELOPE in order to develop APIs focused on CAM vertical needs.
    - Data to TMC operators and road infrastructure operators.
- **End users:**
  - **Description:** Represents the relationship between actors for the exchange of data.

- **Participants:** End users provide data to TMC operators and road infrastructure operators, helping them to optimize traffic and take informed decisions.

It should be highlighted that the ENVELOPE reference model is the most general one, including all the potential stakeholders involved in the provision of advanced CAM services and applications over advanced 5G infrastructure. In this reference model, ENVELOPE plays the role of a provider of specialized APIs, functionalities and network intelligence services like NWDAF and dynamic network exposure interfaces focused on the CAM vertical needs. ENVELOPE can be either an independent entity offering these capabilities or be incorporated within MNOs and/or telecom vendors activities. Another potential merger is between network operators and EDC/MEC providers under the umbrella of the Mobile Network Operators. All these mergers can be revisited in the next phases of WP7 when the business models will be investigated.

The choice of the business model is of paramount importance since it determines not only the delivery of ENVELOPE offerings, but also who controls the access to the advanced network capabilities like slices management, service driven routing or pQoS. ENVELOPE offerings can be exposed to CAM application developers and OEMs through MNOs and telecom vendors who can incorporate them in their commercial platforms. An alternative option (not taken into account in this reference model) is to be directly exposed to CAM application developers and OEMs.

It is interesting to note that the value proposition of ENVELOPE depends on the uninterrupted exchange of context-rich data between ecosystem's stakeholders. APIs allow the bi-directional flow of information between vehicles, network domains and applications including data such as vehicles trajectories, application-layer QoS needs, and network analytics. This interaction enables the service-aware networking, allowing MNOs, applications developers and public authorities to optimize service delivery in real time. The ability to collect and interpret such data via components like NWDAF provides a foundation not only for improved CAM services, but also for the broader evolution towards data driven and predictive 6G networks.

# 4 Factors affecting the market adoption and evolution of ENVELOPE

This section aims to assess the various challenges that are related to the successful adoption of ENVELOPE solutions. In order to identify the barriers and drivers of the uptake of ENVELOPE an expert survey was conducted to rate the different criteria that are expected to be relevant to its success. To assess the relative importance of these criteria, the AHP method was selected as the most appropriate. A set of criteria and their corresponding sub-criteria were selected, and an online survey was implemented. Experts from the ENVELOPE project were invited to express their opinions regarding the factors that will mostly influence the future of the ENVELOPE solution. The responses collected and processed to derive the results.

## 4.1 Decision-making using the AHP framework

In this sub-section, the methodology used to identify the factors affecting ENVELOPE market adoption and evolution is initially presented. The hierarchy along with the identified factors and sub-factors are provided and explained. The questionnaire drafted to conduct the survey is then described. Finally, the results derived from the implementation of the AHP methodology are discussed.

### 4.1.1 Methodology

AHP was proposed and developed by Thomas Saaty [81] in the early 1970s mainly for military purposes. The AHP is a multi-criteria decision-making approach. In the past, AHP was extensively used covering several application areas such as education [82], engineering [83], industry [84], manufacturing [85] and resource allocation [86]. Recently, AHP was widely used for selecting and ranking alternatives in the field of ICT [87]-[90].

AHP is a structured technique for dealing with complex decisions. It describes a rational and comprehensive framework for decomposing an unstructured complex problem into a multi-level hierarchy of interrelated criteria, sub-criteria and decision alternatives. By incorporating judgments on qualitative and quantitative criteria, AHP manages to quantify decision makers' preferences. The priorities of criteria, sub-criteria and alternatives are finally reached by combining these judgments.

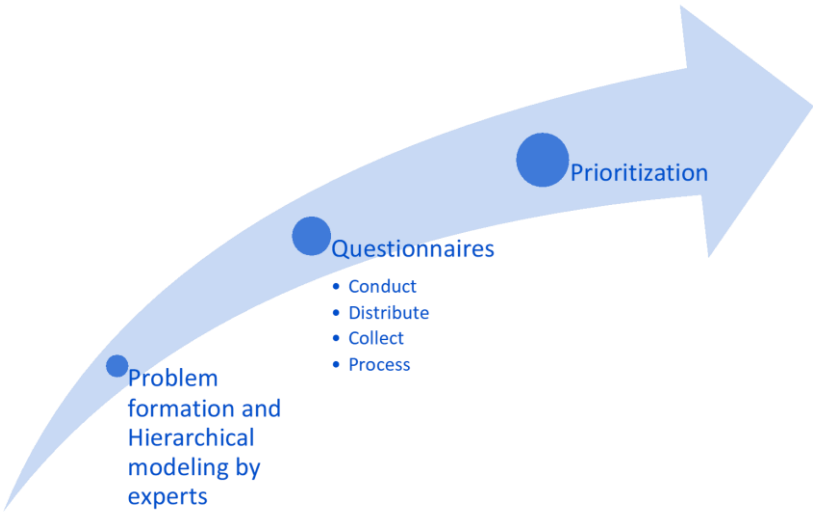


Figure 16: Analytic Hierarchy Process (AHP) steps

Figure 16 illustrates the required steps of AHP. In the first step (Step 1), the problem that is investigated is formed while criteria and sub-criteria contributing to objective's satisfaction are determined through interviews and/or group discussions with experts. The multi-level hierarchy is then constructed (Figure 17) consisting of three levels. In the first level, the objective under investigation is shown. In this work, the factors affecting the adoption and evolution of ENVELOPE and its proposed solution in general is examined. In the next level, the criteria, $C_{rk}$ with $k$=1,2,…,$N$ and $N$ the total number of criteria, participating in the decision-making process, are determined. Criteria should be general enough, incorporating several features resulting in a rough description of the objective. In the lower level, criteria are further analysed into their sub-criteria $SC_{rjk}$, where $j$=1,2,…,$M_k$ and $M_k$ is the number of sub-criteria under criterion k. Sub-criteria represent a specific feature characterizing a criterion. Identification of criteria and sub-criteria is accomplished based on the focus of their preferential independence.

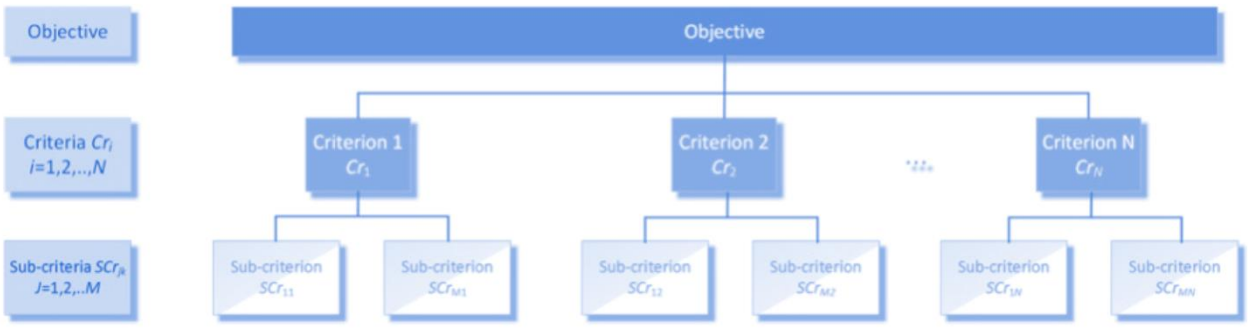


Figure 17: Multi-level hierarchy of interrelated criteria and sub-criteria

Once the hierarchical structure is constructed and criteria and sub-criteria are determined, appropriate questionnaires are conducted and distributed to experts (Step 2). This procedure is based on pairwise judgments of experts from the second to the lowest level of the hierarchy. In

each level, the criteria (sub-criteria) are compared pairwise according to their degree of influence and based on the specified criteria in the higher level. The described comparisons are performed using the standardized nine-level scale shown in Table 2.

