



5GMOBIX

5G for cooperative & connected automated
MOBility on X-border corridors

D6.1

Plan and preliminary report on the deployment options for 5G technologies for CAM

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Control sheet

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ABBREVIATIONS

Abbreviation	Definition
3Gpp	3rd Generation Partnership Project
5G C	5G Core
5G CN	5G Core Network
5GAA	5G Automotive Association.
ASN	Abstract Syntax Notation
BBU	BaseBand Unit
BSA	Basic Set of applications
BSs	Base stations
CAPEX	Capital Expenditure.
CBC	Cross Border Corridor
CAM	Connected and Automated Mobility
CPRI	Common Public Radio Interface.
CPS	Collective Perception Service
DENM	Decentralized Environmental Notifications Message.
DL	Downlink
DoA	Description of Action
DSRC	Dedicated Short Range Communication
DSS	Dynamic Spectrum Sharing
Dx.x.	Deliverable x.x.
E2E	End to end
EC	European Commission
eCPRI	Enhancement Common Public Radio interface
eMBB	Enhance Mobile Broadband
EPC	Evolved Packet Core
GA	General Assembly
gNodeB	Next Generation Node B
GSM	Global System for Mobile communications
GCN	Gateway Core Network
IoT	Internet of Things
ITS	Intelligent Transport System
LTE	Long Term Evolution
MEC	Multi-access Edge Computing
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications
MNO	Mobile Network Operator

MOCN	Multi-Operator Core Network
Mxx	Month xx
NFV	Network Function Virtualization.
NR	New Radio
NSA	Non-Stand Alone
OPEX	Operational Expenditures
PMP	Point to MultiPoint communication
PMR	Private Mobile Radio
RAN	Radio Access Network
RAT	Radio Access Technology
RE	Radio Equipment
REC	Radio Equipment Control
RF	Radio Frequency
RHW	Road Hazard Warning
RoI	Return on Investment
RRH	Remote Radio Heads
S/P-GW	Serving/Packet Gateway
SA	Stand Alone
SDA	Strategic Deployment Agenda
SDN	Software-defined networking
SMCA	Sparse code multi access
TDD	Time Division Duplex
TMT	Technical Management Team
TS	Trial Site
TSL	Trial Site Leader
UCC	Use Case Category
UE	User Equipment
UL	Uplink
URLLC	Ultra-Reliable Low-Latency Communication
US	User Story
V2X	Vehicle-to-everything
WCDMA	Wideband Code Division Multiple Access
WP	Work Package
WPL	Work Package Leader
X-border	Cross-border

EXECUTIVE SUMMARY

This document is the deliverable D6.1 “Plan and preliminary report on the deployment options for 5G technologies for CAM”. The deliverable purpose is to document the work done in T6.1 which, first of all, aims to provide an overview of the technology (5G for CAM) and related projects, as well as the current offer of 5G in the market. This allows to identify the different alternatives within the framework of 5G Technology for CAM, as well as the most relevant areas of innovation. This analysis of the technology also makes it possible to recognize those regions or countries that are strongly committed to 5G technology for CAM, as well as to identify the different actors involved in the value chain and how they interact with each other.

An overview of the costs of 5G for CAM technology found in literature references is also provided, which will be validated by the partners of the 5G MOBIX project in the Deployment Study that Trial Sites and Cross-Border Corridors will carry out for each of their corridors, considering the specific characteristics of each of them. Therefore, this analysis lays the foundation for working on the final D6.5 Final report on 5G technology deployment options for CAM deliverable in the coming months and fulfil the objectives of Task 6.1.

This way, the work done so far allows to acquire a deep knowledge of the technology which will help to identify, in the next months, different products and services in the framework of 5G for the CAM that contribute value to the 5G MOBIX Project, so that it will contribute to the pre-commercialisation of these services and products, by means of the direct application to 5G MOBIX use cases. This is: the identification of how the project could benefit external initiatives and vice versa.

At the same time, T6.1. will contribute to the creation of a multiplier effect on project results by implementing a two-pronged recommendation and deployment strategy called “from local to project to global”, the basis of which are presented in this deliverable.

The present deliverable also shows the current experience and knowledge of the project partners in relation to 5G technology for CAM by identifying the challenges to its deployment and recommendations to overcome them. These recommendations have been analysed, validated, and prioritized, resulting in what are referred to as the macro-level recommendations. So, the final objective of T6.1. is to provide recommendations and deployment options for post-project replication partners.

1. INTRODUCTION

1.1. 5G-MOBIX concept and approach

5G-MOBIX aims to showcase the added value of 5G technology for advanced Connected and Automated Mobility (CAM) use cases and validate the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L₄ and above). To do this, 5G-MOBIX will demonstrate the potential of different 5G features on real European roads and highways and create and use sustainable business models to develop 5G corridors. 5G-MOBIX will also utilize and upgrade existing key assets (infrastructure, vehicles, components) allowing the smooth operation and co-existence of 5G within a heterogeneous environment comprised of multiple incumbent technologies such as ITS-G5 and C-V2X.

5G-MOBIX will execute CAM trials along cross-border (x-border) and trial sites using 5G technological innovations to qualify the 5G infrastructure and evaluate its benefits in the CAM context. The Project will also define deployment scenarios and identify and respond to standardisation and spectrum gaps.

5G-MOBIX will first define critical scenarios needing advanced connectivity provided by 5G, and the required features to enable selected advanced CAM use cases. The matching of these advanced CAM use cases and the expected benefits of 5G will be tested during trials on 5G corridors in different EU countries as well as in Turkey, China, and Korea.

The trials will also allow 5G-MOBIX to conduct evaluations and impact assessments and to define business impacts and cost/benefit analysis. As a result of these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX will identify new business opportunities for the 5G enabled CAM and propose recommendations and options for its deployment (in this document).

Through its findings on technical requirements and operational conditions 5G-MOBIX is expected to actively contribute to standardisation and spectrum allocation activities, this effort is summarized in D6.3.

1.2. Purpose of the deliverable

5G-MOBIX dedicates Work Package 6 “Deployment Enablers” to drawing input from the project trials and identifying options for V2X connectivity deployment. The main objective of WP6 is to exploit the results from the trials and their evaluation. The options may include co-existence or hybridisation possibilities with other technologies. In this sense, WP6 will contribute to the development of the work items relating to the 5G-MOBIX use cases and 5G infrastructures, but also beyond them.

The purpose of this document is to evaluate the current state of 5G technologies with respect to CAM and evaluate its potential for evolution. The specific goal of T6.1. “Plan and preliminary report on the deployment options for 5G technologies for CAM” is:

- To focus on the application of 5G telecommunication infrastructures on the transport sector.

- To contribute to the pre-commercialisation of concrete services and products that are successfully applied to the project use cases – incorporating solutions from external third parties, thus maximizing socio-economic impact beyond the project. (D6.1 & D6.5)
- To contribute to the creation of a multiplier effect on project results by implementing a two-sided recommendation and deployment strategy called ‘from local-to-project-to-global’.
- Provide recommendations and deployment options for post-project replication partners as crystallisation points for taking up project results (D6.1 & future D6.5).
- To achieve this, this first document of T6.1 is based on an extensive analysis of 5G for CAM technology, which will provide an overview of where the technology stands today, facilitating the proposal of recommendations for the full deployment of this technology. This analysis is a necessary steppingstone to assessing its potential for evolution. This document is organised as follows:
 - Chapter 1 (current chapter) introduces the project and the scope of this work,
 - Chapter 2 presents the methodology and analytical process,
 - Chapter 3 explains 5G for CAM considerations,
 - Chapter 4 offers a review of the technology costs,
 - Chapter 5 provides an overview of the challenges that technology 5G for CAM is facing at industrial level,
 - Chapter 6 focuses on recommendations and deployment options in order to simplify deployment and management of 5G for CAM,
 - Chapter 7 synthesizes the conclusions for D6.1 and discusses the next steps in order to validate the T6.1 approach,
 - Chapter 8 reflects the bibliographical references used throughout this document,
 - Chapter 9 contains the Annexes of this deliverable.

1.3. Intended audience

The current document is publicly disseminated and is available as a free download on the 5G-MOBIX website¹. It is meant primarily as a handbook that introduces 5G concepts to CAM stakeholders and discusses the potential evolution of this technology in terms of providing CAM functionalities. Foreseen issues and barriers to the deployment of 5G are discussed, in order to form a common basis of understanding on which stakeholders can initiate discussions on the future of 5G for CAM. Thus, this document aims to serve not just as an internal guideline and reference for all 5G-MOBIX beneficiaries, especially the Trial Site (TS) and the UCC/US leaders, but also for the larger communities of 5G and CAM development and testing. Interested readers may also refer to:

- D6.2 “Plan and Preliminary Report on the business models for cross border 5G deployment enabling CAM” for an analytical discussion on business models, covering the entire 5G CAM value chain,
- D6.3 “Plan and Preliminary Report on the standardisation and spectrum allocation needs” for an extensive analysis of standardisation and spectrum allocation,

¹ 5G-MOBIX website: <https://www.5g-mobix.com/> [Accessed May 2021]

- D6.4 “Plan and Preliminary Report on EU Policies and regulations recommendations” for regulatory analysis and detailed recommendations to policy makers.

These documents are also available as a free download on the 5G-MOBIX website.

2. METHODOLOGY

2.1. Assessment stage

This section aims to show the methodology followed in Task 6.1 during the self-assessment stage to produce recommendations and deployment options to achieve the objectives that are shown in Section 1.2. In this way, the present document starts with an analysis of the technology, which in turn allows the evaluation of the current situation of 5G for CAM technology.

This industry-focused technology study also allows the identification of all the actors involved in the deployment, the current challenges that the technology is facing in several areas, the costs required for the deployment of the technology in the different chain steps, and the subsequent proposal of recommendations for the deployment based on the knowledge acquired from the project and through different actors. The identification of successful innovations in the transport sector, at local level, makes it possible to recommend activities that favour the deployment of technology (D6.1, future D6.5).

The document concludes with a full section of recommendations (micro-level, cross-border environments, and macro-level recommendations) for the successful deployment of the technology (fully validated by the industry and also prioritised by the partners). It pays special attention to the needs at the cross-borders so that the deployment is scalable and allows the technology to function correctly between countries. It also focuses those activities that will favour the deployment of the technology (from "Local to Project to Global").

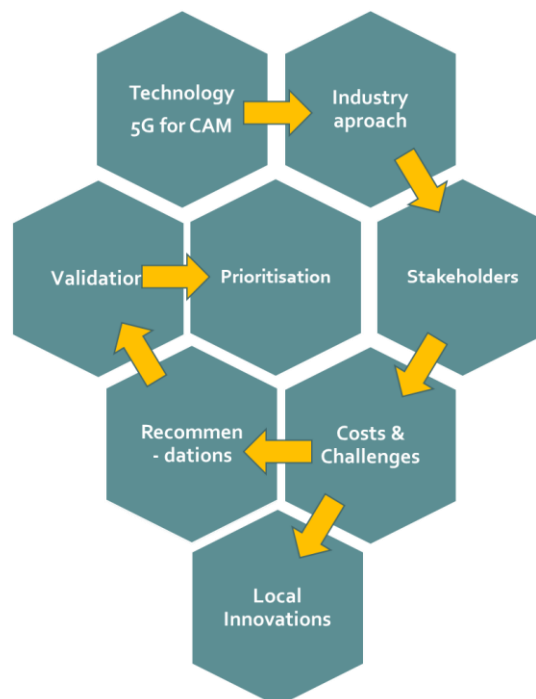


Figure 1. Overview of D6.1. methodology.

2.2. Methodology for the proposal of Recommendations

After the analysis of the technology (summarized in Sections 3), the costs for deployment (Section 4) and the industry approach with the challenges identified by different stakeholders (Section 5), the necessary information was available to establish:

- A set of initial **recommendations at micro level** (Section 6.3.1). These recommendations are specific recommendations proposed by the partners who contributed to D6.1. within their area of expertise and knowledge acquired within the 5G MOBIX project.

A set of possible **solutions for 5G MOBIX Cross-Border environment challenges** by the Technical Management Team (section 6.3.2). These solutions are specifically focused on solving problems that may arise in cross-border environments.

- A set of **macro-level recommendations** (Section 6.3.3). These recommendations have been proposed at a general level as those that the industry should follow to accelerate the deployment of 5G For CAM technology.

2.2.1. Recommendations' categorization

Different categories for recommendations at the 3 detail levels from micro to cross-border, to macro were used. These categories are presented below and used in section 6 to present the actual recommendations.

2.2.1.1. Micro-level recommendations categorization

First of all, the micro-level recommendations proposed by the expert partners in T6.1. and presented in this deliverable D6.1 focus on the following categories:

- Deployment recommendations.
- Data Quality-Validity recommendations.
- Data Property Management recommendations.
- Application and interoperability recommendations.
- Automotive industry and CAM recommendations.
- Cybersecurity recommendations.
- Road recommendations.

2.2.1.2. Solutions for cross-border environment categorization

In relation to the proposed solutions provided by TMT experts, for cross-border environments, the categorization is as follows:

- Telecommunication solutions.
- Telecommunication and Application solutions.

- Application solutions.
- Regulatory solutions.

2.2.1.3. Macro-level recommendations categorization

Finally, the categorization criterion objective for the macro-level recommendations was to define areas of commonality across all the previous recommendations to which the recommendations of D6.2 and D6.3 were included. These areas are:

- **5G Network:** that includes all related with network integration, performance, business models and deployment.
- **5G Architecture:** including all related with vehicle architecture, edge, road infrastructure and network integration.
- **Legal & Standards:** considering all the legislation and standards that are currently in the industry and the gaps in legislation that are not developed yet.
- **Stakeholder collaboration:** this is collaboration between the stakeholders defined in the project: Road operators, OEM, MNOS, Government, ...
- **Road Infrastructures:** Road infrastructure recommendations to adapt to the deployment of 5G for Autonomous vehicles.
- **Business Models:** Business models collaboration and legislation frameworks that have been developed elsewhere to tackle these challenges.

2.2.1.4. Evaluation criterion for prioritisation

The evaluation criterion allows the analysis of the impact that these recommendations would have, as well as to provide visual information on the prioritization of the recommendations. The evaluation criteria assess each recommendation based on two factors:

- **Utility score:** The utility score measures the level of criticalities of the following factors from 1 to 5, with 1 having a Minimal impact and 5 a critical impact. The recommendations are assessed based on the factors that are shown on the next Table 1.

Table 1. Utility score for prioritization.

Scoring System			UTILITY SCORE (Higher is better)					WEIGHTS	SCORE	WEIGHTED SCORE CALCULATION
			Minimal	Low	Average	High	Critical			
			1	2	3	4	5			
1	Impact	Has user value	Has no user value	Has little value, brings awareness to a specific gap	Has average value - somewhat limits an existing gap	It has the potential to simplify CCAM adoption	Has great user value - will greatly help adoption of 5G for CCAM	0,17	3	0,50
2	Impact	Has business value (for Europe?)	Has no business value	Has little value, brings awareness to a specific gap	Has average value - somewhat limits an existing gap	It has the potential to increase investment or the creation of new products and services, or mitigate known gaps	Has great business value - this recommendation can improve investment in 5G for CCAM and will help create new products/services/business models, or solve known gaps	0,17	5	0,83
3	Impact	Has technical value	Has no technical value	Has little value, brings awareness to a specific gap	Has average value - somewhat limits an existing gap	It has the potential to mitigate or circumvent a technical gap	Has great technical value - this recommendation bridges a significant technical gap	0,17	4	0,67
4	Impact	Has operational value	Has no operational value	Has little value, brings awareness to a specific gap	Has average value - somewhat limits an existing gap	It has the potential to improve operational procedures	Has great value in terms of improving operational procedures - it can bring multiple operational benefits	0,17	4	0,67
5	Impact	Has standardisation value	Has no standardisation value, does not utilise or validate an existing standard	Has little value, brings awareness to a specific gap	Has average value - somewhat limits an existing gap	it has the potential to drive standardisation efforts or support an existing standard	Solves a significant standardisation gap or is based on existing well known, industry accepted standard	0,17	5	0,83
6	Criticality	This recommendation is time critical	not time critical	2021-2035	2021-2030	2021-2025	Recommendation is time critical and should be applied within 2021-2023	0,17	5	0,83
SUM SHOULD BE EQUAL TO 1								1	TOTAL SCORE	4,33

- **Lifecycle cost score:** The lifecycle cost analyses the cost of acquisition and utilisation of the recommendation. Defining the acquisition cost of the research, development, deployment, and integration of the solutions based on the recommendations. The cost of utilisation is defined as the cost to operate, train, maintain and dispose these solutions. These factors are shown in Table 2.










Table 2. Lifecycle cost factor for prioritization.

		Just put an "x", ONLY one 'x' per row (lower is better)								
		Very Low	Low	Medium	High	Very High				
Lifecycle Cost factor		1	2	3	4	5	ANSWERS	WEIGHTS	WEIGHT* SCORE	
Acquisition	Cost to research			x			3	0,1	0,3	
	Cost to develop				x		4	0,2	0,8	
	Cost to deploy				x		4	0,1	0,4	
	Cost to integrate				x		4	0,1	0,4	
Utilisation	Cost to operate			x			3	0,1	0,3	
	Cost to train			x			3	0,2	0,6	
	Cost to maintain				x		4	0,1	0,4	
	Cost to dispose	x					1	0,1	0,1	
							SUM OF WEIGHTS should be 1	1	3,3	Cost Score

- **Final Score:** The final score will be based on these two factors: $Final\ Score = \frac{Utility}{Lifecycle\ cost}$, which will give the prioritization value of each of the recommendations.

Once the Utility, Lifecycle cost and Final score are obtained, **percentiles** will be applied to obtain those recommendations that have a higher value from a Utility, Lifecycle Cost or "Final" point of view.

Table 3. Scoring system and use of percentiles to prioritize outcomes.

	Utility (A)	Lifecycle Cost (B)	Final (Utility/Lifecycle cost).
Scoring system	From 1 to 5 The higher the better	From 1 to 5 The lower the better	(A)/(B) The higher the better
Use of percentiles to prioritize outcomes:			
• Percentile > 2/3%			
• 1/3% > Percentile > 2/3%			
• Percentile < 1/3%			

2.2.2. Validation process

2.2.2.0. Micro-level recommendations

Given the impossibility of doing an external validation with industrial stakeholders of the micro-level recommendations, given their extension, the validation of these recommendations was carried out by each and every partner associated with task 6.1. according to their expertise or area of experience, in the different categories in which these recommendations were classified. In this way, the different partners analysed not only the proposed recommendations, but also the prioritization of the recommendations using the methodology indicated in the previous section.

2.2.2.1. Cross-border environment solutions

Regarding the solutions proposed for the cross-border environments, these solutions were proposed by the experts that make up the TMT (Technical Management Team) of the 5G MOBIX project, with a broad vision and technical knowledge of the main problems of the project at cross-border level.

The prioritization of the proposed solutions was carried out by both project cross-border corridors (ES-PT and GR -TR).

2.2.2.2. Macro-level recommendations

After assessing the current challenges of 5G for CAM in Europe and cross-border challenges in Section 5, an initial set of recommendations were defined. In order to validate these recommendations, the WP6 team developed a validation plan (see Figure 2 below) to ensure that macro-level recommendations were in line with the industry and market view.

5G Architecture	5G Network	Legal & Standards	Stakeholder collaboration	Road Infrastructure	Business Models
Series of Interviews with industry experts in the deployment of the technology	 	    	Series of Interviews with experts in international projects	Series of Interviews with experts in road Infrastructure	Series of Interviews with industry experts in the deployment of the technology

Figure 2. Recommendations Validation Plan.

The validation plan developed was targeting two main areas that during the analysis process were highlighted as critical:

- The first critical area of validation was the Standards and Legislation: one of the consortium members, Catapult, did a study to understand the impact of 5G deployment for autonomous vehicles with the objective to define a set of standards and guidelines and allow a framework of collaboration between the

different stakeholders. The study collected all the standards produced by ISO, IEEE, SAE, World Economic Forum, ITU & UN and highlighted some of the guidelines that the BSI recommends for any deployment of 5G projects for autonomous vehicles. The study highlights 300 standards, guidelines and legislation that could support the technological maturity of the product, allow stakeholders to collaborate and laydown some ground rules for network operators and governments to handle the deployment of these technologies. The WP6 team, following Catapult's advice, reviewed all these 300 standards to understand which current standards are applicable to some of the recommendations and identify gaps with no standards, legislation, or agreement in place for the deployment of 5G for CAM.