Table 2: The Saaty Rating Scale

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | The two criteria contribute equally |
| 3 | Moderate importance | Experience and judgment favour one of the criteria |
| 5 | Strong importance | A criterion is strongly favoured |
| 7 | Very strong importance | A criterion is very strong dominant |
| 9 | Extreme importance | A criterion is favoured by at least an order of magnitude |
| 2, 4, 6, 8 | Intermediate values | Used to compromise between two of the above numbers |

The set of pairwise comparisons on the $N$ criteria results in an $N$ x $N$ evaluation matrix $A=[A_{ij}]$ in which the elements $A_{ij}$ (>0) represent the relative importance of criterion $Cr_i$ compared to $Cr_j$. It should be noted that $A_{ii}=1$ for every $i$ while matrix A is symmetrical across the main diagonal, that is $A_{ji}=1/A_{ij}$. The same steps are followed regarding sub-criteria of each criterion $k$ and the results are summarized in a similar to $A$ matrix called $A_k$.

The last step (Step 3) towards the evaluation of the objectives is the estimation of criteria and sub-criteria weights, wk and sjk respectively. This requires the calculation of the principal eigenvector $v=[v_k]$ (or $u_k=[u_{ik}]$) that is the eigenvector corresponding to the maximum eigenvalue $\lambda_{max}$ (principal eigenvalue) of matrix $A$ (or $A_k$). The weights of criterion $k$ and its sub-criterion $j$ are given by:

$$w_k = \frac{v_k}{\sum_{i=1}^{N} v_i} \quad (1)$$

$$s_{jk} = \frac{u_{jk}}{\sum_{i=1}^{M_k} u_{ik}} \quad (2)$$

where $N$ and $M_k$ is the number of criteria and sub-criteria of criterion k respectively.

### 4.1.2 Consistency of pairwise comparison matrices

In order to maintain a certain quality level of a decision, the consistency of the data should also be investigated during the analysis. It should be noted that the rank of matrix $A$ (or $A_k$) equals 1 and $\lambda_{max}=N$ (or $M_k$) if the pairwise comparisons are completely consistent. In this case, weights can be

estimated by normalizing any of the columns or rows of $A$ ($A_k$). A consistency index ($CI$) was introduced by Saaty in 1977 [81]:

$$CI = \frac{\lambda_{max} - N}{(N-1)} \quad (3)$$

where $\lambda_{max}$ is the largest (maximum) eigenvalue and $N$ is the number of criteria. The final consistency ratio ($CR$), showing how consistent the judgments have been relative to large samples of purely random judgments, is given by:

$$CR = \frac{CI}{RI} \quad (4)$$

where $RI$ is the random index calculated as the average $CI$ across a large number of randomly filled matrices using the scale described earlier in this section. The random indices for several values of $N$ were calculated by Saaty in 2003 [91] and are given in Table 3. The consistency ratio should be less than 0.1. A $CR$ larger than the tolerable level of 0.1 demonstrates the need to exclude the pairwise comparison matrix of this respondent for further analysis so as not to affect the overall accuracy of the results.

Table 3: RI values for different values of *n*

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

## 4.2 Determining the set of criteria and factors to be used in the surveys

For the purpose of identifying the factors that influence the adoption of ENVELOPE solutions, a survey was designed in WP7 in line with the AHP methodology. For this purpose, the following set of criteria covering a wide range of factors were initially defined:

- ENVELOPE Technical Features
- Business and Strategy
- Acceptance / Flexibility

Each of these criteria was further broken down into sub-criteria which are usually indicative attributes that can be quantified and are closely related to the criteria. A brief description of the criteria and their sub-criteria is shown in Table 4.

Table 4: Description of criteria and sub-criteria

| (sub-)Criterion | Explanation |
|---|---|
| **Cr1: Technical features** | Features that manage the operation of the systems/networks and associate with the performance/quality of service such as low latency, reliability, etc. |

| (sub-)Criterion | Explanation |
|---|---|
| **SCr1.1: Predictive QoS as a service** | The ability to estimate the expected QoS from the network to be delivered to the application, enabling it to take proactive decisions in case of performance degradation. Such decisions are aimed at ensuring the safety of the CCAM service at hand. |
| **SCr1.2: AT-SSS-compatible multi-connectivity support** | The ability to use parallel network connections (e.g. one 3GPP like 5G and one non-3GPP access network like ITS-G5 or conventional Wi-Fi). It provides enhanced reliability and lower latency. |
| **SCr1.3: Zero-touch management** | It refers to a fully automated approach formanaging, deploying, and orchestrating network and IT services without the need for human intervention. It leverages advanced technologies such as artificial intelligence (AI), machine learning (ML), intent-based networking, and policy-driven automation to simplify operations and ensure seamless service delivery. |
| **SCr1.4: Northbound API exposure** | It refers to the process of making APIs available at the higher layers of a network or system architecture to enable interaction between the network's core functionalities/capabilities and external applications or services. These APIs allow external entities, such as business applications, vertical industries, or service orchestration platforms, to access and leverage network capabilities, data, and services in a programmatic, flexible, and standardized manner. |
| **SCr1.5: Quality on demand, traffic influence** | The ability of a network to dynamically adapt its Quality of Service (QoS) and traffic management mechanisms to meet the specific and real-time requirements of applications, users, or vertical industries. This involves proactively influencing network traffic (actively shape, reroute, or prioritize traffic flows) to ensure optimal performance |

| (sub-)Criterion | Explanation |
|---|---|
| | for high-priority or time-sensitive use cases while maintaining overall network efficiency. |
| **SCr1.6: Service continuity in cross-domain environments e.g., service migration** | The ability to ensure uninterrupted delivery and operation of a service when it transitions across different administrative, or technological domains. This is particularly critical in distributed, multi-domain network environments, such as 5G-Advanced and Beyond 5G ecosystems, where services often span multiple operators, infrastructures, or network slices. |
| **Cr2: Business and strategy** | Aspects related to the business perspectives such as new market opportunities, cost and new business models. |
| **SCr2.1: Cost - Pricing models and affordability for stakeholders** | Induced cost related to hardware, software, installation and maintenance, translated into an affordable price for customers. |
| **SCr2.2: New business models** | Innovative approaches to creating, delivering, and capturing value driven by technological advancements of ENVELOPE and CCAM in general. These models redefine traditional ways of doing business, enabling organizations to stay competitive, unlock new revenue streams, and adapt to changing economic or industry landscapes. |
| **SCr2.3: Market growth opportunities** | The potential to create, access, or expand into previously untapped or emerging markets by identifying new customer needs, technological advancements, trends, or shifts in industry landscapes. |
| **Cr3: Acceptance / Flexibility** | It refers to the overall usability of the system and incorporates many user-related concerns. |
| **SCr3.1: Secure data transfer (security and privacy)** | Measures and protocols implemented to ensure the confidentiality, integrity, and availability of exchanged data. |
| **SCr3.2: Regulatory issues** | Regulatory issues include information exchange, traffic management policies, |

| (sub-)Criterion | Explanation |
|---|---|
| | emergency services, directives setting out minimum safety requirements, etc. |
| **SCr3.3: Compliance to standards and specifications** | The system must follow requirements imposed by the standardization bodies and fora. In addition, the system meets the listed acceptance criteria. It also includes compatibility with legacy systems. |
| **SCr3.4: Scalability** | The ability of systems and processes to adapt and expand dynamically in response to changing demand, market conditions, and operational requirements. |

The full list of the criteria and their sub-criteria is illustrated in the hierarchy of Figure 18.

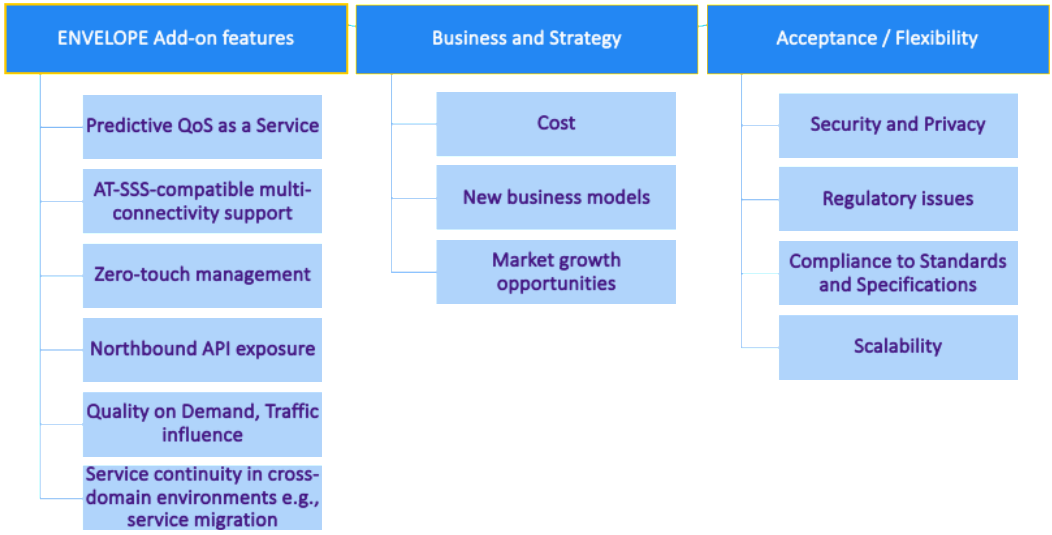


Figure 18: ENVELOPE hierarchy

### 4.2.1 Survey description

The survey[8] was implemented in the form of an online set of questions created using LimeSurvey[9], an open-source tool for web surveys.

[8] https://incites.eu/ENVELOPE/index.php/343784?lang=en
[9] https://www.limesurvey.org/

An introductory page provides information on the project and the AHP methodology as portrayed indicatively in the following figures.

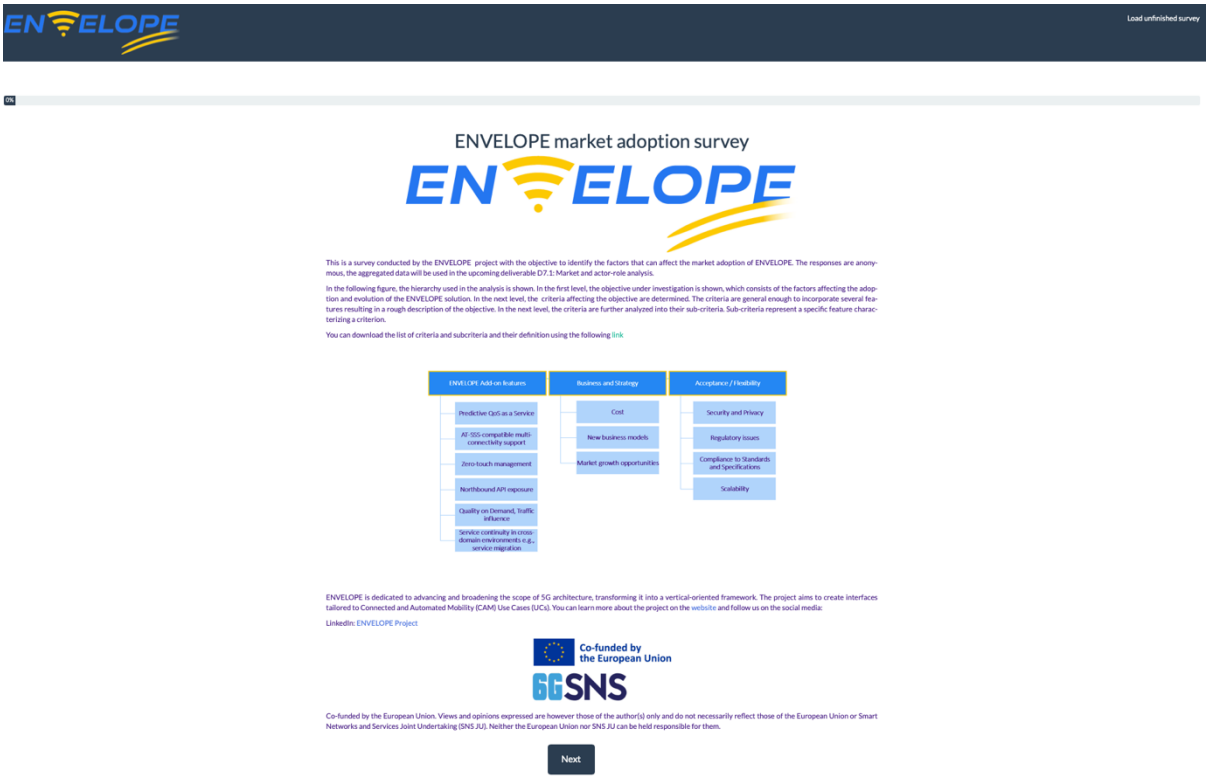


Figure 19: ENVELOPE survey introductory page

The following figure depicts an example of the AHP question implementation in the survey. The necessary calculations were performed using Matlab, leading to an estimation of the weights signifying the importance of criteria and sub-criteria. The responses were strictly anonymous. A brief info sheet was presented to inform responders about the purpose of the survey. In addition, a downloadable file containing detailed descriptions of the criteria and sub-criteria has been incorporated for further reference. Participants in the survey can access this document to gain a comprehensive understanding of the analytical framework used in assessing ENVELOPE solutions.