The team also reviewed some of the work and guidance that the World Economic Forum, 5GAA and 5GPPP developed between 2020 and now to ensure that the voice of the industry was included in our recommendations.

- The second critical activity was to have a set of interviews with industry experts to understand if, after our initial validation, there were any major issues with our recommendation and if those were in line with the vision of the market and the industry approach. In total D6.1. received feedback from more than 20 experts and organisations that validated the set of recommendations.

Table 4. Stakeholders contacted for the validation process.

	Feedback	Position
Catapult	Yes	Lead Architect Mobility Catapult
Reed Mobility	Yes	Autonomus European Ethic Committed
Y-Mobility	Yes	Ex-JLR Chief Architect/ Co-Chairman AESIN Data, Software and Cyber/ CTO Y-Mobility
ARRIVAL	Yes	Chief Strategy Officer
ADA Fundation	Yes	President ADA Foundation
ITU	Yes	Leader of ITU Functional safety for deployment of autonomous vehicles
ISO	Yes	Autonomous Deployment ISO Steering Committee
Thales	Yes	Head of CyberSecurity
AESIN	Yes	Director of AESIN
Capgemini	Yes	VP & Head of Telco UK
Transport Technology Forum	Yes	Member of the steering comitte
UK Automotive Council	Yes	Automotive Council member
Reanult	Yes	Senior Management
Bosch	Yes	Ex-director Mobility
ETAS	No	Chief Architect
NXP	No	Chief Architect
HPE	No	Chier Architect Data
Vodafone	No	Head of Mobility
Siemens	No	Head of Mobility
DFT	No	Head of connected car
ARM	No	Head of Automotive

3. 5G FOR CAM INFRASTRUCTURE CONSIDERATIONS

3.1. CAM Requirements for 5G

Connected, and automated mobility (CAM) demands huge amount of data, a reliable responsiveness, and the capacity of connection of multiple sensors and video devices. These requirements pose a challenge for wireless communications. 5G networks can offer a response for these dares thanks to services like enhanced mobile broadband (eMBB), which provides data rates of 1 Gbps, ultra-reliable low-latency communications (URLLC), with end-to-end latency of less than 10 ms, and massive machine-type communications (mMTC), which allows the connection of a huge number of devices. Thus, these features enable the deployment of smart driving at present [1]. There are a lot of different Use Cases with diverse requirements for the 5G networks, but most of them are related to the bandwidth, low latency, and reliability of the supported messages between the car and the 5G networks, in the Uplink channel and in the Downlink channel. The technical requirements for 5G network infrastructure to be deployed must be generally supported by a business case.

A few high-level network requirement ranges, directly extracted from ETSI standards, are going to be introduced. The users and applications requirements, that includes the Facility layer structure, functional requirements, and the requirements, are defined in ETSI TS 102 894-1[57] and in ETSI TS 102 894-2[58]. More details, dependent on the particular services, are described for the “Cooperative Awareness Basic Service”, the “Decentralized Environmental Notification Basic Service” and the “Collective Perception Service”.

3.1.0. Cooperative Awareness Basic Service

As defined in ETSI EN 302 637-2 V1.4.1 (2019-04) (Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service), the CAM generation frequency is managed by the CA basic service; it defines the time interval between two consecutive CAM generations.

Within these limits the CAM generation shall be triggered depending on the originating ITS-S dynamics and the channel congestion status. In case the dynamics of the originating ITS-S lead to a reduced CAM generation interval, this interval should be maintained for a number of consecutive CAMs.

3.1.1. Decentralized Environmental Notification Basic Service

As defined in ETSI EN 302 637-3 V1.3.1 (2019-04) (Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service), ITS use cases are distributed over multiple instances of ITS stations (ITS-S). ITS-Ss interact in the ITS networks to provide a large diversity of co-operating customer services that satisfy different types of functional and operational requirements.

ETSI TC ITS has defined a "Basic Set of Applications" (BSA) in ETSI TR 102 638 [i.1] that can be deployed within a three-year time frame after the completion of their standardization. In BSA, the Road Hazard Warning (RHW) application is composed of multiple use cases with the objective to improve road safety and traffic efficiency using vehicle-to-vehicle and vehicle-to-infrastructure communication technologies. ETSI TC ITS defines the decentralized environmental notification (DEN) basic service that supports the RHW application.

The DEN basic service is an application support facility provided by the facilities layer. It constructs, manages, and processes the Decentralized Environmental Notification Message (DENM). The construction of a DENM is triggered by an ITS-S application. A DENM contains information related to a road hazard, or to an abnormal traffic condition, such as its type and its position. The DEN basic service delivers the DENM as payload to the ITS networking & transport layer for the message dissemination. Typically for an ITS application, a DENM is disseminated to ITS-Ss that are in a geographic area through communications among ITS stations. At the receiving side, the DEN basic service of an receiving ITS-S processes the received DENM and provides the DENM content to an ITS-S application. This ITS-S application may present the information to the driver if information of the road hazard or traffic condition is assessed to be relevant to the driver. The driver is then able to take appropriate actions to react to the situation accordingly.

3.1.2. Collective Perception Service

Finally, ETSI TR 103 562 V2.1.1 (2019-12) standard (Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Analysis of the Collective Perception Service (CPS); Release 2), prepares the specification of the Collective Perception Service to support applications in the domain of road and traffic safety applications. Collective Perception aims at sharing information about the current driving environment with other ITS-Ss. For this purpose, the Collective Perception Service provides data about detected objects (i.e., other road participants, obstacles and alike). Collective Perception reduces the ambient uncertainty of an ITS-S about its current environment, as other ITS-Ss contribute context information. This includes the definition of the syntax and semantics of the Collective Perception Service (CPS) and detailed description of the data, the messages, and the message handling to increase the awareness of the environment in a cooperative manner.

The minimum time elapsed between the start of consecutive CPM generation events should be equal to or larger than T_{GenCpm} . T_{GenCpm} is limited to $T_{\text{GenCpmMin}} \leq T_{\text{GenCpm}} \leq T_{\text{GenCpmMax}}$, where $T_{\text{GenCpmMin}} = 100$ ms and $T_{\text{GenCpmMax}} = 1\,000$ ms.

3.1.3. Requirements of 5G for the different cases of use of CAM/functionalities

As it is known, in this European project five use case categories are deeply studied. They are advanced driving, vehicles platooning, extended sensors, remote driving vehicle and vehicle QoS Support.

The 5G Automotive Association (5GAA) published a table with the requirements of 5G for the different cases of use of CAM/functionalities (some of them yet under discussion) [59]. The following tables have been

extracted from the previously mentioned document and adapted to the use case categories of the 5G-MOBIX project. The following tables have been extracted from the previously mentioned document and adapted to the use case categories of the 5G-MOBIX project.

Table 5. UC Category 1: Advanced Driving. Source: 5GAA.

Category	Use Case	Required messaging (a message may serve multiple use cases)
Advanced Driving	Real-Time Situational Awareness	300 B messages at a repetition rate of ≤ 10 Hz (≤ 24 kbit/s) (continual)(broadcast). ----- UL or DL: 8 kbit/s (Event triggered) (unicast/groupcast).
Advanced Driving	High-Definition Sensor Sharing	(Under discussion) 1000 B messages at a repetition rate of ≤ 100 Hz (≤ 800 kbit/s) (continual)(broadcast).
Advanced Driving	See Through for Passing	A video stream of 8 Mbit/s (Event triggered) (unicast).
Advanced Driving	Obstructed View Assist	DL/sidelink: Video stream of 5 Mbit/s (Event triggered) (unicast).
Advanced Driving	Awareness Confirmation	Request for confirmation 40 kbit/s (Event triggered) (broadcast). Subsequent confirmations under discussion (continual)(unicast).
Advanced Driving	Vehicle Decision Assist	1000 B in 100 ms (80 kbit/s) (Event triggered) (unicast).

Table 6. UC Category 2: Vehicles Platooning. Source: 5GAA.

Category	Use Case	Required messaging (a message may serve multiple use cases)
Vehicles Platooning (in Steady State)	Traffic Efficiency	MV to MV: 100 B messages at a repetition rate of 10 Hz (8 kbit/s) (continual)(groupcast). HV to MV: 300 B messages at a repetition rate of 20 Hz (48 kbit/s) (continual)(groupcast). DL: 1000 B messages (Event triggered) (groupcast).

Table 7. UC Category 3: Extended Sensors. Source: 5GAA.

Category	Use Case	Required messaging (a message may serve multiple use cases)
Extended Sensors	Exchange of raw or processed data gathered through local sensors or live video data	(Under discussion)

Table 8. UC Category 4: Remote Driving Vehicle. Source: 5GAA.

Category	Use Case	Required messaging (a message may serve multiple use cases)
Remote Driving Vehicle	Tele-Operated Driving	UL: 4 video streams of 8 Mbit/s each, plus 4 Mbit/s sensor data (36 Mbit/s).

		DL: 400 kbit/s. (continual)(unicast).
Remote Driving Vehicle	Tele-operated Driving Support	UL: 4 video streams of 8 Mbit/s each, plus 4 Mbit/s sensor data (36 Mbit/s). DL: 400 kbit/s. (continual)(unicast).
Remote Driving Vehicle	Tele-Operated Driving for Automated Parking	UL: 4 video streams of 8 Mbit/s each, plus 4 Mbit/s sensor data (36 Mbit/s). DL: 400 kbit/s. (continual)(unicast).
Remote Driving Vehicle	Cooperative Manoeuvres of Autonomous Vehicles in Emergency Situations	(Under discussion) 300 B messages at a repetition rate of ≤ 20 Hz (≤ 48 kbit/s) (Event triggered) (broadcast/groupcast/unicast).
Remote Driving Vehicle	Remote Automated Driving Cancellation	Cancellation: 300 B messages at a repetition rate of 0.02 Hz (48 bit/s). Acknowledgement: Same. (Event triggered) (unicast).
Remote Driving Vehicle	High-Definition Map Collection and sharing	UL: 4 Mbits/s (sensors) or $8+35+4 = 47$ Mbit/s (video + lidar + sensors) (continual/event triggered) (broadcast)(unicast). DL: 16 Mbit/s (continual/event triggered) (broadcast).
Remote Driving Vehicle	Automated Intersection Crossing	300 B messages at a repetition rate of ≤ 10 Hz (≤ 24 kbit/s), SPaT: 100 B messages at a repetition rate of 1 Hz (800 bit/s) (continual)(broadcast). MAP: 1000 bytes in 1 second (8 kbit/s) (continual)(broadcast). ----- plea HD map: 1 MB, Trajectory: 25 kbit/s (Event triggered) (broadcast/unicast).
Remote Driving Vehicle	Vehicle Shares Information on Road Hazards /Events	UL/DL/sidelink: A single 300 B message in 20 ms (120 kbit/s) (Event triggered) (broadcast).
Remote Driving Vehicle	Cooperative Lane Merging	(Under discussion) RV to HV: 300 B message HV to RV: 300 B message RV to HV: 300 B message each with latency of 20 ms (120 kbit/s) (Event triggered) (broadcast/groupcast/unicast).
Remote Driving Vehicle	Autonomous Vehicle Disengagement Report	UL: 2 GB in 10 min (27 Mbit/s) (Event triggered) (unicast).
Remote Driving Vehicle	Infrastructure Assisted Environment Perception	UL: 70-155 Mbit/s, DL: 4 Mbit/s (Event triggered) (broadcast/unicast).

Remote Driving Vehicle	Infrastructure Based Tele-Operated Driving	Covered by Autonomous Vehicle Disengagement Report and Tele-Operated Driving
Remote Driving Vehicle	Automated Valet Parking: Joint Authentication and Proof of Localization	1000 B in 500 ms (16 kbps) (Event triggered) (unicast).
Remote Driving Vehicle	Coordinated, Cooperative Driving Manoeuvre	(Under discussion) (Event triggered) (groupcast).
Remote Driving Vehicle	Bus Lane Sharing Request and Revoke	UL: 1000 B in 200 ms (40 kbit/s). DL: 1000 B in 200 ms (40 kbit/s). (Event triggered) (unicast).

Table 9. UC Category 5: Vehicle QoS Support. Source: 5GAA.

Category	Use Case	Required messaging (a message may serve multiple use cases)
Vehicle QoS Support	Periodically notifications of expected or estimated change of quality of service in real time	(Under discussion)

3.2. Envisioned Scenarios

According to the interim finding of a study conducted by a team of independent consultants for the Commission to support the implementation of CEF Digital, and which were presented in a public workshop on 1st October 2019, four scenarios can be devised:

- **Minimum scenario:** This scenario is based on the critical data that should be transmitted in any traffic conditions. The reference is the minimum bitrates observed on the current tests. Use cases that require additional services, such as the video visualization to improve driver comfort and to reassure the driver/passengers, are not considered as critical services during the busy hour.
- **Classic scenario:** A scenario based on the critical data that should be transmitted in any traffic conditions. The reference is the average bitrates observed on the current tests with the possibility to have main use cases at the same time (the majority are not always-on).
- **Breaking scenario:** A scenario based on all 5G CAM use cases, including those that are more specifically designed for the driver (and not for the unmanned algorithm) or those that are designed for V2V communication, or V2N2V as a fallback.
- **Future Proof scenario:** In this scenario, the network will support any conceivable future service, (equipment every 0.4km, bitrate of 100Mbps).

3.3. Agreements between telecommunication operators

The 5G telecommunications infrastructures must be interconnected in order to provide smooth transitions of the vehicles in the borders of the countries and networks.

In network and country borders, the specific scenarios deployed are very relevant, as well as technology readiness and frequency availability in both operators. In some cases, these borders will include several operators from each country.

The main telecommunication components that must be interconnected include the Radio, the Core, the virtualization resources, and the transport networks, so this is summary of some specific requirements and agreements that must be clarified between operators in the borders:

- **Radio sites interconnection:** the radios can be synchronized by signalling the adjacent radio cells in the border between the operator and other parametrization of the nodes of both operators in the border. It is even possible to share radio sites in the border.
- **Core interconnection:** depending on the core components and versions, several options could be implemented. The main components:
 - **Distributed Core:** Entity with reduced functions respect to a central core.
 - **Central Core:** *Architecture with functions as authentication, control traffic, SIMs management and subscriptions.*
- **MEC interconnections:** a deployed fibre connects located MECs in different countries.
- **Transport networks** that support the physical interconnection of the radio or core components. In case of slicing the qualities or the slices must be supported end to end.
- The **Network Operations Centres** to attend users' incidences must be supported, so the interchange of some information must be also included.
- Billing and subscription information **management**.
- Billing between **telecommunications and others CAM providers:** Infrastructure, Cars manufactures, Entertainment services, emergencies agencies.
- **Agreements for roaming vehicles** with countries not involved in the border, at European level, or the rest of the world.
- **Judicial intervention** in other countries agreements.

3.3.0. Network sharing

The paradigm of network sharing is not a new concept for mobile communications broadly or for emerging 5G networks. This idea arose when 3G technology started to be deployed. The main target of network sharing is decreasing Capital Expenditures and Operational Expenditures (CAPEX/OPEX) costs and the establishment of new business opportunities.

In the latest years, the traffic volumes supported by the mobile networks have been increased in a substantial way, hence, MNOs are obliged to accommodate this demand trying to minimize the operational and infrastructure costs. The trend toward network densification for increasing network capacity and the practice of overprovisioning to accommodate peak demands including future traffic volumes adds the operational complexity and cost, diminishing the Return of Investment (RoI).

There are two approaches for implementing the sharing of mobile infrastructures: passive and active sharing.

- In **passive sharing**, the equipment shared between different mobile operators is limited to the passive network elements such as radio masts, power supplies, cabinets, towers, security alarms, etc.
- **Active sharing** extends the list of shared equipment to include the transport infrastructure (fibre, cables, etc.), baseband processing resources, and potentially the radio spectrum.

According to [2], mobile operators need to exploit new revenue sources and break the traditional business model of a single network infrastructure ownership due to the fact 50% of the radio access sites carry traffic that yields less than 10% of the revenue. In a Network sharing model, it is possible to recover 20% of operational costs for a typical European mobile network operator and can at least half the infrastructure cost of passive Radio Access Network (RAN) components, which make up to 50% of the total network cost.

Moreover, MNOs can add network virtualization features NFV (Network Function Virtualization) and SDN (Software Defined Networking), jointly to network sharing, reducing significantly the capital and operational costs in the new 5G systems.

3.3.1. Advantages of applying network sharing (technical and economic)

The strategy of network sharing can provide several benefits in infrastructures and in reducing costs.

The association of several Mobile operators can accelerate network rollouts and offer services to customers with reduced costs. For instance, from the point of view of the location, network sharing in urban areas can help avoiding complex and lengthy processes for site acquisition due to regulation issues, especially in highly populated regions where dense deployments restrict the available space, while for rural areas sharing can reduce the network investment payback period.

The location of the base stations can present some difficulties. Firstly, the space within buildings is usually confined and reasons of aesthetics/civil works limit the choice for MNOs. This means the space where indoor base stations can be installed is restricted. Secondly, operators will compete for a few sites and they will choose the optimal sites, hence, each operator will have to invest in the civil works of antenna and transmission lines. In this context, it would be more rational for operators to share in-building infrastructure or at least the transmission lines to share the burden while achieving reasonable coverage.

The reduction of costs is the other most considerable aspect of network sharing, some cost savings benefits are the following [3]:

- Passive sharing can save up to 16%-35% CAPEX and 16%-35% OPEX.
- Active sharing excluding spectrum can save about 33%-35% of CAPEX and 25%-33% of OPEX.
- Active sharing including spectrum can save up to 33%-45% of CAPEX and 30%-33% of OPEX.
- Core network sharing: core network sharing cost savings are limited.

In addition to the previous benefits, other advantages can be associated to Network sharing [4]:

- Environmental benefits: reduces energy consumption and mitigate citizens' concern over radiation.
- Customer experience: Improvements of quality of the services, better coverage, higher data speed.
- Coverage obligations set by country regulation can be met.

3.3.2. Strategic and technical difficulties for Network Sharing implementation and how it could be committed

The implementation of Network sharing must be well-defined between MNOs. The first steps in Network sharing were given when passive sharing was defined in 3GPP Rel.99 for UMTS networks. Nevertheless, such approaches did not gain significant interest from the industry until the early 2000s.

A step further was accomplished with mast sharing, where mobile operators can co-locate their sites and even share the antenna frame, but still install their own radio equipment, maintaining separate coverage.

With 3GPP Rel-6 (UMTS), Rel-8 (LTE) and Rel-10 (LTE-A), new requirements were needed to shed the light on the potential of network sharing.

Active RAN sharing followed the first generation of network sharing, which focused on sharing access network equipment including base stations, antennas and even mobile backhaul equipment. In active RAN sharing MNOs can pool spectrum resources, which are shared alongside other RAN equipment based on fixed, contractual agreements. The interest in sharing the resources dynamically introduced new requirements, beyond the original RAN sharing concepts, where MNOs share core transmission equipment, billing platforms and core network equipment.

3GPP specified two distinct active RAN sharing architectures:

- **Multi-Operator Core Network (MOCN)**, where each operator has its own Enhanced Packet Core (EPC) providing a strict separation amongst the core network and RAN. Shared base stations, i.e., eNBs and gNBs are connected to core network elements of each different operator, i.e., Mobility Management Entity (MME) and Serving/Package-Gateway (S/P-GW), using a separate S1 interface. Moreover, the same frequency band will be shared by the operators. This feature prevents the operators from being able to control their networks at the cell level. This enables customization, for example allowing load balancing

policies to be provided within each operator's core network. MOCN offers benefits regarding service differentiation and interworking with legacy networks.

- **Gateway Core Network (GWCN)**, where operators share additionally the MME; an approach that further enables cost savings compared to MOCN, but at the price of reduced flexibility, i.e. restricting mobility for inter-Radio Access Technology (RAT) scenarios and circuit switching fallback for voice traffic.