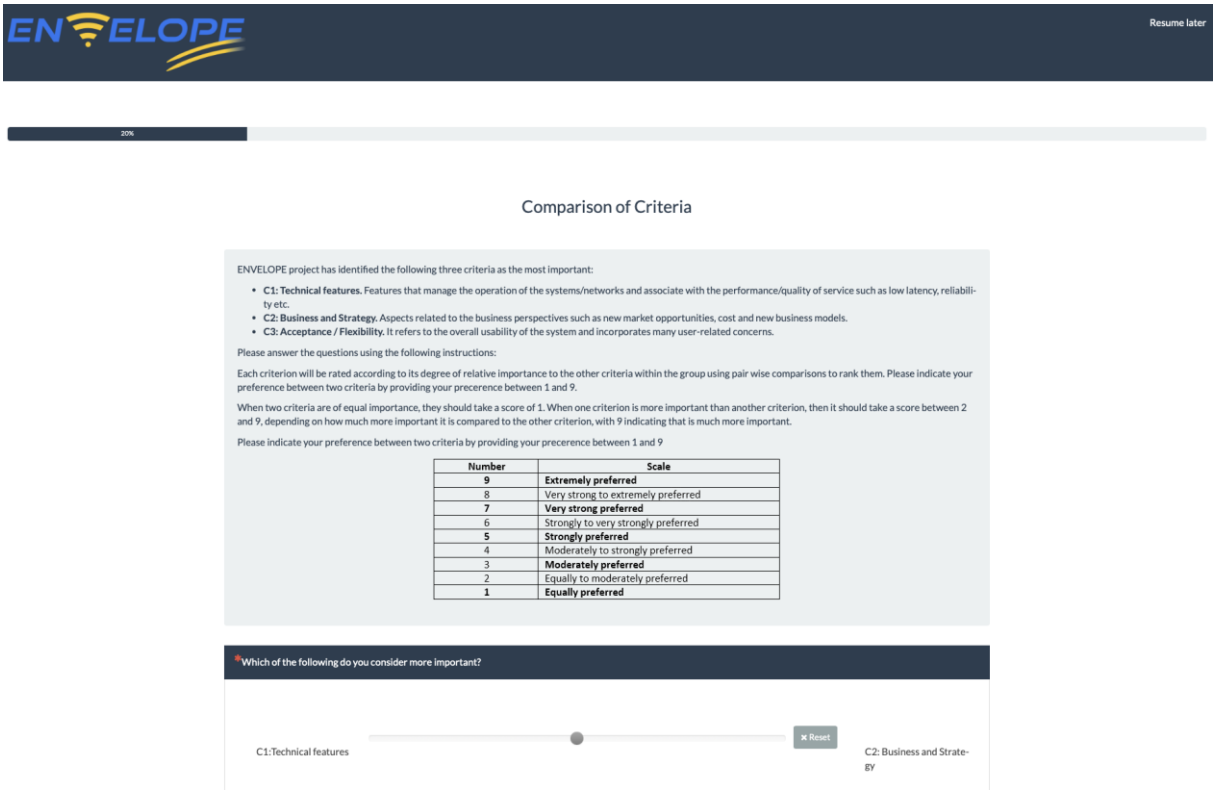


Figure 20: Example of AHP questions

The survey had a total of 29 questions some of which were not AHP based. Table 5 presents an analysis of the number of questions in terms of criteria and sub-criteria.

Table 5: Analysis of the number of questions

| Type | Description | Number | Number of questions |
|---|---|---|---|
| **Criteria** | Criteria that will affect ENVELOPE | 3 | 3 |
| **Sub-criteria** | Related to ENVELOPE technical features | 6 | 15 |
| **Sub-criteria** | Related to business and strategy criterion | 3 | 3 |
| **Sub-criteria** | Related to acceptance / flexibility criterion | 4 | 6 |
| **Demographic** | Type of organization and position | 2 | 2 |

At the beginning of the survey two questions were posed about the type of organisation and the position of the participants. The following figures illustrate the statistics of the participants.

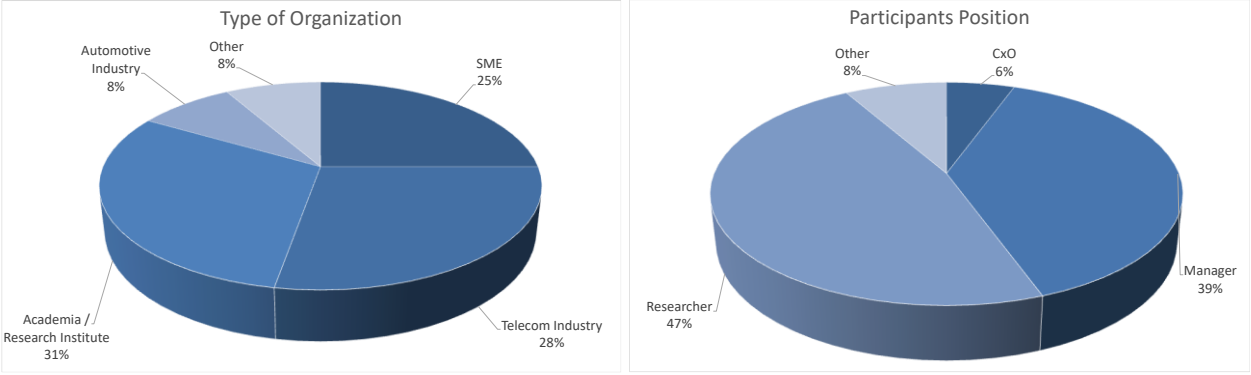


Figure 21: Statistics of the participants

The left part of Figure 21 highlights the distribution of participants based on type of their organization. The largest group, with eleven participants is from Academia/Research Institutes, reflecting a strong representation from this knowledge-driven sector. Following this, ten and nine participants respectively belong to the Telecom Industry and SMEs, indicating a notable involvement of the relevant to ENVELOPE context sectors. Lastly, only three participants each represent the Automotive Industry and Other category, suggesting minimal engagement from them. This distribution underscores a predominant contribution from academia and technology sectors, with comparatively limited input from automotive organizations.

The right part of Figure 21 shows the positions held by the participants within their respective organizations. The majority of participants, seventeen in total, are Researchers, indicating a strong representation from individuals involved in academic or investigative roles. Managers make up the second-largest group, with fourteen participants, reflecting substantial input from leadership and operational roles. Meanwhile, only 2 participants hold CxO positions, indicating limited engagement from top-level executives. Additionally, 3 participants fall into the "Other" category, representing a small but diverse group of unspecified roles. This distribution emphasizes the prominence of researchers and managers in the survey while highlighting relatively minimal participation from executive-level professionals.

### 4.2.2 Results and discussion

In this section, we present and discuss the results of the survey concerning the evaluation of the importance of the criteria and sub-criteria that are expected to affect the market adoption of ENVELOPE solutions. From the thirty-six experts who initially participated in the survey, sixteen questionnaires were discarded as inconsistent, since their associated CR was >0.1. The questionnaires were conducted and completed during a period of 1 month. This can be assumed a sufficient size for an AHP analysis since as shown in [92], [93], the changes in the probability of rank reversal when an additional expert is added to the group are below 1% at M = 15 (where M is the number of experts). Using the methodology described above, one can easily estimate the weights prioritizing the criteria and sub-criteria (Table 6).

Table 6: Weights prioritizing the criteria and sub-criteria

| Criterion / Sub-Criterion | Weight |
|---|---|
| **Cr1: Technical Features** | **0.437** |
| SCr1.1: Predictive QoS as a Service | 0.141 |
| SCr1.2: AT-SSS-compatible multi-connectivity support | 0.13 |
| SCr1.3: Zero-touch management | 0.154 |
| SCr1.4: Northbound API exposure | 0.162 |
| SCr1.5: Quality on Demand, Traffic influence | 0.199 |
| SCr1.6: Service continuity in cross-domain environments e.g., service migration | 0.214 |
| **Cr2: Business and Strategy** | **0.244** |
| SCr2.1: Cost - Pricing models and affordability for stakeholders | 0.314 |
| SCr2.2: New business models | 0.29 |
| SCr2.3: Market growth opportunities | 0.396 |
| **Cr3: Acceptance / Flexibility** | **0.319** |
| SCr3.1: Secure data transfer (Security and Privacy) | 0,288 |
| SCr3.2: Regulatory issues | 0,139 |
| SCr3.3: Compliance to standards and specifications | 0,287 |
| SCr3.4: Scalability | 0,286 |

### 4.2.3 Weighting of criteria

The results concerning the weights of the criteria that are expected to affect ENVELOPE penetration are shown in Figure 22. The evaluation of factors affecting the market adoption of ENVELOPE reveals a clear prioritization which is based on the technical innovation, adoption feasibility and long-term sustainability. According to experts' opinions, the criterion of 'Technical Features' was ranked as the most crucial, assigning it the highest weight (0,437). This mirrors the main mission of ENVELOPE project to provide next generation 5G-Advanced/B5G capabilities tailored to Connected and Automated Mobility (CAM) use cases. Advanced characteristics and technologies are essencial for the support of reliability, low latency and responsiveness required in safety critical applications like autonomous driving. Such characteristics are mandatory for the ability of the platform to operate across multiple high-demand environments and to integrate advanced network capabilities across stakeholders.

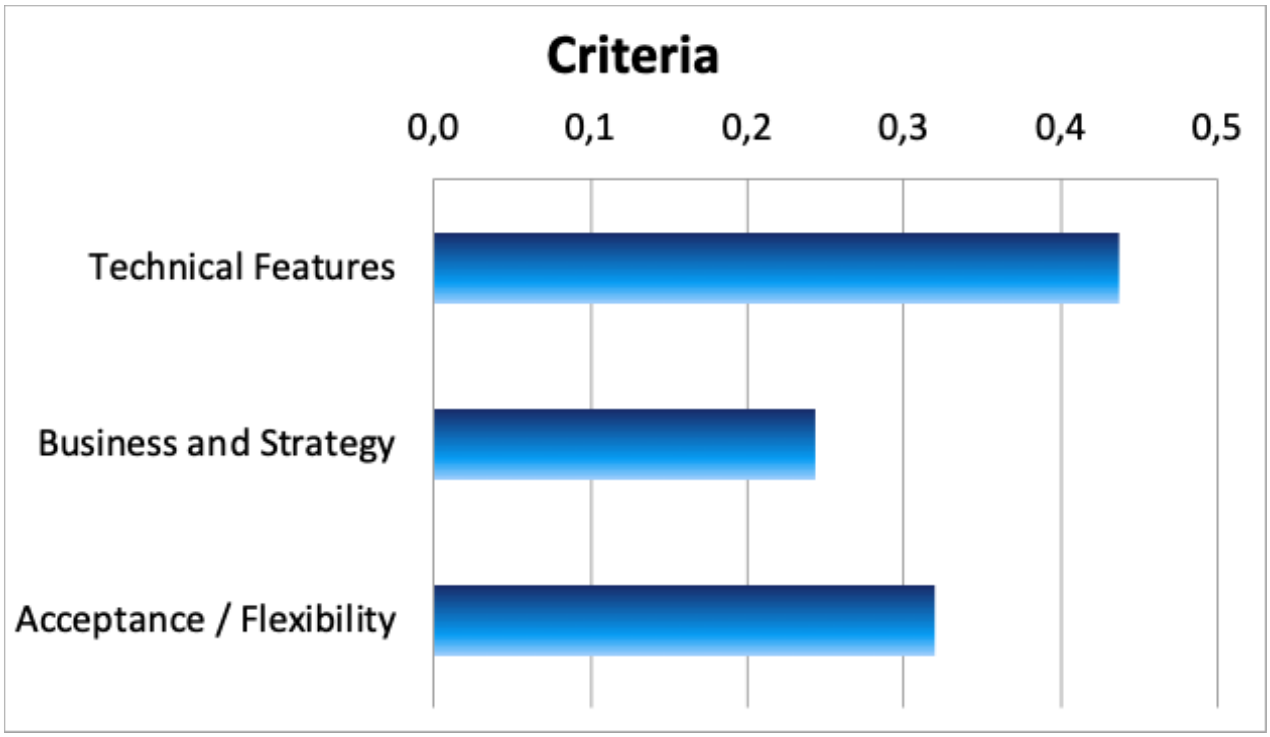


Figure 22: Relative weights of criteria

The Acceptance and Flexibility criterion closely follows in the second position (weight: 0,319). Although this criterion is not as foundational as the technical one, this position underscores the high importance of stakeholders trust, security, legal compliance as well as of adaptability in ensuring the real-world viability. Given the cross-domain nature of CAM, including the cooperation with public infrastructure, vehicle manufacturers and regulatory authorities, the successful deployment heavily depends on the ability of ENVELOPE to address the concerns about privacy, interoperability and scalability.

It is interesting to note that the 'Business and Strategy' criterion received the lowest weight (0,244) although this is relevant to market related issues and aspects that will facilitate the deployment of ENVELOPE solutions, thus playing a significant role. This criterion can be recognized as vital for the long-term viability and market expansion. However, it directly depends on the establishment of robust technical capabilities and the widespread ecosystem adoption. In practice, both business models and the commitment of the interested parties can only flourish after the demonstration of ENVELOPE technical feasibility and the reception of regulatory authorities and users' trust.

### 4.2.4 Weighting of sub-criteria under each criterion

It is also interesting to examine the weights of the sub-criteria under each criterion. Regarding 'Technical Features' sub-criterion (Figure 23), the experts seem more concerned about 'Service continuity in cross-domain environments', with weight of 0,214, in view of the many new CAM applications and services where such requirement is very tight and crucial. This reflects the critical role in enabling seamless service delivery across multiple operators. In safety-critical CAM use cases like teleoperation, autonomous driving and emergency vehicle coordination, uninterrupted connectivity is mandatory. Vehicles are usually crossing administrative boundaries and

heterogeneous network domains, where any service disruption could set into danger both safety and regulatory compliance. Such a feature supports dynamic handovers, MEC transitions, and session's continuity, which is closely aligned with ENVELOPE's emphasis on cross-domain orchestration and the assurance of user's experience.