In general, MOCN requires a higher investment, nevertheless, it is considered to be more flexible, addressing better the conventional MNOs' needs. From the point of view the User Equipment (UE) behaviour in 3GPP architectures, both MOCN and GWCN, are identical, hence, network sharing is transparent to the user. In addition to the previous 3GPP architectures, another, not defined by 3GPP standards can be considered:

Multi-Operator Radio Access Network (MORAN) is an architecture where the eNBs/gNBs are shared, while the core network is proprietary to each network provider. The MORAN standard also proposed the sharing of the Radio Access Network (RAN), using dedicated radio frequencies assigned to each service provider. In this approach, they can independently control cell level e.g., each operator can decide his own optimization parameters, Tx Power to control the cell range and interference [5].

The previous architectures are based on active sharing. Respect to passive sharing, two options could be taken in account, namely site sharing, where physical sites of base stations are shared and, shared backhaul, where transport networks from radio controller to base stations are shared. The technical options will be closely linked to strategic decisions of a mobile operator company; as a result, the last ones will be those that choose the firsts, hence, the main difficulty for mobile operators to consider network sharing options and the technological option to do it is its own characteristics. Some reasoning of large cellular companies to not apply the concept of network sharing are the followings [6]:

- A significant aspect that influences MNOs' decision of whether enabling network sharing is beneficial for their business relies on the purpose of sharing and on the risk of reducing their competitive advantage. For instance, allowing coverage enhancements of their competitors is sensitive for emerging mobile markets where coverage is a significant service attribute, but it becomes more relaxed in cases where QoS provision and service innovation is the key business differentiator.
- Reasons like fearing the operational complexity they may bring, the up-front transformation costs, and the potential loss of control over their own destinies are solid bases to decline network sharing from the point of view of a large operator.
- Some are apprehensive, as their implementation strategies and choices about hardware and vendors could be copied in the future.
- Large operators believe a new regulatory framework could be imposed if the market share becomes larger.
- Big mobile operators mistrust small competitors that can have the funds to the initial cost of a network sharing deal.

- If network assets are to be transferred to the new sharing entity, a significant tax may be incurred, which could have a real impact on the company's income statement.
- Some operators believe a combined network has plenty of technological and operational perils.
- Many operators do not feel confident in the Network sharing process and they consider the negotiation a waste of time.

Nokia, along with leading operators Telenor and Telia, announced in March 2020 that they had deployed the world's most advanced shared wireless network supporting a Multi-Operator Core Network (MOCN) feature, enabled for wireless technologies spanning 2G to 5G. The 5G MOCN feature was deployed for instance on a trial network in Denmark and verified with successful end-to-end test calls. MOCN, the most advanced network architecture model allowing for network sharing, enables distinct mobile operators with their own core network to share a common radio access network infrastructure as well as spectrum resources [7].

This is the first network to include live MOCN capabilities for 2G, 3G, 4G and 5G simultaneously. The live trial utilized Nokia's end-to-end 5G technology, including 5G RAN and 5G cloud core. This trial highlights that through network sharing, operators can drive efficiencies, lower costs, and bring the myriad benefits of 5G to businesses and consumers quickly. 5G MOBIX project hopes that trials demonstrate to operators around the world that there are multiple options open to them to get their 5G networks up and running quickly and at the lowest possible cost.

Network sharing is an efficient and cost-effective way for two or more mobile operators to build and roll out a network at scale without having to duplicate efforts. It is an important strategic consideration for operators that helps them to quickly deploy 5G networks to consumers and businesses while keeping costs to a minimum. Tommi Uitto, President of Mobile Networks at Nokia, said: "As 5G networks require a higher density of radio equipment, such as small cells, to deliver the right performance and coverage, network sharing results in overall lower power consumption compared to individual networks."

4. COSTS OF DEPLOYMENT OF 5G FOR CAM

This section aims to provide an overview of the different costs to be considered when deploying 5G technology for CAM applications. These costs have been identified based on the experience of the 5G MOBIX consortium partners and have been classified into 4 categories: Telecommunication related costs, Automotive OEM Related Cost, Road Operators Related Cost and Cloud costs. Once the different cost categories have been presented, the bibliographic data obtained from the analysis of the different 5G PPP projects will be presented, as confidentiality reasons prevent 5G-MOBIX to provide specific costs from the CBC/TS sites. More accurate estimates are planned to be provided by WP6 to WP5 as input to the cost-benefit analysis.

4.1. Cost's categories

The costs related to telecommunications are quoted and described in the following table:

Table 10. Telecommunication related costs. Source: 5G MOBIX.

	Telecommunication related costs	Explanation
CAPEX	Antennas / Feeder	Antennas are mounted on towers and usually require having nearly uniform patterns in the horizontal plane with shaping in the vertical plane to conserve power. It includes RF front end cost also.
	Transport from Antenna Site	Fibre network to transfer data from antenna to core or MEC etc.
	Network Core Equipment	Core equipment that includes.
	Permits	Permit fees to deploy base station on a specific area.
	Site Civil Works	Civil works to deploy a base station for the first time.
	Labour	Workforces to meet new requirements or maintain connection (software engineers, field engineers etc.).
	Cabinets	A range of enclosures designed for installation of telecommunications equipment inside customers premises. Designed for installation inside telephone exchanges to house standard telecommunication equipment and accessories. Cabinets come supplied with glazed, louvered, or mesh doors.
	Spectrum costs	Costs related to the spectrum licence.
	Bare Metal	Metal part of base station.
OPEX	Antenna Maintenance Visits	Periodic Antenna Maintenance Costs.
	Antenna site rental	Costs of renting the land on which the antenna is located (if applicable).
	Edge cloud cabinet rent & utilities	Costs of edge cloud cabinet rent & utilities.
	Edge cloud operating overhead cost	Costs of Edge cloud operation.
	Edge cloud transport	Costs of Edge cloud transport.
	Edge cloud RAN equipment licensing	Licensing costs.
	Insurances	Cost of insurances.
	Energy costs	kWh necessary * €/kWh.

The costs related to automotive OEMs are quoted and described in the following table:

Table 11. Automotive OEM related costs. Source: 5G MOBIX.

	Automotive OEM Related Cost	Explanation
CAPEX	Sensors	Costs related to all the sensors that need to be installed in the vehicle: cameras, Radars, LIDAR, etc.
	Vehicle architecture modification costs	Costs required for the integration of the previous sensor in the vehicle (body modifications, supports, etc.).
	Modem	5G Modem necessary for the OBU.
	Infotainment Equipment	Costs related to the infotainment equipment in the vehicle.
	Processing Electronic Control Units	Costs related with the Processing Electronic Control Units for Autonomous Functionalities.
	Labour	Cost (Hours) required for full integration in vehicle.
	Homologation validation tests	Costs of vehicle homologation processes.
OPEX	SW Updates	Periodic software update costs.
	Communications fees	Terrestrial & non terrestrial communications fees (sim card & sat fees).
	HD Map Service Fees and Maintenance Fees	Periodic maintenance fees for the high-definition mapping service.
	Insurances	Required insurances

The costs related to Road Operators are quoted and described in the following table:

Table 12. Road Operator related costs. Source: 5G MOBIX.

	Road Operators Related Cost	Explanation
CAPEX	Toll Gates	Toll gate costs
	Labour	Cost (Hours) required for full integration road.
	Modem (RSU)	5G Modem Costs for each RSU
	Transport from Equipment	Fibre optic costs
	Sensors (CCTV, Radar etc.)	Road Infrastructure costs
	Site Civil Work	Costs related to civil works
	Permits and licenses	Costs of permits and licenses required for deployment
OPEX	Operation and maintenance work (Hours)	Labour costs for site maintenance (fixing network issues, physical problems on site, etc.)
	Operating overhead cost	Periodic general operating expenses
	Rental costs	Monthly Rental costs for deployment site, e.g., from city authority for a lantern / other public or private installation site on building or roadside
	Electricity fees for site + KWhe consumed	Annual expenditure on electricity consumption.
	Telecommunication costs	Monthly telecommunication costs per site in case of Fixed Wireless Access: 5G contract including sufficient Data plan for uplink / downlink traffic
	Insurances	Required insurances

The costs related to Cloud are quoted and described in the following table:

Table 13. Cloud Costs. Source: 5G MOBIX.

	CLOUD	Explanation
CAPEX	Server to deploy Cloud applications (ITS CENTER...)	kWh consumed annually

	Server to deploy MEC applications	Server cost
	Broker-MQTT	Broker-MQTT cost
OPEX	Cloud Fee	Fees for Cloud services
	Operating overhead cost	Periodic general operating expenses
	Maintenance	Periodic maintenance costs
	Insurances	Required insurances

4.2. Cost's overview

4.2.1. 5G PPP Projects.

Since it is not possible to present economic deployment costs in the current phase of the 5G MOBIX project, an in-depth analysis of the different projects under the 5GPP has been carried out.

More specifically, the projects analysed are those shown below:

Table 14. 5G PPP Projects Analyzed.

Phase I	Flex5Gware, 5G Norma, METIS II, EURO 5G, 5G-XHAUL, 5G ENSURE, CHARISMA, SESAME, SELFNET, COGNET, VIRTUWIND, 5G EX, FANTASTIC, COHERENT, SONATA, SUPERFLUIDITY, 5G-CROSSHAUL, MmMAGIC, Speed5G.
Phase II	5G ESSENCE, 5G CAR, 5G CITY, 5G MEDIA, 5G-MONARCH, 5GPHOS, 5G-PICTURE, 5G TANGO, 5G TRANSFORMER, 5GXCAST, 5G BLUE SPACE, IoRL, MATILDA, METRO X HAUL, NG PAAS, NRG5, ONE5G.
Phase III	5G EVE, 5G VINNI, 5GENESIS, 5G CROCO 5GCARMEN, 5G SOLUTIONS, 5G TOURS, 5G DRONES, 5G HEART, 5G GROWT, 5G SMART, 5G VICTORI, FULL 5G, ARIADNE, 5G CLARITY, 5G COMPLETE, INSPIRE-5G PLUS, LOCUS, MONB5G TERAWAY, 5G ZORRO, 5G-DRIVE, PRIMO 5G.

From the analysis of the different projects of the 5G-PPP, the following conclusions are obtained in relation to the costs:

- A very high percentage of the projects (75,6%) do not share any economic information, as economic studies are not undertaken or not publicly available. Phase III projects have not concluded yet.
- In some cases, Ecosystem and high-level economic KPIs, Business Canvas-related information or Market Analysis is available, but not detailed economic information.
- Very few projects offer a complete economic overview of the project.

In addition, these projects only present economic information specific to their 5G network developments so the economic information will be completed with additional literature. This is mainly due to the current state of technology (starting in the market) and the strong confidentiality policies of the partners that provide the technology in the projects. Due to the above, only economic information of seven 5G PPP projects is presented below.

Table 15. 5GPPP Costs Overview.

Telecom Related Cost	Project	5G Norma.	Metis II.	Charisma.	5G CAR	5G City	5G Monarch	5G Picture
CAPEX	Antennas / Feeder	<ul style="list-style-type: none"> • Antennas: From £250 (Small cell) to 7200 (Macrocell) • Feeder, install, test and commission costs per site: From £700 to £4400 • RF front end: From part of integrated active equipment to £24k (for 3 sectors). 	<ul style="list-style-type: none"> • 11000€: 5G outdoor small cell including all related cost (integrated antenna, router, security gateway, site related costs, backhauling (a mixer of optical fibre and Microwave)). • 5000€: 5G indoor hotspot small cell including all related cost (integrated antenna, router, Security gateway, inch, site related costs, backhauling (a mixer of optical fibre and Microwave)). • 10000€: mm Wave 5G outdoor cell on existing small cell site. • 8000€: mm Wave 5G indoor cell on existing small cell site- 	<ul style="list-style-type: none"> • 4.000€: Small Cell. • 40.000€: Macro Cell. 	<ul style="list-style-type: none"> • 5G Site:(CAPE X (40K€)) • Digital Infrastructure (CAPEX): 35K€/km • Fibre (CAPEX): 100k€/km • OPEX: 17,5k€/km/year • Inter-site-distance (ISD): 1 km 	<ul style="list-style-type: none"> • Investment costs: <ul style="list-style-type: none"> • 45%- Server • 25% - Small Cells • 13% GPUS • 6% - Switches • 3% - Micro servers • 2%- Air conditioning • 2% - Racks • 1% - UPS • 1%- Cables 		<ul style="list-style-type: none"> • Total yearly CAPEX (Power?) 4297179 €/y
	Transport From Antenna Site		<ul style="list-style-type: none"> • 4.000 €: A new backhaul link for outdoor small cell. 					
	Network Core Equipment						<ul style="list-style-type: none"> • 48% (servers) 	
	Permits							
	Site Civil Works	<ul style="list-style-type: none"> • £ 46,200: Macrocell (3 sectors) • £ 46,200: Small cell (2 sector small cell) • £ 4,800: Picocell (1 sector mm Wave small cell) 		<ul style="list-style-type: none"> • 15000€: Small Cell Site: civil works, connection to utilities, etc. • 10000€: Macro Cell Site: upgrades needed to host the new equipment. 				
	Labour Cabinets						<ul style="list-style-type: none"> • 5% 	

	Spectrum costs		<ul style="list-style-type: none">• 12.000 €: Adding an additional frequency (non-mmWaves) band to an installed 5G macro base station.					
	Bare Metal							
	Edge cloud CAPEX	<ul style="list-style-type: none">• Fixed costs for initial set up pf an installation at edge cloud site: 10,100 £.• Costs include power supply distribution boards, sockets, lighting, enclosure, overhead racking and cabling.• Fixed costs to set up a cabinet/rack at the edge cloud site: 21,400 £• Includes power distribution, Air Conditioning set-up, space set-up, AC distribution and cabinet.• Fixed costs per server 6,500 £ (Maximum of 16 servers per cabinet.• Assumes 35% discount. This is equivalent to just under £490/installed core (for a fully equipped cabinet))						
	Base station (*)		<ul style="list-style-type: none">• (*) 55000 €: 5G macro base station on an existing site, including 5G BS, embedded SW, installation, new MIMO antennas and infrastructure adaptation.• (*)60000€: New macro site build cost, excluding telecommunication equipment.					

OPEX	Antenna Maintenance Visits	<ul style="list-style-type: none">• Macrocell: 10% of Active Equipment / 10% of the RF front end cost.• Small Cell: 25% of Active Equipment• Picocell 25% of Active Equipment	<ul style="list-style-type: none">• 10% Operation & maintenance, including SW licenses (10% of CAPEX)	<ul style="list-style-type: none">• 800€/month [Small cell site: Monthly rent and utilities cost]• 4000€/month [Macro cell site: Monthly rent and utilities cost]	<ul style="list-style-type: none">• Running costs: 29% - Installations29% - Employees14% - Maintenance10% - Venue Rental9% - Network Operation8% - electricity2% - Billing license			<ul style="list-style-type: none">• OPEX energy 39172 €/y• OPEX others 249068 €/y
	Antenna site rental	<ul style="list-style-type: none">• From 1K£ (picocell, small cell) to 20K£ (Macrocell)	<ul style="list-style-type: none">• 800 € (Average macro site rental per year)					
	Site updates		<ul style="list-style-type: none">• 3000€: Upgrade 5G outdoor small cell to 2 bands including all related costs.• 2000€: Upgrade 5G indoor small cell to 2 bands including all related cost)					
	Edge cloud cabinet rent & utilities	<ul style="list-style-type: none">• Server (nominal) cost 10,000 £• Transport: 1150 £• Standing charges / edge cloud: 6,300 £• Site rent and utilities/cabinet: 6,600 £						
	Edge cloud operating overhead cost							
	Edge cloud transport							
	Edge cloud RAN equipment licensing							
	Insurances							
	Energy costs							

4.2.2. Additional literature

In addition to reviewing the projects related to the 5G PPP, a bibliographic analysis has been conducted to give an overview of the costs related to 5G for CAM. This section aims to provide an insight into the costs of 5G Technology deployment for CAM by reviewing the most influential literature on the technology. Once these costs have been evaluated, they can be categorized into:

- Backhaul and 5G Networks costs.
- RSI/RSU costs.

4.2.2.0. *Backhaul Network and 5G Network costs*

In relation to the backhaul and 5G networks, CAPEX and OPEX costs [8] that should be considered are presented below:

- **CAPEX:**
 - **Site infrastructure:** gNBs, network equipment, cabinets, etc.
 - **Civil works:** physical cabinets, fences, antenna masts, etc.
 - **Fibre backhaul** provision along the highway.
- **OPEX:**
 - **Network operation,** maintenance, and replacement, corresponding to the standard assumption of 10% of the accumulated CAPEX.
 - **Site lease:** permissions to use land perimeters.

Below are the cost data obtained from bibliographic sources [8], [9]:

Table 16. Deployment costs and assumptions for 5G V2X Deployment. Source: [8], [9].

Source:		[8]	[9]			
			MINIMUM 5G Scenario	CLASSIS 5G Scenario	BREAKING 5G Scenario	FUTURE PROOF 5G Scenario
			1 Mbps guaranteed bitrate in Highly traffic period	2 Mbps guaranteed bitrate in Highly traffic period	30 Mbps Average guaranteed bitrate Normal Conditions	100 Mbps Average guaranteed bitrate Normal Conditions
Deployment costs	5G site (CAPEX)	64.000 € per site	90.000€			
	Civil works (CAPEX)	20.500 € per site	17.000€/km (*3)	24.000€/km (*3)	70.000€/km (*3)	181.000€/km (*3)
	Fibre backhaul (CAPEX)	23.000 € per site	12.000€/km (*2)	12.000€/km (*2)	19.000€/km (*2)	19.000€/km (*2)
	Network operation (OPEX)	10 % of CAPEX	N/A	N/A	N/A	N/A
	Site lease (OPEX)	5.700 € per site	N/A	N/A	N/A	N/A
Area and capacity demand	Inter-site-distance (ISD)	1 km	≈4km	≈3km	≈1km	≈0,4km
	Number of vehicles	50.000 Vehicles/100km/day	N/A	N/A	N/A	N/A
Deployment rate	Connectivity costs for CAM	0,5 € per 100 km	N/A	N/A	N/A	N/A
	Network deployment rate	55 % for year 1 for coverage	N/A	N/A	N/A	N/A
		5 % for year 2 to 10 for capacity	N/A	N/A	N/A	N/A
	Fibre deployment rate	80%-year 1	N/A	N/A	N/A	N/A
		20 %-year 2	N/A	N/A	N/A	N/A
	Yearly penetration rate	10 % from year 1 to 10	N/A	N/A	N/A	N/A
Cost's evolution	CAPEX yearly price evolution	-3 % from year 1 to 10	N/A	N/A	N/A	N/A
	OPEX yearly price evolution	3% from year 1 to 10	N/A	N/A	N/A	N/A

- *1: Spectrum costs, engineering and procurement costs are not considered as part of CAPEX in this study.
- *2: The existing backhaul along the corridor is 50%.
- *3: Site Upgrade.

4.2.2.1. RSI/RSU costs.

RSI/RSU concept costs can be divided in three categories [10]:

- **Deployment cost** (CAPEX), this is capital expenditure for network assets and infrastructure.
- **Operation and management costs** (OPEX), this is yearly expenses to operate and maintain the network infrastructure.
- **Connectivity costs** that correspond to fees related to connectivity services, considered when the service provider does not own and operate the entire network where the service is provided.

Two different options can be considered:

- Existing cellular network infrastructure for delivering services via V2N2I communications.
- Dedicated RSU-based communication V2I infrastructure (C-V2X PC5 or 802.11p based ITS-G5/DSRC).

Table 17. Cost split for the considered deployment options. Source: [10].