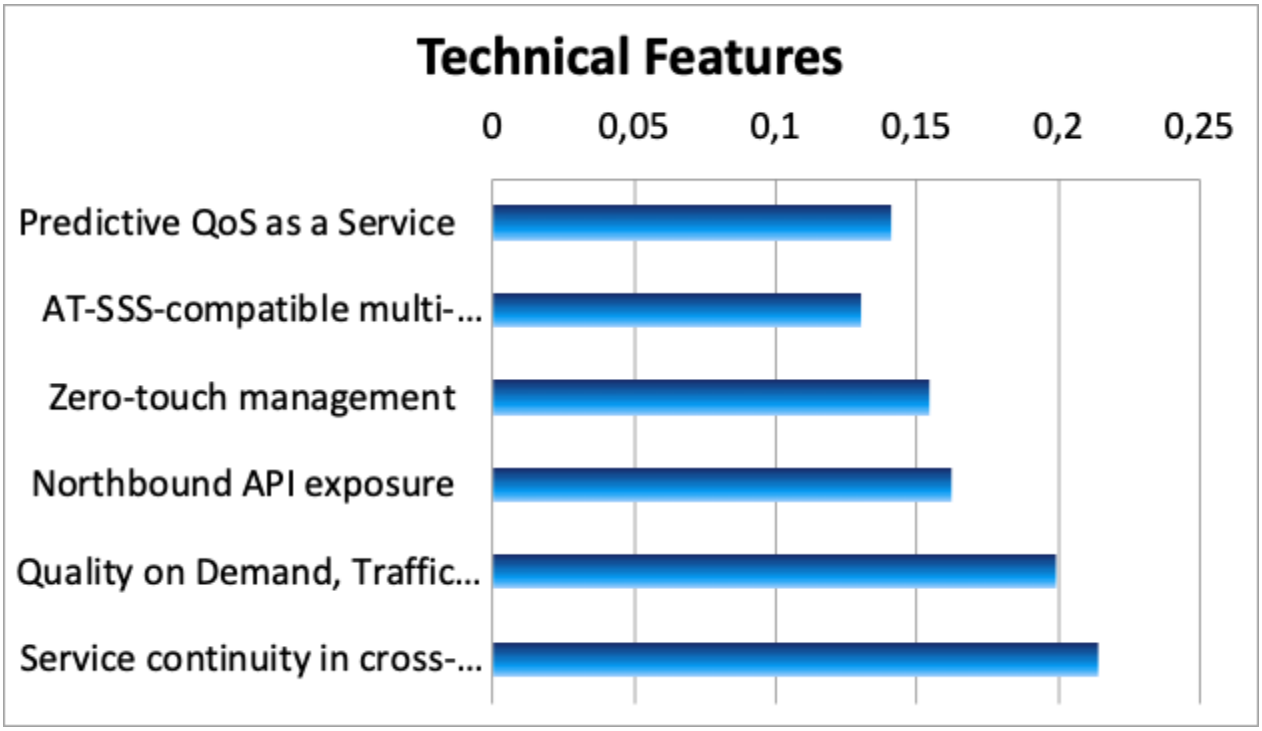


Figure 23: Relative weights of 'Technical Features' Sub-criteria

'Quality on Demand and Traffic Influence' sub-criterion is the second most important feature, accumulating a weight of 0,199. This enables the dynamic allocation and adjustment of network resources based on service's real-time needs. This is extremely significant in CAM scenario like routing of high priority safety data or adaptation to traffic surges, where responsiveness, low latency and data rate flexibility are required. ENVELOPE enables such functionality through the intelligent network slicing and policy exposure, allowing applications to request or prioritize resources contextually. Such capability offers verticals the ability to make network more adaptive and service-aware, thus improving operational efficiency and supporting the differentiated requirements of the different CAM use cases like hazard alerts, automated driving or 3D scene reconstruction.

'Northbound API Exposure' sub-criterion holds the third place with a weight of 0,162, which is key for programmability, modularity and openness. APIs allow third-party developers, OEMs and SMEs/start-ups to interact with the underlying network services, enabling large-scale integration and innovation. By exposing capabilities like slice life-cycle management, events subscriptions or service analytics through standardized APIs (e.g. NEF, CAPIF, CAMARA), ENVELOPE supports a wider ecosystem and lowers barriers to entry. Although its value is detrimental, it is more like a catalyst to other high impact features rather than a factor directly affecting service performance.

In the fourth place, one can find 'Zero-touch Management' sub-criterion with weight of 0,154. Such a feature puts emphasis on the automation of network configuration, service delivery and

orchestration processes. By exploiting AI/ML intent translation and policy enforcement, this feature reduces operational overhead and increases agility, which is critical for scalable CAM deployment in dynamic and fragmented infrastructures. A slightly lower rank of this sub-criterion mirrors its supportive character. While it enhances both efficiency and responsiveness, its benefits can be implemented mainly when fundamental capabilities like API exposure and service continuity have already been established.

Fifth sub-criterion is the 'Predictive QoS as a Service' (weight: 0,141), which introduces foresight into service management by forecasting network behaviour and allowing preemptive adaptation. This is extremely useful for applications that are based on consistent performance, like traffic coordination in real-time or high-definition streaming. Despite its innovation, this sub-criterion is ranked lower mainly due to its dependency on accurate, real-time data and evolving AI models. The value of this feature depends on its integration with traffic influence and decision-making mechanisms, making it powerful but less universally applicable at the moment.

'ATSSS-Compatible Multi-Connectivity Support' sub-criterion can be found in the last place with a weight of 0,130. This is somehow unexpected since such feature is of paramount importance, providing redundancy and resilience, allowing devices to simultaneously use multiple access networks. Although valuable in ensuring session continuity and failover capabilities, its impact is being limited by the current deployment limitations, the dependencies on hardware and the relatively immature stage of its commercial adoption. It can be assumed as a complementary factor enhancing existing capabilities rather than a driver of innovation or performance.

In summary, the analysis of the sub-criteria of 'Technical Features' criterion reveals a clear prioritization of ENVELOPE's needs. Core features like 'Service Continuity' and 'Quality on Demand' ranked first, followed by features enabling ecosystem openness, automation and foresight. This prioritization is closely aligned with the main mission of ENVELOPE to deliver technically advanced, scalable and service-aware solutions meeting the unique requirements of CAM application while enabling the real-world flexible and sustainable deployment.

Figure 24 shows that 'Market Growth Opportunities' is ranked first (weight: 0,396) indicating its increased importance. Unlocking new application domains, geographical areas and cross-domain use cases like cooperative sensing, smart logistics or urban mobility intelligence, offers the biggest long-term economic and societal benefits. By opening digital mobility spaces that current infrastructures cannot reach, ENVELOPE becomes the catalyst for investments and feeds sustainable development across all sectors like smart mobility, supply chain, public safety, etc.

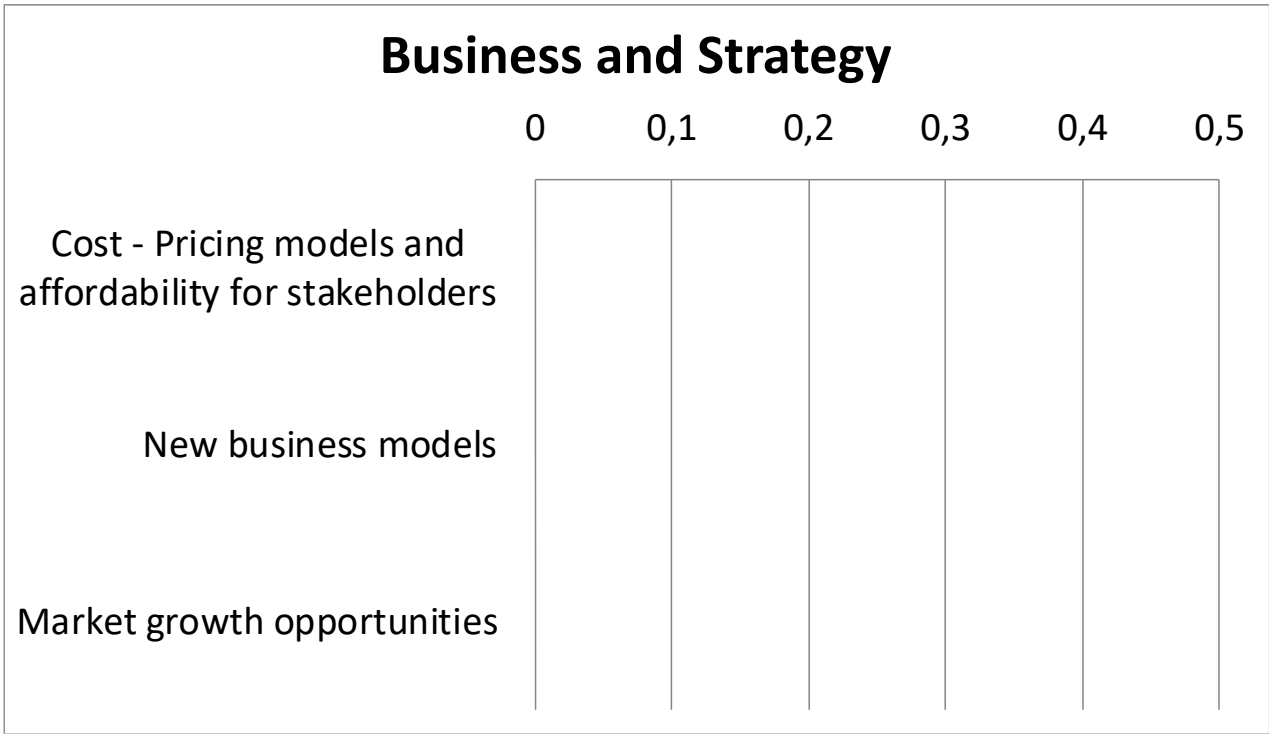


Figure 24: Relative weights of Business and Strategy Sub-criteria

According to the experts' opinions, 'Cost – Pricing models and affordability for stakeholders' is in the second place (weight: 0,314). This is not surprising, as the cost of deployment is very important for the adoption of any new system. Affordability plays a crucial role in the widespread acceptance of the systems, influencing both consumers and businesses. Reducing costs can enhance accessibility and drive broader adoption.

In the last position, one can find New Business Models sub-criterion (weight: 0,29). This is somehow strange since new business models are integral to the business and strategy of ENVELOPE. They offer avenues for revenue generation, provide a competitive advantage, enable adaptability to market changes, foster collaboration within the ecosystem, and enhance the overall user experience. Ignoring the importance of innovative business models could limit the success and widespread adoption of ENVELOPE.

Regarding the sub-criteria of the Acceptance / Flexibility criterion, the importance of the three of them, namely 'Secure Data Transfer (Security and Privacy)', 'Scalability' and 'Compliance to Standards and Specifications', appears to be roughly equal. 'Secure Data Transfer (Security and Privacy)' issues are the most important (weight: 0,288). The very high importance of security and privacy in ENVELOPE and CAM, in general, is driven by the need to safeguard human lives, protect sensitive data, build user trust, and ensure the reliability of critical transportation infrastructure. Addressing these concerns is integral to the responsible and successful deployment of both ENVELOPE and CAM.

As shown in Figure 25, 'Scalability' can be found in the second place with a weight of 0,287. As the adoption of ENVELOPE solutions increases, scalability becomes essential to accommodate a larger number of users. In addition, the ability to scale ensures that ENVELOPE solutions will remain efficient and effective as traffic volumes increase. In general, scalability supports the vision

of creating an ecosystem that can seamlessly integrate with existing infrastructure and accommodate future developments.

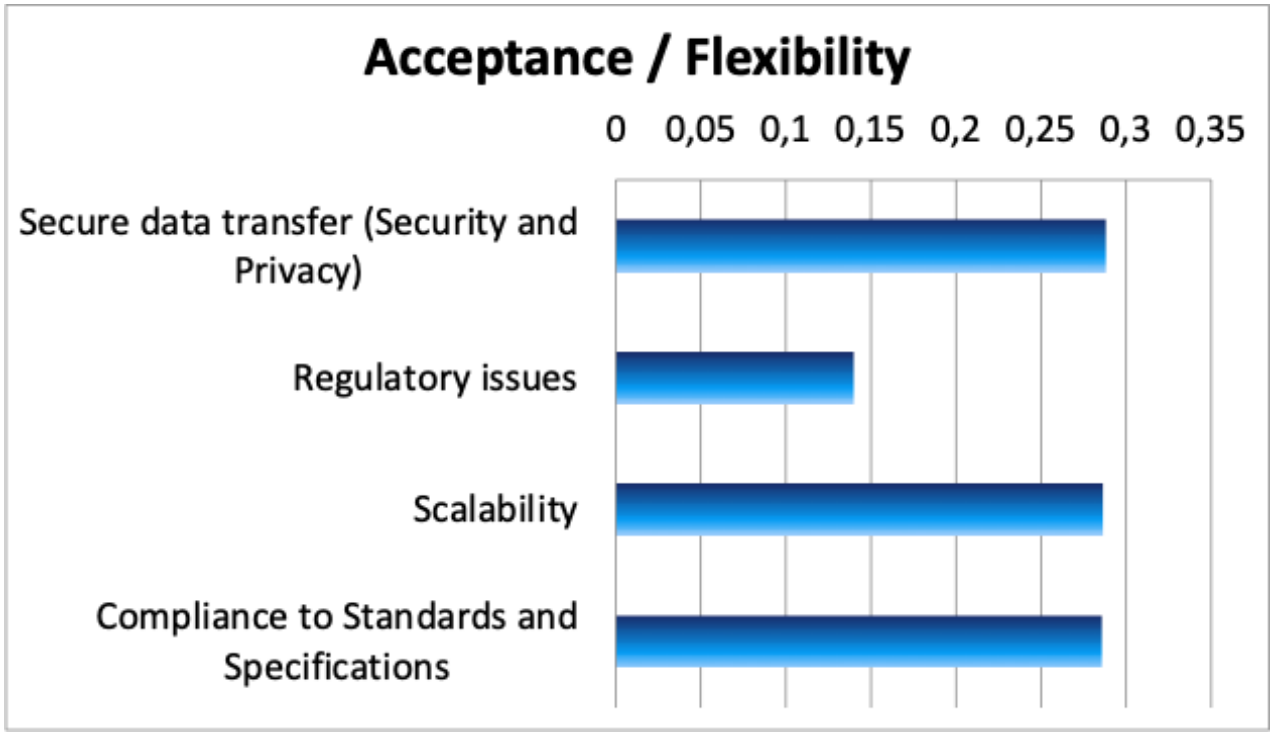


Figure 25: Relative weights of Acceptance / Flexibility Sub-criteria

Compliance to Standards and Specifications is ranked the third choice among the experts, with weight 0,286. Compliance to Standards and Specifications is critical for the successful implementation and adoption of ENVELOPE since it ensures interoperability, easy integration, safety, and reliability as well as getting regulatory approval and building trust among users and other stakeholders.

Surprisingly enough, regulatory issues are deemed of secondary importance (weight: 0,14). Regulatory issues are highly important in the context of ENVELOPE They are instrumental in providing a legal and ethical framework for the development and deployment of ENVELOPE, contributing at the same time to the responsible and sustainable integration of the proposed technologies into the broader landscape. The inability to comply with existing national or European regulations related to cross-border data exchange or spectrum allocation, etc., could hinder the market adoption of ENVELOPE. Thus, the low priority of regulatory issues is somehow unexpected and cannot be easily explained. A possible explanation could be that regulatory requirements are usually evolving slowly, and as such they can be addressed in parallel with the deployment. As a result, regulatory issues have less direct impact to the overall acceptance/adoption calculus since ENVELOPE's architecture is already secure, scalable and aligned to the standards.

#### 4.2.4.1 Global priorities of sub-criteria and policy implications

In applying the Analytical Hierarchy Process (AHP) to prioritize the factors influencing market adoption and evolution of ENVELOPE, estimating global priorities is essential to ensure a comprehensive and balanced evaluation. Given that the criteria and sub-criteria encompass heterogeneous dimensions—such as technical features, business considerations, and user

acceptance—global priorities enable the aggregation of diverse perspectives into a coherent framework. This holistic view allows decision-makers to compare and weigh fundamentally different elements on a common scale, accounting not only for the individual importance of each factor but also for its relative influence within the broader decision hierarchy. By calculating global priorities, the methodology integrates both qualitative and quantitative judgments, facilitating more objective and defensible strategic decisions in complex, multi-faceted environments.