	Deployment costs (CAPEX)	Operation and maintenance costs (OPEX)	Connectivity costs
Existing cellular network infrastructure for delivering V2N2I	<ul style="list-style-type: none"> • Network deployment costs (MNOs) • The cost for service providers is reflected in the connectivity fee) • Existing cellular networks are capable to satisfy the demand to communicate with vehicles for several V2N2I services • Possible costs for road infrastructure upgrades (such as local processing units) are out of scope for the cost analyses. 	<ul style="list-style-type: none"> • Network costs are covered by MNOs (these costs are reflected in the subscription fees for connectivity) • Opportunities for cost support by V2N2I service providers are mentioned but not explored • Possible costs for new road infrastructure components are out of scope for the cost analyses. 	<ul style="list-style-type: none"> • Subscription costs are estimated for the traffic to/from all the vehicles (if covered by a single service provider) • Estimated subscription costs per vehicle per year (over ten years) are presented as alternative.
Dedicated RSU-based V2I infrastructure	<ul style="list-style-type: none"> • RSU deployment costs are the responsibility of the service provider • Possible costs for road infrastructure upgrades are out of scope for the cost. 	<ul style="list-style-type: none"> • RSUs O&M costs are assumed to be covered by the service provider • Possible costs for O&M of new road infrastructure components are out of scope for the cost. 	<ul style="list-style-type: none"> • No connectivity costs to communicate with vehicles associated with this technology • Possible connectivity costs to connect RSUs with backend inf. are out of scope for the cost analyses.

In relation to the existing cellular network infrastructure for delivering services via V2N2I communications, the estimated costs per bit are presented in the next table:

Table 18. Estimated cost per bit. Source: [10].

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
10^{-10} EUR/bit	0,12	9,4	7,52	6,016	4,81	3,85	3,08	2,46	1,97	1,58

In relation to the dedicated RSU-based communication V2I infrastructure (C-V2X PC5 or 802.11p based ITS-G5/DSRC). The RSUs Cost are:

Table 19. RSU Costs. Source: [10].

CAPEX Cost element	Cost per device (EUR)	MINIMUM 5G Scenario	CLASSIS 5G Scenario	BREAKING 5G Scenario	FUTURE PROOF 5G Scenario
Hardware	3500	5 k€		20k€	
Installation	1000				
Design & planning	2700 (60% of hardware and installation costs)				
Interdistance	[300m-1km]	3 km		2 km	
Total CAPEX	7200	5000	5000	20000	20000
OPEX Cost element	Yearly cost per device (EUR)	N/A	N/A	N/A	N/A
Power	20	N/A	N/A	N/A	N/A
Maintenance	225	N/A	N/A	N/A	N/A
Security	40	N/A	N/A	N/A	N/A
Annualized replacement cost (over ten years)	250	N/A	N/A	N/A	N/A
Total OPEX	735	N/A	N/A	N/A	N/A

5. CHALLENGES TO 5G FOR CAM

5.1. General challenges for 5G for CAM

In this section, some of the main challenges for the deployment of 5G technology for CAM applications are presented. It should be noted that in relation to the challenges related to business models, standardization, spectrum allocation and European regulation & policies will be addressed in the deliverables of tasks T6.2, T6.3 and T6.4, (D6.2, D6.3 and D6.4 respectively), so they are not addressed in this document that reflects the work of T6.1.

5.1.1. Deployment

The implementation of a new mobile communication technology implies the deployment of a novel network architecture, hence, the availability of new 5G equipment depends on the vendors and their capability of manufacturing the elements fulfilling this new architecture. Vendors, in turn, depend on the maturity of the standardization by 3GPP to be able to develop their new network products portfolio and gradually add new functionalities to these devices as they are standardized. This fact can be translated in the assessment of maturity of 5G technology, for instance, some automotive applications cannot be completely tested in laboratory or real conditions due the technology is not still fully deployed. Therefore, the evolution of the technology and the availability of new deployments become fundamental in user cases like CAM.

Additionally, 5G technology requires mobile service providers to address CAM applications and other growth markets and move beyond a subscriber-driven revenue model, therefore some considerations must be provided in these new networks:

- Every component of the network must be ready for 5G technology, where the network will only be as fast as its slowest link. Each element must be dimensioned for 5G speeds. And for a true 5G experience overall with low latency, high bandwidth, and an ability to connect with billions of devices an end-to-end evolution plan is needed. That means upgrading the core, radio and all the transport links that connect them.
- A distributed cloud-based architecture is mandatory, where much of the network must be pushed to the edge using cloud technology. In fact, ultra-low latency applications would be extremely hard to create without localized service delivery since light can only travel about 100 km in one millisecond round trip in a fibre.
- Security is required everywhere and managed proactively. This means that security needs to be incorporated into every element of the network and embedded in every step of network operation.
- Get ready to serve customers beyond consumers: A new end-to-end, cloud-native, secure 5G architecture can handle the complexity of many different CAM use cases. End-to-end slicing allows CAM applications to be individually customized. The possibilities are tremendous in our rapidly changing world.

In conclusion, the cooperation between vendors and operators is fundamental for the deployment of 5G networks and the implementation of new use cases like all the ones related to CAM.

In first steps of 5G network deployments, telecommunication companies (vendors and operators) need the wide dissemination of 5G NR open-source simulation tools, like NS3 or Omnet++, to accelerate their deployment, hence, the continuous update of these instruments is a strict recommendation. This kind of tools can also help to assess on the deployment of services with certain QoS requirements in environments where these might not be met. Simulation is necessary to avoid the fallacy that network service level will be homogenous across regions, borders, and geographical areas in general and to assume unrealistic Business Model given that aspects like QoS and continuity needs to consider potential vast differences in available resources for adequate service provision.

Detailed technological studies for the deployment of 5G networks shall be executed determining the deployment of a proper amount of 5G NR base stations to guarantee high throughput speed, low latencies, and extreme reliability for the demanded services for the network users. Technological studies are complemented with economical ones. GSMA [1] estimates the cost per square kilometre of building a 5G network to be four times more expensive than that of a 4G network. This is due not only to telcos having to install compatible antennas and upgraded equipment to cope with requirements of radio connectivity and transport signals to deliver 5G data in a smooth and secure manner, but also needing to lay the derived groundwork for having to install all the fibre optic cables needed to be in place to connect each antenna due to higher bandwidth demands. Thus, the deployment costs imply the site installation and the extensive fibre backhaul supporting a dense 5G infrastructure which is even more critical in the case of small cells. These increased costs make it even more important to use new techniques like NSA deployments or DSS (Dynamic Spectrum Sharing) in addition to reaching agreements that allow the sharing and use of existing and future infrastructure between MNOs. These cooperative approaches can be beneficial for all the parts involved: less sites to be deployed for each MNO save costs. The deployment costs imply the site installation and the extensive fibre backhaul supporting for a dense 5G infrastructure, for instance, small cells.

For cross-border sites the mobile operators need to interconnect their data-network infrastructure. This could be done over underlying medium such as IPX/GRX or public internet but with these approaches there is significative vulnerability to negative communication impacts. A solution with dedicated direct data networking between operators is needed to have low latency, jitter, and packet loss on the communication path.

As a complement to the mobile network, the terrestrial network plays a determining role in the deployment of 5G networks and CAM use cases are also affected. Terrestrial fibre connectivity gaps are one of the major issues for autonomous vehicles that rely on CAM messaging. The lack of coverage could have severe implications on functional and safety aspects of connected vehicles. Solutions as satellite bearers, using hybrid communication platforms, use intelligent routing functionality. But using a single radio bearer creates a single point of failure putting critical CAM functionality at risk, especially when it comes to MCM messaging. In 5G architecture, this is addressed at multiple levels – including Radio and System levels. To

this end, high QoS for resilience and redundancy in the communication link shall be delivered through the combined use of 5G NR and satellite access. Such a solution will be deployed at the French trial site through a hybrid platform that utilizes both 5G-NR and Low Earth Orbit Satellite Connectivity.

When the 5G networks are deployed and working, E2E virtual resource management is a complex task where multiple stakeholders are involved. Globally, multi-site, remote monitoring of network performance and control of the network resources is hardly developed, and is critical in intensive applications, therefore, development of the performance monitoring and management components for E2E scenarios is strictly necessary for the proper network operations and for the implementation of CAM use cases.

As mentioned before, optical fibre deployment is a challenge for operators due to the poor availability of fibre networks in many sites. Areas where deploying fibre backhaul cannot be considered cost effective, wireless technology like PMP (point-to-multipoint communication), mmWave and satellite communications can provide a solution for 5G deployment. From the governmental point of view, policymakers may consider removing tax burdens to reduce investment cost associated with fibre to facilitate the deployment of 5G networks, in addition, local authorities may consider agreeing upon standardized wayleave agreements to reduce the cost and time of deploying fibre networks. Moreover, operators can extend the sharing concept used in 5G sites and apply it to the fibre backhaul to speed up the deployment and reduce costs for 5G network infrastructures. Collaboration between the public and private sectors will ensure the successful and swift deployment of 5G by means of reaching mutual agreements in terms of business models, costs deployments or security/privacy issues. Another action to help stakeholders in the deployment of 5G technology will be the creation of a central database showing all available infrastructure and utility assets, such as existing local authority or utility ducts, fibre networks, CCTV posts, lampposts, etc. Such a database should also identify key contacts and the process for securing access to the assets. This would help operators plan their infrastructure deployment more accurately and effectively.

Once the network deployment is complete, network optimization becomes a key job to ensure that the network provides the desired performance, hence, preliminary field tests are strictly necessary to identify possible issues in the 5G networks. Specifically, for the ES-PT CBC, in the Spanish side of the border, tests were executed when the deployment of the 5G network was concluded in February 2020. As a result, some issues were discovered where Network Planning and Optimization teams had to work to improve the performance of the network. One of the issues detected was small radio power in the border and regions without 5G coverage in testing areas. This implied the antenna locations must be deeply studied, and each 5G site must be located in an optimal distance to the border, in this manner, downlink/uplink throughput will not be affected in a negative way. In addition to this, radio signal was lost many times due to the orography (terrain) and other elements, both natural (vegetation) and artificial (bridge structures, buildings, etc), that prevent direct line of sight to the 5G antennas affect the network performance deeply. Consequently, the search for the best possible radio link configuration is necessary. In addition to this, the use of the best possible automotive antennas, careful modem selection for OBU adoption and communication equipments should guarantee the coverage in the positions without direct line of sight of

the 5G site and to improve possible restrictive conditions and will provide reliable services dependent on vehicle data collection and exchange.

In this project, the 5G network is oriented to CAM applications, this can be complicated to manage, as many parameters have to be considered and may influence the choice of antenna configuration and position, which depends on the targeted applications, number of users, etc. Artificial intelligence and optimization techniques can power 5G antenna deployment recommendation tools. The development of these decision support tools could be done using road and network traffic simulators.

As we will discover in the following sections, CAM applications need resource migration solutions. Currently there is a lack of open solutions to guarantee the migration of edge resources assigned to vehicles, hence a holistic architecture offering edge capabilities across MNOs, countries and network/security domains is required. 5G networks need solutions offering orchestration and resource allocation through different computing domains and using locally available network resources in mobile scenarios such as CAM, hence a distributed architecture coping with mobility, security and QoS is required.

5.1.2. Data

Information and data generated by CAM sensors and applications will be analysed under two key aspects: Data Quality-Validity and Property & Management. These aspects and the associated challenges are perceived, and addressed, by 5G-MOBIX project as follows:

- **Data Quality-Validity** is associated to many issues such: data sensor quality, calibration, health, ASIL (Automotive Safety Integrity Level), error probability or trustworthiness. Data fusion must consider different road users being weighted according to the reported data quality level. Data statistical relevance will be considered to increase data quality and statistical sound results. Time validity and data life cycle is also relevant since vehicles will share data and the time context can be slow (road works) or highly (vehicles positions) dynamic. Contradictory data content can happen because sampling moments are very close (e.g., traffic lights status). Thus, data must ensure robustness, constancy, and reliability, providing credibility. It is a critical safety issue if data quality-validity is not met.
- **Data Property & Management** deals with different identified barriers, such as the access to the data economy. Specifically, the different levels of GDPR adoption by many infrastructure operators served as a barrier that hindered their cooperation. The Commission's Ethics Guidelines for Trustworthy Artificial Intelligence (AI) produce guidelines to ensure that AI does not negatively impact societal and personal wellbeing, by focusing, among other measures, on data privacy, accountability, non-discrimination, and fairness. These guidelines should apply to CAM use cases and actors involving AI, like Autonomous Vehicles. The Open Data Directive (Directive (EU) 2019/1024 provides a common legal framework for a European market for government held data and hence would apply to public sector stakeholders in CAM (public road operators, municipalities, state agencies and authorities etc.). It is built on two key pillars: transparency and fair competition and focuses on economic aspects of the re-use of information.

5.1.3. Application and interoperability

CAM applications are part of the core for the automated driving functions. They need to always work reliably during all conditions. These applications are part of an infrastructure connecting in-vehicle apps, backend apps, road-side units and much more. A failure in one of the elements may never lead to a safety critical situation. This means we need to design the chain of different elements in a robust way and always expect failures. Also, considering the number of OEM brands, road and network owners and operators, we need to design our infrastructure for all possible combinations and create an interoperable infrastructure. When considering all this, two categories of measures stand out to consider:

1. Interaction between applications and networks
2. Standardization across countries and OEM's

Interaction between applications and networks

CAM applications rely increasingly on networks. We expect the application to function cooperatively and exchange information between traffic participants and traffic centers. The networks needed for this are not always optimized to deliver on the expectations, so measures need to be taken to deal with possible shortcomings.

1. It has been found at country borders that seamless roaming has not yet been implemented at present. We expect that it will take some time before operators start to implement seamless roaming. This is because of limitations in current roaming techniques but also because of the associated costs and the limited demand from customers. In-vehicle applications need to be designed to cope with this. It is therefore recommended that:
 - a. Vehicles are aware of where seamless roaming is implemented and where it is still lacking. This should be known at the level of the networks to which they are attached.
 - b. Depending on the desired performance, measures should be taken to limit or prevent disconnection from the network in cross border areas. This can be done either using a dual modem setup or a fast reconnect setup. For both setups, special applications are needed to steer the modem to the right network. In addition, subscriptions should be requested from the home operator with steering of roaming disabled.
2. Future technologies are expected to have the vehicle always connected to the closest edge. These technologies are new, different options are possible and the technologies still need to be implemented in operator networks. Because of this, variations are to be expected across operators. Also, the level of integration between application and network is something that needs to be determined. For instance:
 - a. The in-vehicle system might be able to trigger the connections to the closest edges using specific data networks that cover certain areas. The in-vehicle system would need to know which data network to connect to. A discovery mechanism for this would be needed.
 - b. It might be that the network takes care of the connection to the closest data network, e.g., using SSC Mode 2 or 3. It is however unknown at this time how the client application can be triggered to set up a new connection to the application running at the new edge. A possible

solution for this would be to have a special application function running at the core of the network which informs the vehicle of certain network events that require a connection change on the client application side.

3. In future mobile networks it will become possible to request special low latency slices. These slices will require more resources from the network per transferred byte, compared to the normal eMBB slices. These low latency slices can only be made available if the applications can limit the data volume using these slices. Only essential data should be sent with as less redundancy as possible.
4. It is almost inevitable that connections will sometimes be lost or work less reliably. Applications should always be designed to take this into account. In addition, it would even be better to build functions in our networks that can inform applications ahead of time of possible network degradations. Such functions require special integrations with the network, possibly by using a specific application function that functions at the core of the mobile network.

Standardization across countries and OEM's

Collaboration between traffic participants, road-side infrastructure and traffic centers can only take place if they all "speak" the same language. Data interoperability is key for this:

1. Data is almost always exchanged with respect to certain areas. Different concepts have been developed for this in the past, for instance by copying the short-range message over a UDP long range channel, or by using a subscription model where the vehicle subscribes to a message service for certain geo-tiles. The later one based on a subscription model seems to be getting more traction the last few years. The vehicle gets control over the area of interest and standard message exchange mechanisms can be used to implement this. It is recommended that we standardize across Europe the usage of a message exchange which is light weight (less overhead), uses topic structures containing the geo-tiles, message type, message version and possible station id.
2. Transfer of state between areas almost always causes extra delays but is sometimes inevitable. Where possible, systems should be designed such that no specific state information needs to be kept, other than the session information. If the vehicle connects to a new edge, only a new session needs to be set up and no state information is then needed from the previous edge. If state information would be needed a transfer is needed between the edges before the new edge can be utilized, causing extra delays. If state information still is needed, extra intelligence can be built into the system to start pushing the new state before the vehicle arrives at the new edge.

5.1.4. Cybersecurity

According to the ENISA "Report on Recommendations for the Security of Connected and Automated Mobility" [11], seven cybersecurity challenges were identified in accordance with the stakeholder consultation and multiple recommendations can be found for all stakeholders of the CAM ecosystem. These challenges are:

1. **Governance and cybersecurity integration into corporate activities:** Cybersecurity governance is an organisational and technical challenge for all stakeholders. In the CAM ecosystem especially, digital

technology, connectivity, high automation etc. are coupled with new transport technologies. 5G-MOBIX also supports this conclusion, as the Value Network Model for our specific user stories in the project's CBC/TS exposes this complexity. Dedicated and skilled cybersecurity teams are required in order to manage risks and address any exposed vulnerabilities.

2. **Lack of top management support and cybersecurity prioritization:** Cybersecurity is a key topic in the lifecycle of 5G and CAM products and services. There needs to be a level of control and trust in the 5G for CAM supply chain and organic interactions between cybersecurity executives and corporate executives, leading to sufficient support (e.g., for research & development, awareness and training programmes, operational activities etc). 5G-MOBIX considers cybersecurity and appoints security experts within the consortium to monitor security within the CBC/TS.
3. **Technical complexity in the CAM ecosystem:** Given the large array of stakeholders, the implementation and management of cybersecurity proves to be a challenge. Delineating liability borders when components and services are provided by many parties and retracing a fault or providing digital forensics can be nearly impossible. Furthermore, obtaining cybersecurity information is difficult to achieve in any industry and critical infrastructure. Although reporting standards exist (i.e., TAXII, STIX 1.0/2.0), lack of information sharing is a common occurrence in cybersecurity as actors are unable or unwilling to share critical information pertaining to security incidents.
4. **Technical constraints for implementation of security into CAM:** Cybersecurity needs to be addressed in the early conception phases of a product or service to ensure that there are no gaps or vulnerabilities, but also within the supply chain. Furthermore, the existence of cybersecurity measures has the capacity to positively affect latency and service QoS.
5. **Fragmented regulatory environment:** In Europe, regulations tend to be harmonised by the Member States, but there are also countries with specific and independent regulations. An organisation may therefore be subject to different schemes in a single product range. The current regulatory framework does not include any test requirements or performance criteria for cybersecurity evaluation/assessment. Furthermore, the telco environment is regulated by legislation targeting protection of critical infrastructures.
6. **Lack of expertise and skilled resources for CAM cybersecurity:** The 5G and CAM ecosystems require highly skilled cybersecurity professionals that are trained in the specificities of 5G and CAM. Expertise in cybersecurity can range from software security, network security, cryptography, embedded systems, operational technology, etc. and the amount of specialization required can be a major obstacle. Furthermore, specialized products need to be developed for automated driving, protecting MEC and next-generation core networks etc. It is important to note, that in the case of 5G for CAM, degradation of a service can be as critical as unavailability of service.

7. **Lack of information sharing and coordination on security issues among the CAM actors:** Establishing a root of trust between parties and data governance is a key challenge to address in order to implement a resilient 5G for CAM infrastructure. Cybersecurity challenges may be unprecedented. Harmonisation of cybersecurity rules in the 5G for CAM ecosystem at an international level is necessary.

5.1.5. Automotive industry and CAM

Automotive Industry is one of the most competitive industries. OEMs are always going after new technologies to improve their products for customers. Currently, there are several autonomous vehicle development activities and OEMs generally believe that with the help of 5G applications it will be possible to send vehicle or infrastructure sensor data to edge or cloud centres and have perception on these centres. The resulting perception data could then be transferred to autonomous vehicles. This kind of service will reduce the advanced sensor needs on the vehicles; hence, it would lead to reduced vehicle production costs. Additionally, OEMs will be able to provide novel enhanced services to their customers with the help of the 5G, such as tele-operated driving, automatized operations of vehicles in confined areas etc.

While 5G is quite important for future services served by OEMs, there remain unsolved challenges and open questions that are needed to be answered on the road. We list the most prominent ones below:

- Service continuity is key for autonomous vehicles. If communication is lost between vehicles or cloud/edge centre and vehicle, then vehicles need to take actions to mitigate safety issues. Changing the mobile network operator while crossing borders must be seamless to avoid safety issues in autonomous vehicles.
- All vehicles need to "speak" the same language to achieve interoperability. If vehicles cannot "hear" each other, that could cause huge safety problems also.
- Liability at and around borders for 5G-CAM services need to be defined between stakeholders. Otherwise, in case of an accident, the responsibility will not be clear.
- It is still unknown when 5G will be broadly available and where the first major deployments will take place. This will affect product portfolio of the vehicle manufacturers (OEMs). OEMs need to know which vehicle segments will need the connectivity features first.
- What if a country supports 5G-CAM, but another neighbouring country does not? How should a L4 vehicle act in such cases?
- Common cloud usage for a 5G-CAM application is needed. If OEMs use different cloud centres for the same applications, then the usability and the associated benefits of the application will be limited.
- Will all operators in a country support 5G-CAM? If yes, all operators need to provide the required application requirements.
- Who will pay for 5G data? Customer / OEM / Road Operator etc.? This uncertainty affects the motivation of OEMs regarding 5G-CAM deployment.
- For which applications is 5G essential? Where are the limits of 4G/LTE both on the application level and from a regulatory perspective?

- Cyber security for 5G-CAM applications. For instance, what are the fallback solutions if the 5G-CAM is under a denial-of-service attack. How can it be ensured that the exchanged data is trustworthy? As stated in the previous section, a common trust base between OEMs and road operators will be required.

5.1.6. Road

The main operational objectives of Road Operators are:

- To **improve road safety** on the road network.
- **Optimise traffic flow** on the arterial and motorway networks.
- **Manage incidents**, reducing delays and adverse effects of incidents and congestion, weather, road works, special events, emergencies, and disaster situations.
- **Effectively manage maintenance and construction work** to minimize its impact on safety and congestion.
- Provide the traveller with **timely and accurate information**.

5G technology can play an important role here by connecting people and vehicles on the move with road infrastructure and road operators, namely through driver assistance information, which can both reduce the accident rate and improve the flow of traffic. However, from the Road Operator's point of view there are several issues and challenges that should be addressed:

- **Spectrum:**
 - The long timescales for agreement on spectrum use are already having an impact on 5G development. As road operators, implementation proposals are being considered to meet the objectives listed at the top of the page. However, the lack of clarity and agreement on spectrum use, makes the initiatives progress at a slower pace than desired.
 - Harmonization of spectrum allocation across regions and countries. From the point of view of road operators, it is of great relevance since all initiatives under development seek to ensure interoperability and continuity of services regardless of geographical location. It is also extremely important for the development of technology, as it has a major impact on economies of scale and incentives for road integrators to develop products.
- **Standardization:** The implementation of 5G is ahead of regulatory standards. Road operators are planning a capacity crunch towards the end of this decade, which is why they are seeking to deploy emerging technologies as soon as possible in order to maintain service levels. Regulatory processes often have long lead times, so initial 5G deployments will not meet standards because they are not sufficiently developed.
- **Coverage:** More equipment is required for greater coverage in certain use-cases. Although 5G offers a significant increase in speed and bandwidth, its' more limited range will require more infrastructure. The higher frequencies allow for highly directional radio waves, which means they can be targeted or directed - a practice called beamforming. The challenge is that 5G antennas, while capable of handling more users

and data, emit over shorter distances. From the road operator's point of view, this implies a rationalization of the existing equipment. However, not all the networks must be under 5G coverage, solutions as 3G and 4G have proved to have a good latency under 300 milliseconds. This was proved in the use-case of GLOSA (Green Light Optimization Speed Advisory) and is included in an internal working document of DGT 3, available under request.

- **Implementation cost:** It is not a question of building a layer on top of an existing network, but of laying the groundwork for a new complementary structure. Once it is truly viable, vehicles will be connected in completely new ways. Apart from the coverage investment made by communications companies, roads operator should have platforms to exchange traffic information with a good processing system to filter and trigger events.
- **Security and privacy:** 5G will have to deal with both standard and sophisticated cyber security threats. As a road operator it will be necessary to ensure that data virtualization and cloud-based services are as airtight as possible to protect users' data and privacy. In relation to privacy, road operator platform should only host anonymized data from users.

5.2. Cross Border Challenges

After an initial proposal of the main challenges in cross-border areas of 5G technology for CAM in the early stages of the project, the Technical Management Team has worked, with the knowledge acquired in the project, on a new version of the main challenges of the technology in border areas (Table 20).

Table 20. Cross Border Challenges.

ID	Category	X-border Issue Title	X-border Issue definition
XBI_1	Telecommunication	NSA Roaming interruption	With current networks, when a UE crosses a border, it tries to keep the connection to the previous network. This can result in a connection loss of several minutes. A new connection needs to be established and a new data session needs to be set up. This behaviour is even worsened because of steering of roaming that is implemented by MNO's, trying to steer the UE to a preferred network and by doing so deny certain roaming requests.
XBI_2		SA Roaming interruption	Currently Roaming for SA networks has only been defined for basic roaming. No handover is specified and the equivalent of the S10 interface for ePC (N14) has not been referenced as a roaming interface. Because of these limitations it is expected that the same issues will arise as seen in current networks leading to disconnect times of minutes.
XBI_3		Inter-PLMN interconnection latency	Currently operators interconnect using a GRX network used for both signalling and user plane data. This network extends over multiple countries and operators and is typically designed for high continuity and throughput, this at the expense of low latency. Moreover, GRX connectivity may redirect traffic through far-away nodes (based on the GRX operator architecture) further increasing E2E latency, which is unsuitable for CAM applications
XBI_4		Low coverage Areas	Looking at current border areas, we see very low coverage areas because of sparse populations at the border. In addition, given the current regulations, operators must consider the maximum field strengths allowed at the border. On both sides of the borders the same frequencies are in use. Operators need to try and limit the interference. In addition, border areas are often sparsely populated, giving little incentives to provide for increased capacity or coverage in those areas. As a result, areas of low or no coverage may appear close to the border, threatening the CAM application continuity.
XBI_5		Session & Service Continuity	<p>When directing the UE to a new, closer, data network or to a neighbouring mobile network, the IP stack will likely change (other IP address and routing information). Current mobile networks do not give insight to which location the UE is connected or when a change of location has happened. This can cause continuity issues or suboptimal latencies.</p> <p>A handover event can imply the change of network address with impact on running UDP/TCP communications and service disconnection. Moreover, a change of MNO in a roaming situation can imply a different set of protocols used in each domain e.g., IPv4 vs. IPv6. All this becomes especially evident in the case of edge computing, where latency requirements impose a switch to a different instance of an application server i.e., both ends of a communication session change. Under these circumstances, the applications' ability to adapt to underlying network changes becomes increasingly important, to reduce the impact of mobility and ensure service continuity.</p>
XBI_6		Data routing	When roaming, normally the data traffic will be routed to the home network and connect to the data network at home. Crossing the border from home-PLMN to a visited-PLMN will then lead to higher latencies. As an alternative it is also possible that the UE uses a local breakout roaming, connecting to the closest edge which will resulting in a lower latency. However, setting up a connection to a new data network will take time which might result to a connection interruption and the potential

			loss of data. Also finding the closest edge might take time if a query is needed by the UE to discover the closest edge after the switch to the PLMN.
XBI_7	Telecommunication and application	Insufficient Accuracy of GPS Positioning	Global Navigation Satellite Systems (GNSS) positioning cannot meet the stringent CAM requirements i.e., down to 20-30 cm accuracy, cannot be used while indoors (for example in tunnels, indoor parking/garages, or lower decks of multi-level bridges) and have strong limitations in dense urban environments. GNSS also lack a refresh rate high enough to be used in safety critical applications. Without accurate geo-positioning, CAM applications that require external information based on absolute positioning cannot merge this information onto local maps with relative positions (distance to other vehicles/obstacles, lane position, etc.).
XBI_8	Application	Dynamic QoS Continuity	It's possible to adapt the service provisioning features/characteristics by the CAM application based on the current QoS network parameters. A sudden drop in the network connection quality may happen when the vehicles move from one MNO to the other in a cross-border area. This can lead to performance degradation at the application level, hindering the full potential of CAM solutions.
XBI_9		Data and Protocol Stack Interoperability	The existence of different vehicle providers, technology vendors and network domains often causes major challenges around data and application-level protocol interoperability. Inconsistent data schemes and protocols hinder the exchange of information and the overall communication between vehicles from different providers, different network domains, infrastructure systems or federated services. The cross-border context amplifies this situation as there are potentially different road operators and MNOs at each side of the border that have deployed different infrastructure, interfaces, etc. As a result, interoperability may be a restrictive factor in the support of CAM applications across borders.
XBI_10	Regulatory	Geo-Constrained Information Dissemination	A connected vehicle usually needs to receive traffic information directly related to its surroundings, not the whole flow of CAM messages exchanged through the edge computing node it is connected to. When it is travelling close to the border, it might also want to receive some data from neighbouring geographical areas covered by a MEC node located in another PLMN. Also in this situation, not all CAM information exchanged through the neighbouring MEC is of interest to that specific connected vehicle. For instance, in the platooning application, the connected and autonomous members of the platoon solely need to exchange data with the platooning vehicles and possibly with some other vehicles and sensors in the vicinity. As a result, a geo-constrained information dissemination scheme should be devised in order to disseminate the relevant CAM data to the appropriate vehicles.
XBI_11	Regulatory	Law enforcement interaction	As automated driving technology becomes widely adopted, law enforcement entities across countries must be able to interact with automated vehicles on the roads. For instance, one can easily envision situations in which police officers may need to force a vehicle to stop if there is a suspicion that it is carrying a wanted individual. Dedicated communication procedures and protocols will need to be in place to ensure that authorities can communicate with vehicles, even if they originate from a different country being generally served by a foreign network provider

6. RECOMMENDATIONS AND DEPLOYMENT OPTIONS

6.1. 5G Strategic Deployment Agenda for Connected, Automated Mobility (CAM).

The “5G Strategic Deployment Agenda for CAM” [12] sets the “shared view of a wide group of industry stakeholders supporting the objectives of the 5G Strategic Deployment Agenda (SDA)”. The aim is to support Connected and Automated Mobility (CAM) in Europe and set the basis for “future-proof 5G infrastructure, technologies and vehicles”. The SDA envisions that deployment of 5G is a major enabler for commercial (e.g., infotainment) as well as safety services, due to improved speed and reliability. In addition, the service-based approach is expected to transform vertical industries and spark economic growth.

The 5G SDA for CAM revolves around the deployment objectives, cooperation models and regulatory innovations as its main elements. These were defined during the first open stakeholder workshop that took place in February 2019. The common principles that underline the SDA were hence defined:

- **Deployment of 5G should follow an evolutionary path:** To account for future market needs and technical developments, the deployment of 5G should follow an evolutionary path. 5G should co-exist and be interoperable with other networks like 4G LTE. The 5G SDA does not consider 5G to be a prerequisite for automated driving functionalities, as some services can already be implemented using existing technologies. Therefore, a stepwise migration allows to incrementally build 5G capabilities on top of 4G to deliver high-speed and reliable secure broadband.
- **Service Continuity across borders and actors:** As many CAM services (e.g., guidance, auto-overtake etc.) can be considered “mission critical”, there needs to be reliable, uninterrupted connectivity and coverage, with service continuity across borders and actors.
- **End-to-end cybersecurity:** A high level of end-to-end cybersecurity is necessary to ensure trust in CAM services, but it also needs to be held to high performance and reliability criteria.
- 5G for CAM needs to be a **Multi-service/Multi-application platform** with standardised interfaces and data formats.
- **Coordination among public & private actors in V2X** for the deployment of 5G infrastructure is necessary. Starting from major corridors and highways, the benefits of 5G for CAM can be demonstrated. Coverage can then be extended to secondary roads and urban areas.
- **Public authorities and administrations** in charge of roads should collaborate for the deployment of connectivity along major corridors.
- **Cooperative planning & cost optimisation** is necessary to deliver improved networks in a cost-effective way.
- **Digital transformation** for industry verticals must be accelerated.

The 5G SDA also considers three major ecosystem categories for CAM:

- **Driving safety and Automation sub-system.**
- **Enhanced Broadband Emergency Services.**
- **High-value commercial 5G services along transport paths.**

5G-MOBIX considers the SDA as a starting point and attempts to further analyse the technical, cooperation and business barriers that may hinder large scale deployments and the overall vision of the Agenda.

6.2. Possible activities to favour the deployment of the technology

The purpose of this section is to identify how technologies developed within the project can benefit external initiatives, and vice versa. This is an essential activity for the technological, scientific, and business maturation of 5G-MOBIX's activities that will take place throughout the project. While the present section of this deliverable focuses on the definition of a methodology and on preliminary data, the final results, and the implementation of concrete actions with external stakeholders will be carried out for deliverable D6.5, which is to be delivered in M44.

The work presented in this section is divided into two logical and complementary axes:

- 1) **Axis 1:** from "**Local to Project**", which aims to create concrete links with innovations that can benefit (from) 5G-MOBIX and that are developed at a national level for each of the countries represented by the consortium. As described earlier in the document, these innovations can take the form of projects, patents, policies, or products implemented locally for instance by SMEs, OEMs and entrepreneurs.
- 2) **Axis 2:** from "**Project to Global**", which aims to support the market take-up of the innovations and services that are demonstrated in the project use cases. This support will be done by reaching concrete agreements to support the post-project exploitation plan, considering innovators, technology adopters/customers, and private investors. Concrete recommendations on how to deploy the innovations according to the targeted use-cases or to address the project's issues are also expected.

The remainder of this section details the data known to date for these two approaches as well as the associated methodology for the remainder of the project.

6.2.1. Axis 1: from "Local to Project"

The methodology and preliminary results obtained for this first axis are described in the 4 successive steps below.

6.2.1.0. *Step 1: identification of successful innovations (self-assessment)*

In an effort to collect representative information from the different countries represented by the consortium, the project partners have all been consulted and invited to give preliminary indications on the innovations they considered relevant to the project and which are national in scope. This first step is to be

considered as a self-evaluation carried out with the support of the consortium to identify external stakeholders and innovations that can be quickly contacted and activated.

Table 21 below lists the 43 entries that have been identified at the time of writing this deliverable, together with background information.

Table 21- Preliminary list of successful innovations in the transport sector at local level. Source: 5G MOBIX.

Watcher (5G-MOBIX partner)	Name (if applicable)	Type (Project, patent, product, etc.)	Location (country)	Purpose (what are the key interests and benefits of innovation?)	Can this local innovation benefit 5G- MOBIX?	Can 5G-MOBIX solutions benefit this local innovation?
INTRA	-	Policy	Germany	Germany opens the way to industrial partners for private 5G licenses https://5gobservatory.eu/german-authorities-opened-process-for-private-5g-licences/		
INTRA	-	Trial	Denmark	Telia, Nokia and Telenor complete first 5G MOCN deployment illustrating how infrastructure sharing can be used https://www.telecomtv.com/content/5g/nordic-telcos-get-together-on-5g-with-mocn-trial-37922/		
CTAG	1st 5G cross border data connection	Demo	Spain	Optimization of multimedia content download under roaming context	Yes, 4K bus monitoring	
CTAG	5G Andalucía Pilot	Project	Spain	Optimization of multimedia content download process in Malaga bus station https://www.piloto5gandalucia.es/	Yes, 4k bus monitoring (fixed spot)	
CTAG	5G Connected Ambulance	Project	Spain	Remote medical support for critical interventions by in real time HD video sharing https://5gbarcelona.org/es/pilotos/ambulancia-conectada-5g/	Yes, 4k bus monitoring	
CTAG	5G Connected Car, SEAT	Project	Spain	Driving safety and efficiency improvement by providing info on VRU presence and traffic light information. https://5gbarcelona.org/es/pilotos/coche-conectado-5g/	Yes, automated overtaking	
CTAG	5G Galicia Pilot	Project	Spain	Driving safety improvement by providing info on existing traffic events along Cereixal tunnel before entering and weather conditions outside before exiting. https://piloto5ggalicia.com/	Yes, automated overtaking	
CTAG	5G Technological Cities, Telefonica	Project	Spain	Multimedia download in autonomous driving context (shuttle) https://www.saladeprensa.vodafone.es/c/notas-prensa/np_primera_llamada_5g_roaming/	Yes, automated shuttle driving, 4k bus monitoring	
FRAUN	5G-AUTOSAT	Project	Germany	Using 5G-New Radio direct access over satellite for different automotive use cases (support of autonomous driving, vehicle monitoring etc.). https://www.dlr-innospace.de/gefoerderte-projekte/5g-autosat/	Yes, connectivity without terrestrial infrastructure	
VTT	5G-DRIVE	project	Finland, China	C-ITS messages over PC5 and Uu in urban setting https://5g-drive.eu/	Yes, CoCa	

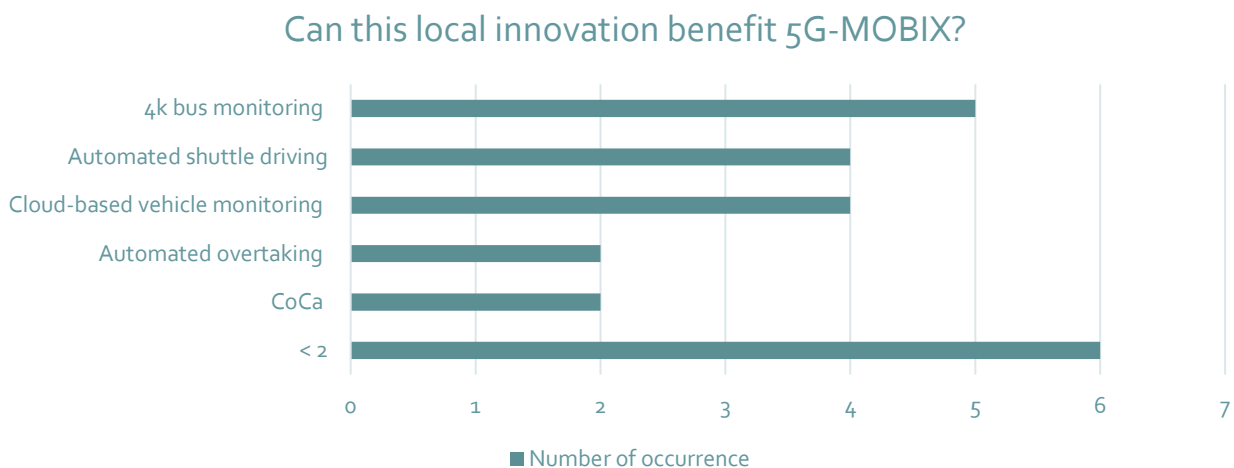
LIST	5G-EMIT	Project	Luxembourg	EMF monitoring platform for facilitating 5G deployment initiatives in Luxembourg		
CCG	Anepb	Public	CCG, University of Minho	To evaluate VRU (pedestrians) behaviour in crosswalks.	Yes, automated shuttle - VRU US	Yes, by supporting the development of an additional communication layer between VRUs and vehicles.
COSMOTE	AVINT	Project	Greece	Automated buses (3 buses of 10 passenger each) fully integrated with the city transport network. https://www.avint-project.eu/		
CCG	BUILD - Urban Innovation Laboratory	Public	CCG, University of Minho, Braga Municipality, INL	To influence traffic behaviour in a Smart City context in order to prevent traffic jams, increase safety and improve citizens quality of living.		
COSMOTE	Car2MEC	Project	Germany	Investigating MEC for connected cars https://www.mobileeurope.co.uk/press-wire/13804-deutsche-telekom-and-partners-conclude-connected-car-mec-trials		
Siemens	Drone Safety Evaluation	Project	Lisbon	The objective is to measure the following time-based safety indicators -Time to Collision, Post Encroachment time and Time Headway. Using a drone to collect the images and perform a video analytic to infer the safety parameters	Yes, Impact safety evaluation	
LIST	EcoBus	Project	Luxembourg	Design and evaluate a system approach exploiting the potentials of the C-ITS (Cooperative ITS) paradigm to meet the requirements of next generation public transport systems.		
CTAG	First Free Technology Zone (FTZ) in Portugal	Project	Portugal	Making of Matosinhos the first city of fifth generation mobile in Portugal https://bit.ly/2XPWzRe		
LIST	HAVELSAT	Project	TURKEY, EU	A software defined radio experimentation CubeSat. 5G use-cases under evaluation for low/mid orbit satellites.		
VEDECOM	Indid	Project	France	InDiD is a pilot Action aiming to evaluate how connected infrastructures will bring enhanced perception to road users. https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/2018-fr-tm-0097-s		
CCG	INNOVCAR	Project	CCG, Bosch, University of Minho	Significant National (PT) project around the problematic of the vehicle of the future. It covers, vehicles, manufacturing processes, VRUs and RSI. https://innovativecarhmi.com/		
FRAUN	Kronach-5G	Project	Germany	Using 5G for different remote driving use cases.	Yes, remote driving	