However, it should be highlighted that when comparing heterogeneous elements, clear criteria definitions and stakeholder alignment are critical. While comparing heterogeneous factors may seem counterintuitive, AHP provides a robust framework to do so in a structured, transparent, and justifiable way. AHP is specifically designed to handle such complexity. It uses pairwise comparisons and a hierarchical structure to normalize diverse criteria, effectively enabling comparison across domains. This doesn't mean the factors are inherently comparable in real-world terms, but rather that their relative importance to a specific goal can be meaningfully assessed.

The global priorities are obtained by multiplying the local priorities (sub-criteria weights) by their parent's priority (weight). The global priorities for all the sub-criteria add up once again to 1. Table 7 presents the global weights (in descending order) for all the sub-criteria considered.

Table 7: Global Priorities of sub-criteria

| Criterion / Sub-Criterion | Weight |
|---|---|
| SCr2.3: Market growth opportunities | 0,096 |
| SCr1.6: Service continuity in cross-domain environments e.g., service migration | 0,093 |
| SCr3.1: Secure data transfer (Security and Privacy) | 0,092 |
| SCr3.4: Scalability | 0,091 |
| SCr3.3: Compliance to standards and specifications | 0,091 |
| SCr1.5: Quality on Demand, traffic influence | 0,087 |
| SCr2.1: Cost - Pricing models and affordability for stakeholders | 0,077 |
| SCr2.2: New business models | 0,071 |
| SCr1.4: Northbound API exposure | 0,071 |
| SCr1.3: Zero-touch management | 0,067 |
| SCr1.1: Predictive QoS as a Service | 0,062 |
| SCr1.2: AT-SSS-compatible multi-connectivity support | 0,057 |
| SCr3.2: Regulatory issues | 0,045 |

Global priorities ranking of sub-criteria clearly reflects experts' opinion about the most critical factors affecting the design, development and sustainability of ENVELOPE solutions and ENVELOPE-enabled CAM services. At the top of the list is SCr2.3 'Market Growth Opportunities' with global weight of 0,096, showing a strong strategic emphasis on innovation and growth. This priority highlights the belief that the technological progress alone is not sufficient without the ability to extend solutions into emerging sectors and unlock new user bases. Thus, economic sustainability and outreach is still of paramount importance.

SCr1.6: 'Service Continuity in Cross-Domain Environments' closely follows with a global weight of 0,093 revealing its high importance. Such a feature ensures the uninterrupted service delivery, especially in mobility scenarios incorporating roaming and multiple operators, which is crucial for users' safety, trust and experience. Its high ranking confirms that end-to-end resiliency is an unnegotiable feature in next generation CAM systems.

SCr3.1: 'Secure Data Transfer (Security and Privacy)' is of almost equal importance, with a global weight of 0,092. This is a critical feature for all systems that are based on data exchange, especially when privacy, cybersecurity and trust are main barriers for their acceptance/adoption. The fact that this sub-criterion along with the next two: SCr3.4: Scalability (0,091) and SCr3.3: Compliance to Standards and Specifications (0,091), with almost equal global weights, belong to the 'Acceptance/Flexibility' criterion highlights its critical role in the successful deployment and societal integration of new technologies and CAM services.

Moving lower in the list, one can find SCr1.5: 'Quality on Demand' (global weight: 0,087) sub-criterion revealing that networks must be adapted intelligently to performance needs. However, more technical features such as 'North-bound API Exposure' (global weight: 0,071) and 'Zero-touch Management' (global weight: 0,067) are placed middle to low showing that most probably such mechanisms are more supportive than fundamental. It is also interesting to note that sub-criteria SCr1.1: 'Predictive QoS as a Service' (global weight: 0,062) and SCr1.2: 'AT-SSS Multi-Connectivity' (global weight: 0,057) are placed lower maybe due to deployment complexity or immediate applicability across all contexts.

Surprisingly enough, SCr3.2: 'Regulatory Issues' (global weight: 0,045) is at the last place highlighting that, although significant, most probably is considered as a compliance factor rather than a differentiator. Overall, the rankings demonstrate and suggest a balanced focus across market scalability, services resilience and trust while in parallel pure technical control features are somehow downgraded, maybe due to the fact that they are not immediately critical for end-user or market impact.

# 5 Conclusions

While the first commercial deployments of Beyond 5G and CAM systems are underway, it is crucial to address and understand various challenges. The embryonic stage of these systems, coupled with the multi-disciplinary nature of impacting factors, adds complexity to the situation. Consequently, a well-defined roadmap encompassing technical, economic, regulatory, and other considerations is needed. Critical decisions should be highlighted within this road-map, and a successful rollout strategy requires clearly defined business cases.

In this deliverable, we conducted an analysis of the current state of ENVELOPE components in the market, identifying their characteristics and trends. Additionally, we performed an initial road-mapping exercise, addressing technological, techno-economic, standardization, and regulatory issues integral to a successful deployment strategy. Finally, we defined the ecosystem around ENVELOPE to guide the definition of profitable business models and cases.

Market analysis underscored the dynamic growth of all investigated markets in terms of revenues, market size, growth, and the number of players/competitors. The findings indicate that now is the opportune time to initiate the deployment of innovative solutions related to Beyond 5G and CAM.

To assess factors influencing the market adoption and evolution of ENVELOPE solutions, the AHP methodology was employed. Through discussions with experts, a hierarchy of the main objective was established, and criteria and sub-criteria were selected. A questionnaire was then distributed, and collected responses were processed and analysed, leading to the following conclusions.

The fact that ‘Technical Features’ ranked first as the most critical criterion indicates that decision makers in this sector put significant emphasis on the operational and functional robustness of the system. This prioritization shows a realistic orientation between stakeholders, maybe due to the need for reliable performance in complex environments which is a characteristic of both CAM and Beyond 5G systems.

The high ranking of ‘Acceptance/Flexibility’ as the second most significant criterion indicates the importance of adaptability in different operational and regulatory frameworks. This indicates the fact that the technical excellence alone is not sufficient without the ability of integration into different, evolving infrastructures and users’ requirements.

On the other hand, the lower weighting of ‘Business and Strategy’ criterion shows that although strategic alignment and long-term business goals cannot be ignored, they considered at this stage as of secondary importance compared to the immediate functional and integration challenges. This reflects the embryonic or transitional stage of CAM and Beyond 5G development, where technical viability is prequisite for later strategic scaling.

The high global ranking of both ‘Market growth opportunities’ and ‘Service continuity in cross-domain environments’ sub-criteria shows a focus on future scalability and economic viability as well on operational resilience. The emphasis on the ‘Secure data transfer (Security and Privacy)’, ‘Scalability’ and ‘Compliance to standards and specifications’ further supports this, indicating a wider trend of risk-aware growth. Such preferences reveal the concerns of stakeholders regarding trust maintenance, meeting regulatory requirements and ensuring uninterrupted operation across all sectors, which are all very important characteristics in safety-sensitive environments with increased data usage like CAM and Beyond 5G systems.

Overall, experts choices reveal a pattern where technical resillience, interoperability and security have a priority over long-term strategic concerns. This could indicate a short- or mid-term focus on creating robust, trustworthy and scalable systems capable of operating effectively in different domains with the strategic and commercial parameters to become more important as the technological foundation matures.

An analysis of the ENVELOPE ecosystem was also conducted, defining involved actors, identifying new players, and describing their relations along with revenue streams.

The deliverable provided an initial insights into the business aspects of ENVELOPE, serving as guidance for ENVELOPE partners and other stakeholders interested in Beyond 5G and CAM. Beyond investment strategies, efforts should focus on increasing awareness of the benefits arising from such systems. Finally, though regulatory issues might not be among the top preferences of experts, relevant aspects should be seriously considered, as they can significantly impact the success.

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