Satellite Applications Catapult	LightBar	Project	UK	The project utilizes seamless connectivity on mission critical data delivering critical/safety services based on end-to-end system architecture and design https://artes.esa.int/projects/lightbar		
Sensible 4	LuxTurrim5G	Project	Finland	Innovation ecosystem developing and demonstrating fast 5G network based on smart poles with integrated antennas, base stations, sensors, displays and other devices. https://www.luxturrim5g.com/		
CTAG	MobiCascais	Project	Portugal	Public transport under autonomous driving context (shuttle) https://www.mobicascais.pt/news/veculo-autonomo-vai-comear-a-circular-regularmente-MTly	Yes, automated shuttle driving	
LIST	MOBIREGIO	Project	Luxembourg, Greater Region	Mobiregio is a meeting platform for public transport operators in the Greater Region.		
CTAG	Nodo de Cooperación 5G de Galicia "5G Cooperation Node"	Collaboration	Spain	5G Cooperation Node where developers of 5G solutions can converge with potential demanders, in order to define the ecosystem of 5G services starting with the possibilities that already allow exploring the current 4G networks. http://nodo5g.gal/		
VEDECOM	PACV2X	Project	France	The PAC V2X project purpose is to augment the vehicles perception of their environment via a cooperation between the infrastructure and the vehicles themselves. The vehicles will fuse collected data by means of their own sensors with data received by I2V and V2V local telecommunication. http://pacv2x.fr/	Yes, Infrastructure-assisted advanced driving	
IT	PASMO	Project	Portugal	To develop an open living lab for cooperative ITS and smart regions https://pasmo.pt/project/pasmo		Yes, V2X connectivity, roadside sensors, geo-messaging
UMU	Perseides National Project	Project	Spain	P2P content distribution scheme	Yes, multimedia content P2P distribution might benefit to, e.g., 4k bus monitoring	
UMU	Perseides National Project	Project	Spain	IPv6 integration for multi-radio access technology vehicle monitoring	Possibly: cloud-based vehicle monitoring by integrating IPv6	

CTAG	Portugal Smart Cities Summit,	Demo	Portugal	In real time tx of medical information from ambulances in emergency operation to hospitals https://tekgenius.pt/cidades-do-futuro-nos-demonstra-5g-na-fil/	Yes, 4k bus monitoring	
VALEO	Shuttle-Modellregion Oberfranken (SMO)	Project	Germany	To test the operation of driverless shuttles as a complementary component of public transport in public streets in the cities of Hof, Rehau and Kronach. https://www.bmvi.de/SharedDocs/DE/Artikel/DG/AVF-projekte/shuttle-modellregion-oberfranken.html		Yes, V2X connectivity, 5G network infrastructure
LIST	SWAM	Project	Luxembourg	Smart waste collection platform that relies on IoT and optimisation techniques.		
VTT	Tampere CAM test site	Collaboration	Finland	5G network in urban area for testing of CAM, including in harsh winter conditions	Yes, CoCa	
LIST	Terminal	Project	Luxembourg, Greater Region	TERMINAL is the first project in Europe to test a cross-border bus line operating with electric automated minibuses in real traffic conditions.		
LIST	TOGG	Project	TURKEY, EU	Electrical car and related mobility solutions. https://www.togg.com.tr/content/mobility-solutions		
IT	TRUST	Project	Portugal	To deploy Transportation and Road monitoring system for Ubiquitous Real-Time information services, focusing on weather-related warnings with alert dissemination to drivers https://microio.pt/project/trust/		Yes, V2X connectivity, weather sensors, information layer
LIST	TURKISH AIRLINES CONNECTIVITY	Project	TURKEY, EU, US	Connectivity: High speed internet connection in commercial airplanes and ground stations. 5G will be evaluated with Airbus, Boeing, and IT partners. https://turkishtech.com/	Possibly: Cloud-based vehicle monitoring (e.g., for parking)	
LIST	TURKSAT	Project	TURKEY, EU, US	5G Satellite Services Evaluation https://www.turksat.com.tr/en/ict/it-services/turksat-globe		
LIST	ULAK	Project	TURKEY	Country wide 5G deployment. https://www.ulakhaberlesme.com.tr/index.php/en/		
UMU	USE-IT	Project	Spain	Distributed and anonymised key distribution scheme	Yes, urban mobility security (post-project possibility)	
LIST	YONGATEK EMBEDDED SYSTEMS	Project	TURKEY	NLOS non line of sight (satellite communication), low error rate high-throughput Ka-band datalink and testbed for 5G https://yongatek.com/	Possibly: Cloud-based vehicle monitoring	

The following observations can be made:

- The table above shows a total of 43 entries, most of which are projects.
- Of these projects, 49% are financed by public funds, 40% by a public-private partnership, and only 11% exclusively by private parties. This shows the strong willingness of Member States to contribute to the deployment of 5G.
- The TRL (Technology Readiness Level) of these technologies, not shown in the table, is mostly between 5 and 7, which shows a strong attractiveness for the development of experimental projects, leading to advanced prototypes and not to products that are immediately market ready. This is an added value for the innovations developed in 5G-MOBIX, which could directly benefit these innovations by helping them to mature their technological level at least to a TRL 8.
- There is a lack of innovation related to SMEs, OEMs, and entrepreneurs. This is crucial and can be explained by the fact that a large part of the project partners are focused on research and innovation projects, usually involving universities and RTOs.
- As shown in the graph below, local innovations can for the time being mostly benefit from 4k bus monitoring, which is compatible with the current plans at CBC level.
- It is important to note that the possibilities described in the table above are still to be explored during but also after the project. Detailed activities related to security, for example, are not foreseen within the framework of 5G-MOBIX but represent a key asset that will have to be explored in the long term.



6.2.1.1. ***Step 2: identification of successful innovations (extended assessment).***

The data presented in the first step is needed to make a first snapshot of the local innovations at the local level, but since it is limited to the consortium, it naturally lacks representativeness. At the same time, it is difficult in the context of this deliverable to make a more detailed analysis, as it ultimately depends on the final characteristics of the technologies that will be developed within 5G-MOBIX.

To overcome this gap, the data presented above will be supplemented with:

- 1) **External innovations:** the material identified in Chapter 4 will be completed and filtered, so that we can identify clear and tangible external innovations that are connected to 5G-MOBIX. Local innovations that are not directly known by the members of the consortium will not be considered, unless market studies carried out in the framework of other tasks/WPs provide additional data, and to avoid the additional effort this would represent. For each innovation, the stakeholders will be further characterized, so that SMEs, OEMs, and entrepreneurs can be prioritized. EU incubators and accelerators, SME instrument champions and VC funds will eventually be consulted to enrich the list of local innovations, and agreements will be made where necessary with them, so that contact between the consortium and these local innovators can be facilitated. This will be supplemented by market studies and by using the above-mentioned innovation areas as clustering indicator.
- 2) **5G-MOBIX's innovations:** at the same time, 5G-MOBIX's innovations will be better characterized and fully validated by other WPs so that precise technical links can be found external innovations. This work will be carried out in parallel with the innovation activities of the project, which should precisely identify these elements of innovation.

6.2.1.2. *Step 3: scoring and integration of successful innovations into one of the project's use-cases.*

Each of the external innovations listed in Step 1 and 2 will be scored so that the most important ones can be accurately selected according to the interest and scope of 5G-MOBIX. This score will be defined with the trial site leaders, who are the scenario owners and who will directly interact with/be the integrator of these innovations coming from external stakeholders. This score will be given by each CBC corridor, and it will be the sum of the following sub-scores (preliminary criteria – subject to changes):

- A [0:10] = Alignment with regard to the trial site activities.
- B [0:10] = Capacity to support the cross-border issues identified in D2.1.
- C [0:10] = Business impact potential.

Innovations with the highest scores will be given priority, and their owners contacted to assess their interest, with a questionnaire. Where possible, agreements might be established so that these owners can be integrated into the project's trial sites, with a timeline that may go beyond the project depending on each trial site's individual plan. This will provide them with a large-scale pan-EU showcase that will contribute to facilitate its take-up and introduction into the market. This step will of course take place independently of the evolution of the trial sites, so as not to disturb the work and the timeline established in WP3, WP4 and WP5.

6.2.2. Axis 2: from "Project to Global"

This axis aims to go one step further towards the market and to ensure that the innovations developed in 5G-MOBIX can have an impact on a global scale, benefiting other solutions, either by facilitating the link

with the market (step 1 below) or by providing deployment recommendations that are applicable on a larger scale (step 2 below).

6.2.2.0. *Step 1: establishment of tri-lateral agreements:*

The objective here is to support the market take-up of concrete innovations and services demonstrated in the project use cases. This applies both to innovation coming from external stakeholders and innovation brought by project partners. It is foreseen that this support will be implemented by establishing tri-lateral agreements among:

- Innovators.
- Technology adopters/ customers.
- Private investors.

A link/correlation matrix will be created so as to evaluate the most interesting potential links between innovators/customers/private investors, using a scoring methodology close to what is described in the previous sub-section. Ultimately, and with the support of the consortium, it is expected that a preliminary list of agreements is presented in D6.5 in M44.

6.2.2.1. *Step 2: provide recommendations and deployment options for opening the door to post-project extensions and replications*

The deployment of the innovations described above have led to challenges and barriers, which are contextualized for the purposes of this document in Section 5. The objective of this step is to use all the knowledge accumulated during the project to propose concrete deployment recommendations, which can serve as a reference for similar deployments, for external stakeholders and to facilitate the integration of the project innovations. In this context, we plan to present two sets of recommendations:

- 1) Recommendations that come directly from the consortium and from their experience in 5G MOBIX and in other projects undertaken (micro-level recommendations).
- 2) Recommendations especially focused on the cross-border area.
- 3) Recommendations at macro-level validated from external stakeholders.

Each of these recommendations categories is presented in each one of the following sections.

6.3. Recommendations and solutions for deployment and fundamental innovations.

The recommendations resulting from the work done in T6.1 are shown below. These recommendations are provided at the micro, cross-border, and macro level. The methodology was presented in the 5G-MOBIX stakeholder workshop “Workshop on the Deployment Methodology of 5G for CAM on Cross-Border Corridors” (26 March, online).

The prioritization of the measures is shown next to the recommendations under the following terms:

U: Utility Score	● High priority
C: Lifecycle Cost Score	● Medium priority
F: Final Score = (Utility Score/Lifecycle Cost Score)	● Low priority

The details of the prioritization can be found in the Annex 9.1.

6.3.1. Recommendations at micro level

For the preparation of this document, in a first stage, the experts in the different areas of the 5G MOBIX project provided a series of recommendations at micro-level within the following categories:

- Deployment recommendations.
- Data Quality-Validity recommendations.
- Data Property Management recommendations.
- Application and interoperability recommendations.
- Automotive industry and CAM recommendations.
- Cybersecurity recommendations.
- Road recommendations.

These recommendations are presented in the following sections.

6.3.1.0. Deployment recommendations

The following are the deployment recommendations provided by the 5G MOBIX project partners in relation to 5G technology for CAM applications.

Table 22. Deployment recommendations. Source: 5G MOBIX.

ID	Issue name	Issue Description / Recommendations	U	C	F
DEP1	Tools or services to support the deployment of 5G antennas	<p>The deployment of a 5G infrastructure for CAM applications can potentially be complicated to manage, as many parameters have to be considered and may influence the choice of antenna configuration and position, which depends on the targeted applications, number of users, etc.</p> <ul style="list-style-type: none"> • Using artificial intelligence and optimization techniques has the potential to lead to 5G antenna deployment recommendation tools. 	● 3,5	● 3,4	● 1,0

		The development of these decision support tools could be done using road and network traffic simulators.			
DEP2	Availability of 5G NR simulation tools	Need for wide dissemination of 5G NR open-source simulation tools to accelerate deployment. • Continue updating simulation tools such as NS3 or Omnet++	3,0	2,0	1,5
DEP3	Availability of 5G NR equipment	Non-availability of some 5G NR equipment • Expected to be solved in the medium term. Progressively, vendors will manufacture more equipment and add new functionalities depending on the pace of 3GPP standardization.	4,3	3,5	1,2
DEP4	5G NR deployment	Need for deploying 5G NR base stations across EU to guarantee good service • Expected to be solved in the medium term. Mobile operators will deploy new sites according to the maturity of 5G technology.	4,3	3,6	1,2
DEP5	Resource migration solutions	There is a lack of open solution to guarantee the migration of edge resources assigned to vehicles. • Holistic architecture offering edge capabilities across MNOs, countries, and network/security domains	4,0	3,0	1,3
DEP6	Orchestration and allocation of resources in mobile scenarios	Need for solutions offering orchestration and resource allocation through different computing domains and using locally available network resources in mobile scenarios such as CAM. • Holistic and/or distributed architecture coping with mobility, security and QoS required in CAM	4,7	3,2	1,5
DEP7	Low latency, Jitter, Packet Loss on Communication path	Mobile operators have their own data-network infrastructure that they need to interconnect to each other over underlying medium such as IPX/GRX or public internet where vulnerability to negative communication impacts exists. • Dedicated Direct data network between operators to be used as alternative to conventional inter-operator data exchange model is needed.	4,0	2,6	1,5
DEP8	Network densification implications for communications infrastructure	5G will imply network densification, that is the process of deploying a high number of small cells. The fact of deploying lots of new communication sites across the territory will need an extensive fibre backhaul for supporting them. • Extend the 5G NR networks in order to support 5G new sites.	3,5	2,5	1,4
DEP9	Network densification implications for MNOs & high infrastructures cost.	MNOs operating in the same areas will face a need of deploying large sets of 5G sites in order to upgrade its services to the new generation of telecommunications. GSMA [22] estimates the cost per square kilometre of building a 5G network to be four times more expensive than the 4G network. This is meant not only by telcos having to install compatible antennas and upgraded equipment to cope with requirements of radio connectivity and transport signals to deliver 5G data in a smooth and secure manner but also to lay the derived groundwork for having to install all the fibre optic cables needed to be in place to connect each antenna. • Agreements between MNOs for sharing and reusing telecommunication physical infrastructure may be beneficial for all the parts involved: less sites to be deployed for each MNO (save costs).	3,7	2,4	1,5
DEP10	Fibre backhauls	Deploying fibre backhaul networks for small cells – to support high data rates and low latency – will be one of the largest challenges faced by operators due to the poor availability of fibre networks in many cities. • Where it is not cost effective to deploy fibre backhaul, operators should consider wireless backhaul technologies. A portfolio of wireless technologies including PMP, mmWave and satellite should be considered in addition to fibre where this is the case. • Policymakers may consider removing tax burdens to reduce investment cost associated with fibre in order to facilitate the deployment of 5G networks. • Local authorities may consider agreeing upon standardized wayleave agreements to reduce the cost and time of deploying fibre networks. • Infrastructure sharing: Commercially led network-sharing agreements are preferred by most NRAs and seem to have gained	3,2	2,5	1,4

		significant market traction. These can speed up the deployment and reduce costs for 5G networks where network sharing ranges across mobile infrastructure as well as fibre.			
DEP11	Complexity of multi-stakeholder involvement in E2E management of virtual resources.	<p>Multi-site, remote monitoring of network performance and control of the network resources is hardly developed, and is critical in intensive applications</p> <ul style="list-style-type: none"> Development of the performance monitoring and management components for E2E scenarios. 	● 4,7	● 3,3	● 1,4
DEP12	Heterogeneous availability of network physical resources for service provision.	<p>There seems to be an assumption that network service level will be fairly homogenous across regions, borders, and geographical areas in general. It is difficult to imagine a Business Model where this is true and/or viable at any large area, and therefore, aspects like QoS and continuity needs to consider potential vast differences in available resources for service provision.</p> <ul style="list-style-type: none"> An assessment on the deployment of services with certain QoS requirements in environments where these might not be met is necessary. <p>Complex environment simulation tools need to be developed.</p>	● 3,0	● 2,4	● 1,3
DEP13	Lack of terrestrial connectivity	<p>Terrestrial connectivity gaps is a major issue for autonomous vehicles that rely on CAM messaging. The lack of coverage could have severe implications on functional and safety aspects of connected vehicles</p> <ul style="list-style-type: none"> Satellite bearers can provide a solution on the issue, using hybrid communication platforms, utilizing intelligent routing functionality. Using a single radio bearer creates a single point of failure putting critical CAM functionality at risk, especially when it comes to MCM messaging. In 5G architecture, this is addressed at multiple levels – including Radio and System. To this end, high QoS for resilience and redundancy in the communication link shall be delivered through the combined use of 5G NR and satellite access. Such a solution will be deployed at the French trial site through a hybrid platform that utilizes both 5G-NR and Low Earth Orbit Satellite Connectivity 	● 3,5	● 3,4	● 1,0
DEP14	Cooperation among authorities and industry	<p>Different interests on where to speed up the 5G deployment processes: digital infrastructure (i.e., related to smart cities), transport (e.g., major roads and railways... Lack of engagement with different stakeholder plans is creating barriers for a global and speedy 5G deployment.</p> <ul style="list-style-type: none"> Seek for a greater collaboration between the public and private sectors. The complex blend of stakeholders – mobile operators, businesses, landowners, local and national government must work together to ensure the successful and swift deployment of 5G by means of reaching mutual agreements in terms of business models, costs deployments or security/privacy issues. 	● 3,7	● 2,1	● 1,7
DEP15	Lack of information - Stakeholders	<p>Operators have often cited that it would be helpful to have a central database showing all available infrastructure and utility assets, such as existing local authority or utility ducts, fibre networks, CCTV posts, lampposts, etc. Such a database should also identify key contacts and the process for securing access to the assets.</p> <ul style="list-style-type: none"> Local authorities may consider holding a central database identifying key contacts, showing assets such as utility ducts, fibre networks, CCTV posts, lampposts, etc. to help operators cost and plan their infrastructure deployment more accurately. 	● 4,0	● 3,0	● 1,3
DEP16	Mobile service	<p>5G requires the mobile service providers to address CAM applications and other growth markets and move beyond a subscriber-driven revenue model.</p> <p>The telecommunication providers need to capture this growth, so the following measures must be provided in these new networks:</p> <p>Every part of the network must be ready for 5G, where the network will only be as fast as its slowest link. Each element must be dimensioned for 5G speeds. And for a true 5G experience overall with low latency, high bandwidth, and an ability to connect with billions of devices an end-to-end evolution plan is needed. That means upgrading the core, radio and all the transport links that connect them.</p> <p>Security is required everywhere and managed proactively. This means that security needs to be incorporated into every element of the network and embedded in every step of network operation.</p>			

		Gear up for services beyond connectivity, where automotive sector will play a very relevant role in the mid-term. Get ready to serve customers beyond consumers: A new end-to-end, cloud-native, secure 5G architecture can handle the complexity of many different CAM use cases. End-to-end slicing allows CAM applications to be individually customized. The possibilities are tremendous in our rapidly changing world.			
DEP17	Small power radio	Small radio power in the border and regions without 5G coverage in testing areas. <ul style="list-style-type: none"> The antenna locations must be deeply studied, and each 5G site must be located in an optimal distance to the border, in this manner, downlink/uplink throughput will not be affected in a negative way. It is required to search for the best possible radio link budget configuration. In addition to this, the use of the best possible automotive antennas will guarantee the coverage in the positions without direct line of sight of the 5G site and to improve possible restrictive conditions. 	4,2	2,2	1,9
DEP18	Loosing minimal radio signal	Loosing minimal radio signal many times due to the orography and other elements both natural (vegetation) and artificial (bridge structures, buildings ...) that prevent direct vision with the 5G antennas <ul style="list-style-type: none"> Study strictly the area to deploy the new NR base stations to have, as far as possible, direct vision with 5G antennas. 	3,8	1,7	2,3

6.3.1.1. Data Quality-Validity recommendations

The following are the Data Quality-Validity recommendations provided by the 5G MOBIX project partners in relation to 5G technology for CAM applications.

Table 23. Data Quality-Validity recommendations. Source: 5G MOBIX.










ID	Issue name	Issue Description / Recommendations	U	C	F
DQ-V1	Quality of (Sensor) Data: <ul style="list-style-type: none"> Verify sensor calibration chain Monitor sensor health ASIL protection of vehicle data 	<p>The generation of reliable HD maps relies on the trustworthiness of the received sensor data from all vehicles.</p> <p>Erroneous sensor data may corrupt the distributed HD map and may pose severe safety issues. It needs to be ensured that the sensors are calibrated and fully operational (no SW / HW error, no physical blockade, no timing issues etc.). Moreover, individual data samples need to be protected from being converted to wrong values e.g., by bit flips induced by cosmic particles.</p> <ul style="list-style-type: none"> Signing sensors with Digital Calibration Certificates as currently developed in the GEMIMEG project (https://www.gemimeg.ptb.de/) Enforcing the use of Automotive Safety Integrity Level (ASIL) for safety-critical shared data. 	4,0	1,8	2,2
DQ-V2	Traceability: <ul style="list-style-type: none"> Monitor and weight quality of data Statistical analysis conforms with GDPR 	<p>The quality of fused data for CAM applications (EDM, HD maps) relies on the quality of the samples provided by individual road users. This quality depends on the type, calibration, and health of their sensor package.</p> <p>In the data fusion, the information provided by different road users is weighted according to the reported data quality.</p> <p>To this end the road user needs to be traceable to collect a statistical measure of its provided quality of data.</p> <p>This tracing needs to be implemented in a way conform with the GDPR.</p> <ul style="list-style-type: none"> GDPR conform tracing of road users to statistically assess the quality of shared data. 	3,8	1,8	2,1

DQ-V3	Validity: • Life cycle of shared data	Data shared among vehicles and roadside units need to be assigned an adequate period of validity. This period depends on the data type, e.g., vehicle positions require a frequent update while road hazards (potholes, obstacles, ...) have a longer lifetime.			
		• Assign a time-to-live for all communicated data.	● 3,5	● 1,5	● 2,3
DQ-V4	Validity: • Mitigation of race conditions	Data is provided to the eRSU at discrete times/timestamps. It is therefore possible that data is received from two vehicles with the same timestamp but with contradictory content, while in both cases the data was valid at the time of data acquisition. E.g., two vehicles report different data on the status of a traffic light as their individual observation is some ms apart, but the sending time was identical.			
		• In the case of such a race condition, we choose the conservative/safety prioritizing option.	● 2,7	● 1,0	● 2,7
DQ-V5	Right level of information	Required to ensure the operations reliability. To ensure the robustness and constancy of the data quality and reliability is a critical safety issue.			
		<ul style="list-style-type: none"> • It is essential to Improve reliability of static maps. • Improve reliability levels of in-vehicle systems and components as an element of accident avoidance. • Define and harmonise, at the EU-level, Operational Domains to ensure real-time decision-making for safe and secure CAM for all types of traffic situations and roads. • Ensure interoperability of systems and services provided by the different actors (vehicles, infrastructure, road users, road/fleet operators, public authorities, etc.), develop standardised C-ITS messages and message sets (e.g. for manoeuvres) and test EU-wide interoperability and compatibility. • Develop a harmonised approach for data sharing based on open and interoperable programming interfaces (APIs) and access control by defined user rights. • Provide a complete and secure system architecture that complies with privacy, data security and cybersecurity requirements while allowing access to in-vehicle real-time data and resources, on-board and remotely, as needed. 	● 4,2	● 3,7	● 1,1

6.3.1.2. Data Property Management recommendations

The following are the Data Property Management recommendations provided by the 5G MOBIX project partners in relation to 5G technology for CAM applications.

Table 24. Data Property Management recommendations. Source: 5G MOBIX.

ID	Issue name	Issue Description / Recommendations	U	C	F
DPM ₁	Data Barriers: <ul style="list-style-type: none"> • Combatting GDPR fragmentation • Combined use of AI, automation, and responsible analytics • Standardised data access, use of open data and ensuring data quality 	<p>Transforming Transport (TT) is an innovative ICT project that addressed the digitisation needs of the transport sector, through the lens of big data and other enabling technologies such as IoT. Deliverables D3.13 "Policy Recommendations" and D2.4 "Lessons learned through cross-pilot analysis" contain the lessons learned from TT pilots and stakeholder surveys. The main barriers that were identified deal with data management and access to the data economy. Specifically, the different level of GDPR adoption by various infrastructure operators served as a barrier that hindered their cooperation. In its policy brief, TT considered that the path to an innovation framework demands alleviating data-related barriers.</p> <ul style="list-style-type: none"> • The organisation of CAM data pilots is a necessary step towards achieving interoperability and combatting GDPR fragmentation (i.e., the disparities in the level of compliance among actors). Big data pilots focusing specifically on CAM/5G use cases should answer a lot of questions regarding: <ul style="list-style-type: none"> • The types of data formats preferred among actors and the level of interoperability. • The types of data collected and their usefulness in training AI models. • The modalities for data sharing and need for anonymisation 	 3,8	 2,9	 1,3
DPM ₂	Responsible AI: <ul style="list-style-type: none"> • The impact of using AI for data analysis needs to be determined • Data quality needs to be assured • Accountability & Transparency 	<p>The Commission's Ethics Guidelines for Trustworthy Artificial Intelligence (AI). These guidelines suggest measures to ensure that AI does not negatively impact societal and personal well-being, by focusing, among other measures, on data privacy, accountability, non-discrimination, and fairness.</p>	 3,3	 1,8	 1,9
DPM ₃	Open Data Sharing: <ul style="list-style-type: none"> • Standardised data access, use of open data and ensuring data quality • Anonymisation on-the-fly • Access to a data economy/platform. • Data Sharing among public and private actors. 	<p>The Open Data Directive (Directive (EU) 2019/1024 replacing the Public Sector Information (PSI) Directive 2003/98/EC) provides a common legal framework for a European market for government-held data and hence would apply to public sector stakeholders in CAM (public road operators, municipalities, state agencies and authorities etc.). It is built on two key pillars: transparency and fair competition and focuses on economic aspects of the re-use of information. Technical means need to be in place to simplify data sharing among stakeholders. Similar efforts in other verticals include the Copernicus DIAS platforms.</p> <ul style="list-style-type: none"> • Recent efforts by the government of Canada have focused on defining a methodology for "Algorithmic Impact Assessment" for AI products. A similar effort could be undertaken where ethical specifications are provided for AI algorithms and rigorous testing can provide insight on unwanted bias in AI algorithm results. Seeing as the need for training data is a major concern in the development and testing of AI algorithms, any future CAM data pilots should also address Responsible AI. 	 4,0	 3,7	 1,1
DPM ₄	Source platforms	Open-source platforms will be needed, with the use of shared data to design and improve services and service operations.			

		<ul style="list-style-type: none"> The multitude of sensor and other data coming from CAM services spells an intriguing opportunity to create a data economy where third parties can create products and analytics services. However, this means that on-the-fly sanitisation and anonymisation of data through big data platforms as “Ethical Data Proxies” is a must-have, while common data formats accepted as industry standards should be developed. Furthermore, there is a need to improve data sharing among Critical Infrastructures (e.g., road operators etc.) that can benefit from an “Ethical Data Proxy” approach. 	● 4,0	● 3,5	● 1,1
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6.3.1.3. Application and interoperability recommendations

The following are the Application and interoperability recommendations provided by the 5G MOBIX project partners in relation to 5G technology for CAM applications.

Table 25. Application and interoperability recommendations Source: 5G MOBIX.

ID	Issue name	Issue Description / Recommendations	U	C	F
AI1.1	V2X Continuity	Currently while crossing the border v2x applications are faced with large disconnection times. The modem tries to stay connected to the network it is connected to, even falling back to other technologies (like 3G) to accomplish this. Only when there is no connection for a certain amount of time the modem starts to search for other networks, doing a full network search in most cases.			
		<p>There are solutions possible for short term to overcome the issues we face today but also solutions should be developed for the long term such that we are able to reach a scalable solution.</p> <p>Short-term:</p> <ul style="list-style-type: none"> Using user-space applications running on the device (or even on the SIM) the device can be triggered to do a full network search before crossing the border and can be instructed to connect to a new network before the connection is degraded. Tests show that a disconnect time can be lowered from minutes to a few seconds. If a disconnect time of a few seconds is not allowed, a multi modem approach can be taken to first connect to the new network before breaking with the old. Since there is no handover taking place, the in-vehicle application needs to be developed such that it can handle reconnects and works seamlessly with the on-board modem. 	● 4,7	● 2,3	● 2,0
AI1.2		<p>Mid-term:</p> <ul style="list-style-type: none"> Currently in the standardization a possible solution is foreseen with which an extra roaming interface is added between the bordering PLMN's. For 4G this is present in the standard (using the S10 interface), for 5G it is not yet described. It is expected that in the future some operators will implement such an extra roaming interface making it possible that the network takes care of handing over the connection to the other PLMN, maintaining the current data session. This will however come at the cost of: <ul style="list-style-type: none"> Different latency after handover. When for instance the car is moving from the home network to the visited network the traffic will be routed over the roaming interface between the two PLMN's. The application should be able to handle sudden changes in latency. The integration between PLMN's is prone to errors. Each base station needs to be configured using information from the other network and changes in the other network can lead to dropped connections when doing a handover. The integration between PLMN's does not seem scalable at this moment because of the high level of integration needed with the S10 	● 4,7	● 2,9	● 1,6

		<p>interface, the dependencies between networks and because of the limited possibilities to steer the roaming traffic to certain PLMN's (respecting roaming agreements).</p> <ul style="list-style-type: none"> Only possible for 4G Roaming. The vehicle needs to be connected to a an ePC for the handover to work. 			
AI1.3		<p>Long term:</p> <ul style="list-style-type: none"> Long term solutions will take significant time to accomplish knowing that current standards need to be changed. These changes should be made with respect to the following requirements (to be revised in cooperation with for instance GSMA and 3GPP): <ul style="list-style-type: none"> The handover should be made possible with a 5G SA Core. The home PLMN should have influence on the actual selection of the roaming network such that it can: <ul style="list-style-type: none"> Respect roaming contracts. Select a suitable candidate based on performance requirements. The home PLMN should have insight in network resource availability of roaming networks such that it can steer future roamers to a suitable roaming network. The interworking between cross border networks should be such that a minimal level of integration or manual intervention is required: preserve topology hiding. Service continuity should be made possible such that the UE can set up a connection to the new edge prior or after the handover before breaking the old connection. 	4,7	3,1	1,5
AI2	Reconnection to the edge	<p>When crossing the border, the application should be able to instantly reconnect to the edge in the new network and use the applications without significant latency or other issues. There are however some issues to be expected:</p> <ul style="list-style-type: none"> Currently no session and service continuity protocol exist that is capable of working cross border. The network should be able to connect the UE to the closest edge in the new network and make the application aware of the new connection. <p>It is expected that different countries have different implementations by also different road operators or service providers. Currently no harmonization exists between countries, MNO's, Vehicle manufacturers or service providers on how the vehicle communicates with V2X services on the network, what data products are provided, etc.</p> <p>The recommendations can be split in different categories:</p> <p>Network</p> <ul style="list-style-type: none"> The PLMN should be able to offer a certain continuity protocol like SSC mode 2 or 3, allowing the application to always have a connection to the network services. Also, the application should be notified by the network of new connections that are offered and where the new applications can be found. This can be accomplished using an application function, working closely together with the network and steering the on board v2x application to the correct edge, triggering state transfers, etc. Currently it is unclear if or how SSC should work when roaming to or from a new network, to be better specified in the standards and adopted by the vendors (UE and Core). <p>Application</p> <ul style="list-style-type: none"> The application should be able to handle sudden transitions to new services or edges. This can be accomplished for instance integrating more closely with the mobile network using the before mentioned application function. Depending on the level of standardization we are able to reach also different protocols and data formats can be expected, depending on the country, road operator and/or service provider. 	4,7	3,4	1,4
AI3		Inconsistent data schemas exchanged across vehicles vendors, network domains, infrastructure systems or federated service servers			

	Data Interoperability	<ul style="list-style-type: none"> Defining a "Master ITS centre" to Conflict resolution techniques for DENM/CAM messages. Push for standardized data formats / APIs. Translation SW into single format for border areas. 3rd party reference clock. Pro-active clock drift compensation based on analytics. 	4,7	3,2	1,5
AI4	Geo-driven Discovery	<p>Inefficient indexing of vehicles and attachment of data when ignoring geo-position of UEs Discovery.</p> <ul style="list-style-type: none"> Coordinated geo-distribution mechanisms among network components, RSI and MEC between countries. Single digital image of the cross-border environment. Enhanced positioning accuracy via differential GPS and camera/radar relative positioning. Proactive pre-allocation of resources in new spectrum 	4,7	3,2	1,5
AI5	State transition between MECs, for stateful Applications when crossing the border	<p>Certain application follows the state of the user, and once a HO is performed the application instance running on the other side of the border needs to have the previous user information/data from the instance running in the originating country border.</p> <ul style="list-style-type: none"> Inter-cloud. Inter-MEC. <p>Single instance app with IP change.</p> <ul style="list-style-type: none"> Harmonized application-level solution needed (ideally following indications from ETSI ISG MEC) 	4,7	3,2	1,5
AI6	KPI measurement synchronization across different components and across neighbouring 5G networks	<p>Absolute clock synchronization of OBUs, RSUs, 5G network, sensors, etc. for accurately measuring KPIs (e.g., to estimate the E2E latency and break it down to its components the OBUs and the network need to be synchronized. Problem intensifies when communicating across the borders as MNOs may have different synch clocks.</p> <ul style="list-style-type: none"> Common clock reference, such as GPS timing, might be a solution but it is not always possible as low tier/low-cost devices may not be capable for this. 	3,3	1,6	2,1
AI7	Dependability requirements of CAM services	<p>Dependability requirements of CAM services</p> <ul style="list-style-type: none"> Fault-prevention and fault-tolerance mechanisms, for instance redundant 5G networks, are typically employed to ensure such high dependability requirements. In order to prove the correct operation of the system, fault-injection procedures may be employed to shorten the testing and verification period. 	3,0	2,7	1,1
AI8	Fallback in case of network outage	<p>A standard to regulate OBU behaviour is required in case of network outage. In case of network outage, a set of basic rules must be defined to module OBU behaviour, especially when the vehicle interacts with other vehicles. A lack of a fallback rules can lead to critical events between autonomous vehicles.</p> <ul style="list-style-type: none"> Fall-back to 4G or national roaming 	4,2	2,6	1,6
AI9	Dimensioning of critical V2X communications	<p>Dimensioning of maximum number of V2X users in one area in case of traffic jams in unusual location.</p> <ul style="list-style-type: none"> Priority mechanisms in case of congestion of the V2X slice using different classes for the most critical communication scenarios. 	4,2	2,2	1,9
AI10	Coordinated V2X Sidelink resources among operators across borders	<p>Since the task of resource pool definitions is up to individual operators, it could occur that two vehicles using the same band on different sides of the border cannot communicate due to using different resource pools. The definition of resource pools dedicated for side link is dependent on multiple properties, e.g., allowed Slots for Sidelink transmissions, the size and number of declared subchannels, the used slot structure for side link. Thus, any variations on how the resource pools are defined between two operators could cause the vehicles not to be able communication from one vehicle not visible to the other.</p> <p>To ensure the continuity of V2X services, not only the frequency bands used need to be coordinated, but also the how the Sidelink Resource pools are defined. This could be achieved by having one universally coordinated resource pool dedicated in both the SIB and the dedicated RRC configuration for cases of potential communication with vehicles operated by another mobile operator.</p>	4,2	2,3	1,8

AI11	Quicker network handover in cross border scenarios	When the user crosses the border the network handover may take some time.			
		<ul style="list-style-type: none"> RAN configuration of neighbours between cross border cells should be defined in order to reduce interruption time during Handover procedure. Requires interconnection (S10 interface) between the Home Operator and the Visited Operator. 	4,3	2,0	2,2
AI12	URLLC V2X traffic classification	URLLC slice has lower spectral efficiency and consumes more resources from MNO cell capacity. Not all CAM traffic should be mapped on URLLC slice.			
		<ul style="list-style-type: none"> Standardization of CAM traffic profiles that defined which critical traffic should be mapped on URLLC slice and non-critical on eMBB or mMTC slices. 	3,8	1,8	2,1
AI13	Coordinated V2X Sidelink resources among operators across borders	Since the task of resource pool definitions is up to individual operators, it could occur that two vehicles using the same band on different sides of the border cannot communicate due to using different resource pools. The definition of resource pools dedicated for side link is dependent on multiple properties, e.g., allowed Slots for Sidelink transmissions, the size and number of declared subchannels, the used slot structure for side link. Thus, any variations on how the resource pools are defined between two operators could cause the vehicles not to be able communication from one vehicle not visible to the other.			
		<ul style="list-style-type: none"> To ensure the continuity of V2X services, not only the frequency bands used need to be coordinated, but also the how the Sidelink Resource pools are defined. This could be achieved by having one universally coordinated resource pool dedicated in both the SIB and the dedicated RRC configuration for cases of potential communication with vehicles operated by another mobile operator. 	4,0	2,4	1,7
AI14	Distributed applications for edge computing	New automotive services that need use of MEC architecture for low latency requirements must be implemented on distributed applications that run partly in MECs and partly on internet. These applications have not been developed yet or are immature.			
		<ul style="list-style-type: none"> These applications need to be developed and their behaviour tested thoughtfully 	3,7	2,9	1,3
AI15	Handover	Terrestrial coverage gaps, especially in CBC situation creates issues with service and application continuity			
		Redundant connection using dual SIM can provide a solution to make handover between different cellular networks. This requires a proper management of data flows in the same end node, using an intelligent router	4,5	2,6	1,7

6.3.1.4. Automotive industry and CAM

The following are the Automotive Industry and CAM recommendations provided by the 5G MOBIX project partners in relation to 5G technology for CAM applications.

Table 26. Automotive Industry and CAM Recommendations. Source: 5G MOBIX.

ID	Issue name	Issue Description / Recommendations	U	C	F
AI & CAM1	Possible interference with current automotive radars	Some automotive radars use the 24-GHz-band, which is planned to be used for High-Speed 5G communications. Even if it is difficult there is a direct impact due to the reduced range of the radars in these cases, there would be an increase in the noise level, which might reduce the performance of such radars.			
		<ul style="list-style-type: none"> Automotive radars could finally abandon 24-GHz band and be restricted to 77-81 GHz band. Otherwise, a study would need to be done on the possibility to limit the power level from the 5G antenna in nearby roads. 	2,8	1,8	1,6
AI & CAM2	Lane markings	Consistent lane markings of good quality and visibility will be needed by vehicles utilising cameras as the vision system. Special marks for easier RADAR and LIDAR sensing may be introduced.			
		<ul style="list-style-type: none"> Road works need to be managed in a harmonised and rather standardized manner with regard to the markings, management processes and digital information. Standardisation of road signs (physical and digital) and road markings in the EU. 	4,2	2,2	1,9

		<ul style="list-style-type: none"> To facilitate automated driving also on snowy and icy roads, winter maintenance and especially snow removal and de-icing need to be enhanced in countries and regions with frequent occurrence of ice and snow on roads. 			
AI & CAM₃	Difficulties for testing in real conditions	<p>Testing some technologies, such as autonomous driving, in real conditions, may cause fatalities, when unexpected behaviours happen</p> <ul style="list-style-type: none"> Initial tests based on simulations or on closed areas until technology gets mature enough. 	● 2,5	● 1,7	● 1,5
AI & CAM₄	Dependability requirements of CAM services	<p>In order to provide trustworthy operation of connected autonomous vehicles, very high levels of reliability and availability are required both in the 5G network, as well as in the vehicle, road, and cloud infrastructure systems. For that purpose, extensive testing needs to be performed, so that it can be guaranteed the provision of continuous and failure-free service provided by 5G applications.</p> <ul style="list-style-type: none"> Fault-prevention and fault-tolerance mechanisms, for instance redundant 5G networks, are typically employed to ensure such high dependability requirements. In order to prove the correct operation of the system, fault-injection procedures may be employed to shorten the testing and verification period. 	● 4,0	● 2,8	● 1,4
AI & CAM₅	HD Maps not updated	<p>HD Maps information is not updated in real time so there is no certainty that the map shows the actual state of the road. Base imagery and geometry capture by satellite, airborne sensors and/or mobile mapping and its postprocessing requires weeks despite HD maps providers talk about daily updates.</p> <ul style="list-style-type: none"> Crowd-sourced information from the users currently on the road seems to be one of the few options to collect updated information. Requires a very high throughput mobile network to stream data to the C-ITS centre and back to the users' vehicles once processed with the necessary MEC capacity. 	● 3,8	● 3,1	● 1,2
AI & CAM₆	HD maps maintenance	<p>HD maps providers cannot detect by themselves map changes like lane closures, roadworks, traffic jams, etc. at the required pace.</p> <ul style="list-style-type: none"> Road operators must collaborate detecting map changes and noticing C-ITS platforms, so changes are merged in the HD map and vehicles receive the updated map. 	● 3,8	● 2,6	● 1,5
AI & CAM₇	Road infrastructure compatibility with CAM	<p>Connected autonomous driving functions require, not only a reliable 5G network but also other fixed infrastructure elements like sensors, RSUs, specific road signs and road/lane markings, etc. This may require newly designed roads so they could be used by connected autonomous vehicles, segregated or not from conventional vehicles (non-connected or autonomous).</p> <p>"Connected autonomous ready" roads (or lanes) and infrastructures. (Road new design)</p>	● 4,0	● 3,1	● 1,3
AI & CAM₈	"Connected autonomous ready" infrastructure cost	<p>To define the payment for "connected autonomous ready" infrastructure cost and maintenance.</p> <ul style="list-style-type: none"> Government subsidized via taxes (toll free roads). PPPs financed with tolls/PAYD (pay as you drive). 	● 3,2	● 2,0	● 1,6
AI & CAM₉	Vehicle readiness	<p>How can be guaranteed that vehicles ADAS/HAD systems are up to date? Who is responsible for the update of vehicle systems?</p> <ul style="list-style-type: none"> The vehicle should have a certain version of the firmware and SW, including any critical or security update. Dedicated infrastructure should be able to check it and reject vehicle connection or certain functions if needed. 	● 3,3	● 2,2	● 1,5
AI & CAM₁₀	CAD functions revenue collection 1	<p>It is needed to identify how are those updates to be paid and which is the revenue stream in the business model.</p> <ul style="list-style-type: none"> Down payment with the vehicle acquisition and lifelong license Update fees Subscription 	● 3,2	● 1,7	● 1,9

AI & CAM11	CAD functions revenue collection 2	It is needed to identify who will collect fees.			
		<ul style="list-style-type: none"> Vehicle manufacturers, OEM, HD maps provider, C-ITS platform, others... 	● 3,2	● 1,7	● 1,9
AI & CAM12	Accurate positioning	Accurate and robust vehicle positioning systems needed.			
		<p>Recent advances in the telecommunications industry and the resulting applications such as autonomous vehicles, vehicle surveillance and traffic safety has increased the demand for accurate and robust vehicle positioning systems.</p> <p>Autonomous driving of intelligent vehicles is started from knowing where a vehicle is located on the map. The knowledge of the vehicle position on the map is offered by navigation (localization) algorithm.</p> <p>The commercial development of large autonomous land vehicles requires the corresponding development of high integrity navigation systems. Such systems are necessary to provide knowledge of vehicle position and trajectory and subsequently to control the vehicle along a desired path. The need for integrity in such systems is paramount: undetected, erroneous, position or trajectory data can lead to catastrophic failure of the autonomous vehicle, such as road departure and collision with obstacles or other vehicles. Therefore, provision of accurate and robust position information is a crucial prerequisite for safe autonomous driving.</p> <p>Integrated navigation is much advantageous over the single navigation system. Although the Global Position System (GPS) has a higher positioning accuracy than other positioning approaches, it is vulnerable to a wide-ranging variety of interferences, such as the multipath effect from radars, electromagnetic interference, block of signals and so on [13]. To determine the accurate and robust position information, many kinds of positioning algorithm were developed which integrates GPS information with on-board sensors such as inertial sensors, rate-gyro, wheel speed sensors, and a steering angle sensor. Due to the complementary nature of the GPS and the on-board sensors, information fusion-based positioning algorithm can provide more robust and smooth position information of vehicle compared to only GPS based positioning solution [14].</p> <p>A growing number of research groups around the world are developing autonomous land vehicle systems for various applications (see [15], [16], [17] and [18] for example):</p> <ul style="list-style-type: none"> SSR centimetre accuracy GPS in the average infotainment system today has approximately 5 m accuracy which is enough for simple navigation. High-precision GNSS receivers, on the other hand, can place you on the map with centimetre accuracy. This exceptional precision can be achieved by combining GNSS signals with corrections from local reference stations. Such reference station networks, such as SSR networks, are being setup today in the US and in many other parts of the world. To create such a reference network, a stationary GNSS receiver is needed about every 300 km along the road. It can be attached to existing infrastructure such as telecommunication towers or to roadside units. "When the customer starts the engine in the vehicle, we need to deliver continuous GPS corrections to the car, and that's to ensure we know which lane the vehicle is operating in", said Curtis Hay, Technical Fellow at GM in an interview at the International Motor Show, 2018. Integration with IMU and odometry 	● 3,7	● 2,5	● 1,5

		<p>High degree of reliability is possible in specialized GNSS receivers due to their multi-frequency, multi-constellation GNSS technology. This means that the receiver is using all the signals being sent out by all GNSS satellites available world-wide: GPS, GLONASS, Galileo, BeiDou and QZSS. GPS receivers need a line-of-sight to at least 4 satellites to know where they are, and they need even more satellites for centimetre-level positioning. When the view of the sky is partially blocked, in urban areas or under trees, having access to more GNSS signals can make a big difference for availability and accuracy. When the sky is temporarily blocked, other sensors such as IMU or wheel odometry continue localization by providing relative position to the last known GNSS location. In contrast to camera, LiDAR, radar, and ultrasound sensors, the IMU is a sensor that requires no information or signals from outside a vehicle. The IMU measures the forces of acceleration (gravity and motion) and the angular rates of the vehicle. The inertial navigation system (INS) is a completely autonomous navigation system with good concealment, strong anti-interference ability, immunity to meteorological conditions, etc. However, pure INS suffers from accumulated error. Thus, when the IMU is used alone, it results in greater error than other approaches (performance degrades with time due to the accumulation of measurement errors). In order to improve the accuracy of integrated navigation, the estimation algorithm based on integrated navigation has been widely investigated in recent years.</p> <p>Perception sensors and GNSS have their strengths and weaknesses in different areas and can complement each other to deliver optimal safety for automated piloting. The localisation system identifies the location of the vehicle on a global coordinate system while the perception system evaluates the driving environment around the vehicle and identifies elements such as other road users, traffic signals and obstacles.</p> <p>GNSS, GPS, and their variants are not accurate and cost efficient enough for all autonomous driving environments, such as urban canyons or tunnels. To address the GNSS limitations, there has been important studies on radio-based positioning techniques and the 5G has not been an exception. Features such as large bandwidths, high frequencies (e.g., 28 GHz), and large number of antennas in 5G are the key enablers for high accuracy positioning.</p> <p>Providing wireless connectivity to vehicles enables communication with internal and external environments, supporting vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-sensor, and vehicle-to-internet communications. Such information can be integrated to localisation systems to further improve both accuracy and robustness and to address the line-of-sight issues associated with on-board sensors at a relatively low cost. Similar to V2V techniques, the quality of service in V2I networks is also a limitation for implementation as noise can affect the received signals causing erroneous inputs and packet loss and latency can cause degradation in performance or failure of localisation systems.</p> <p>Cellular systems are not designed to maintain LOS for the UE all the time. Jain, Kumar, and Panwar [19] presented a simplified model for blockage probability, frequency, and duration in mmWave cellular systems and they suggest that the design of mmWave networks may sometimes be driven by blockage rather than capacity requirements.</p>			
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		<p>Since the positioning techniques based on 5G are going to suffer from LOS blockage, integrating 5G positioning with INS using Kalman filter is expected to make a better positioning system [20]. As mentioned above, INS usage could help GNSS in the outage periods and it might be able to compensate high errors of 5G based positioning systems during the outages.</p> <p>5G support to accurate positioning might depend on network deployment aspects, and therefore the foreseeable differences in deployment across geographical areas might affect performance of positioning in critical applications. The analysis shows that augmenting off-board information to sensory information has potential to design low-cost localisation systems with high accuracy and robustness however their performance depends on penetration rate of nearby connected vehicles or infrastructure and the quality of network service.</p> <p>5G is being deployed and various configurations of it with different resource management schemes are being defined. Different factors are involved in order to satisfy the quality of service (QoS) delivered to the user: bandwidth, time, UE antenna system, BS antenna system, transmitter power, cell radius, and etc. The question is how each of these factors should be designed in order to make a 5G/INS positioning system achieve the required accuracy. Simulation tools for complex network environments, with varied multi-site physical resources, local and remote-control capabilities, and E2E applications should be developed.</p>			
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6.3.1.5. Cybersecurity recommendations.







The following are the Cybersecurity recommendations provided by the 5G MOBIX project partners in relation to 5G technology for CAM applications.

Table 27. Cybersecurity recommendations Source: 5G MOBIX.

ID	Issue name	Issue Description / Recommendations	U	C	F
CB 1	Cybersecurity: <ul style="list-style-type: none"> • SDN/NFV Security as-a-Service • AI-powered detection • Attestation & Infrastructure trust • End-to-end Encryption 	Projects such as SHIELD, ANASTACIA, nloVe have tackled security challenges in a more generic way, i.e., not tailored to CAM cases, but taking a generalised approach to the protection of service-based infrastructures. Results have shown that multiple measures should be applied, as some attacks are not identified by traditional perimeter defences.			
		<ul style="list-style-type: none"> • The security value chain has to be considered at each level of the value chain – from vehicle parts up to the transport infrastructure including the related services and ensuring the protection of users' privacy and integrity. 	● 4,0	● 3,1	● 1,3
CB 2	Cybersecurity Validation:	Cybersecurity services specifically tailored for CAM should be extensively tested and validated. Although there are projects that focus directly on automated driving and IoT cases (e.g., CARMEL, nloVe, Headstart etc.) there needs to be extensive validation in a 5G for CAM "Cyber Range". It is important not only to assess the effectiveness of security measures, but also to assess how they affect running services (e.g., in terms of latency & performance).			
		<ul style="list-style-type: none"> • EU cybersecurity label • Validation of security measures (penetration testing) • Validation of the effects of security measures (e.g., effects on latency, performance of CAM) • CAM "Cyber Range" 	● 4,0	● 2,4	● 1,7

CB 3	Interoperation of trust and security domains	Need for implementing solutions to guarantee the maintenance of security and privacy capabilities in a cross-country way			
		<ul style="list-style-type: none"> Federated approaches, hierarchical EU-level approaches, agreements between countries and MNOs. Ensure robustness and redundancy, availability of communication channels (network coverage) and a minimum quality of service (QoS) especially for higher levels of automation. 	 3,8	 3,1	 1,2
CB 4	Security	As the number of devices accessing to data networks will be highly increased, including millions of IoT devices, the attack surface will be expanded exponentially, especially in terms of DDoS attacks. Also, attacks may come laterally across 5G supporting infrastructure coming from leveraging components of previous 3G and 4G networks to get to the intended target.			
		<ul style="list-style-type: none"> Upgrade networks with the latest security tools like firewalls and distributed denial of service (DDoS) detection to ensure the network is protected from malware, intrusions, and DDoS attacks so that 5G services can be delivered with zero interruption. Include the use of techniques like threat modelling, which allows to map out attack vectors and provide the right countermeasures, reinforcing the importance of thinking like an attacker in order to stop them. 	 3,7	 3,0	 1,2

6.3.1.6. Road recommendations.

ID	Issue name	Issue Description / Recommendations	U	C	F
ROAD 1	Spectrum: <ul style="list-style-type: none"> Long timescales for agreement on spectrum use Harmonization of spectrum allocation across regions and countries. 	The implementation of 5G is ahead of regulatory standards. Road operators are planning a capacity crunch towards the end of this decade, which is why they are seeking to deploy emerging technologies as soon as possible in order to maintain service levels. Regulatory processes often have long lead times, so initial 5G deployments will not meet standards because they are not sufficiently developed.			
		<ul style="list-style-type: none"> The lack of clarity and agreement on the spectrum use, makes the initiatives progress at a slower pace than desired. From the point of view of road operators, it is of great relevance since all initiatives under development seek to ensure interoperability and continuity of services regardless of geographical location. It is also extremely important for the development of technology, as it has a major impact on economies of scale and incentives for road integrators to develop products. 	 4,2	 2,5	 1,7
ROAD 2	Standardization: The implementation of 5G is ahead of regulatory standards.	The implementation of 5G is ahead of regulatory standards. Road operators are planning a capacity crunch towards the end of this decade, which is why they are seeking to deploy emerging technologies as soon as possible in order to maintain service levels. Regulatory processes often have long lead times, so initial 5G deployments will not meet standards because they are not sufficiently developed.			
		<ul style="list-style-type: none"> It is useful to reused standards that already exists and have proved good result, like DATEX. It is not necessary to start a new standard from scratch. As they do in Data for Road Safety, the standard used is SRTI, which is a DATEX simplification. 5G networks must initially coexist with these technologies and must be interoperable with 4G and other communication 	 4,2	 3,2	 1,3

		technologies to provide reliable, safe and high-speed services for all users. The infrastructure must be capable of providing connectivity without boundaries, offering the continuity of the service between all stakeholders: mobile network operators, vendors, manufacturers, traffic managers, road operators and service providers.			
ROAD 3	Coverage: More equipment is required.	<p>More equipment is required for greater coverage in order to be used for certain use-cases. Although 5G offers a significant increase in speed and bandwidth, its more limited range will require more infrastructure. The higher frequencies allow for highly directional radio waves, which means they can be targeted or directed -a practice called beamforming. The challenge is that 5G antennas, while capable of handling more users and data, emit over shorter distances. From the road operator's point of view, this implies a rationalization of the existing equipment.</p> <p>However, not all the networks must be under 5G coverage, solutions as 3G and 4G have proved to have a good latency under 300 milliseconds. This was proved in the use-case of GLOSA (Green Light Optimization Speed Advisory) and is included in an internal working document of DGT 3, available under request.</p> <p>To start with CAM is essential to check the capacity to work with the already existing network communication coverage, with 3G and 4g, along the road network.</p>	3,2	1,7	1,9
ROAD 4	Implementation cost	<p>5G will have to deal with both standard and sophisticated cyber security threats. As a road operator it will be necessary to ensure that data virtualization and cloud-based services are as airtight as possible to protect users' data and privacy.</p> <p>In relation to privacy, road operator platform should only host anonymized data from users.</p> <ul style="list-style-type: none"> Coordination between public and private actors responsible for providing V2X services is essential for the deployment of 5G infrastructure for CAM, starting with the main pan-European cross-border corridors, followed by coverage of the rest of the roads to achieve wider coverage including secondary roads and urban areas. Stakeholders in the deployment of connectivity along the CAM corridors have a common goal and that is to use 4G and 5G technology as a complement to other technologies to reduce accidents and improve emergency services, optimize traffic management, save energy and reduce CO₂ emissions. Therefore, public administrations in charge of road management and those in charge of mobile networks should work together to create synergies for the deployment of 5G technology. 	3,3	2,5	1,3
ROAD 5	Security and privacy:	<ul style="list-style-type: none"> Reused security standards and be able to be anonymized data from users. For example, in DGT 3.0 standard TLS x509 is used for security and in Data for Road Safety every data is anonymized previously by the OEMs platforms. 	3,5	1,7	2,1

6.3.2. Recommendations for cross-border environments

The possible solutions proposed by the 5G MOBIX TMT partners to the challenges identified in cross-border environments are listed below.

Table 28. Recommendations for cross-border environments.



















ID	Category	X-border Issue Title	Considered solutions
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XBI_1.1	Telecommunications	NSA Roaming interruption	1) Inter-PLMN HO using extra interface between the 2 PLMN + Release with redirect
XBI_1.2			2) Single modem with application to steer connectivity
XBI_1.3			3) Multi-modem / multi-SIM implementation
XBI_2		SA Roaming interruption	1) Requirements and proposed architecture for inter-PLMN handover with SA networks
XBI_3.1		Inter-PLMN interconnection latency	1) Considering the low latency possible with a direct connection (theoretical lower limit).
XBI_3.2			2) Comparing impact when using a shared connection (not optimized for latency, e.g., Internet based), giving a worst-case scenario
XBI_4.1		Low coverage Areas	1) Satellite connectivity
XBI_4.2			2) Multi-modem / multi-sim
XBI_4.3			3) Small cells deployment
XBI_5.1		Session & Service Continuity	1) Non-connection-oriented protocols such as UDP, when possible;
XBI_5.2			2) Resilience features related to connectivity management e.g., service discovery;
XBI_5.3			3) Disruption tolerant behaviour in what concerns state management e.g., stateless applications, context migration of state-full applications, imminent HO detection, pro-active IP change notification.
XBI_5.4			4) Pro-active communications and/or caching of static information
XBI_5.5			5) Information exchange across MEC nodes
XBI_5.6			6) Multi-modem / multi-technology solutions
XBI_5.7			7) Service continuity with make before break connections coordinated with central application function in SA network
XBI_6.1		Data routing	1) Local breakout versus Home routed for NSA 5G networks
XBI_6.2			2) Local breakouts for SA 5G networks
XBI_7.1	Telecommunication and Application	Insufficient Accuracy of GPS Positioning	1) Augmenting positioning through the use of compressed sensing techniques on the OFDM signal (improves localization accuracy where only few reference base stations are available)
XBI_7.2			2) Taking advantage of known angle-of-arrival/departure and the sparsity of mmWave channels in the angular domain substantially
XBI_8.1	Application	Dynamic QoS Continuity	1) Graceful degradation mode
XBI_8.2			2) Warning to switch to manual drive or disabling some ADAS functions
XBI_8.3			3) The service degradation is monitored at both ends by ACK messages timestamped. When QoS is not guaranteed, the remote driving application will stop the Shuttle, requiring manual drive.
XBI_9.1		Data and Protocol Stack Interoperability	1) Use of standard C-ITS messages and commonly agreed data formats for other CAM applications, such as HD-Maps updates.
XBI_9.2			2) Use of message queueing protocols (e.g., MQTT, CoAP) for disseminating the CAM information across different countries.
XBI_10.1		Geo-Constrained Information Dissemination	1) MQTT broker publisher/subscriber architecture based on quadtree tiling schemes for the geo-localized dissemination of standard ETSI C-ITS messages and other relevant CAM information.
XBI_10.1			2) Use of communications technologies holding geo-localized characteristics by design, such as PC5 or 5G sidelink, in order to implement specific use cases only requiring short-range communications, e.g., platooning.
XBI_11	Regulatory	Law enforcement interaction	1) Active involvement of Law enforcement (customs) agents in the CAM communication (reception of CAM/DENM messages) from both side of the border, and capability to override and issue autonomous driving commands (stop command to incoming vehicle)

Table 29. Solutions for Cross Border Environments challenges. Prioritization for ES-PT and GR TR CBC.

			ES_PT CBC	GR-TR CBC
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ID	X-border Issue Title	Considered solutions	U	C	F	IM PA CT	U	C	F	IMPAC T
XBI_1.1	NSA Roaming interruption	1) Inter-PLMN HO using extra interface between the 2 PLMN + Release with redirect	4,3	2,9	1,5	5	4,	2,6	1,5	4
XBI_1.2		2) Single modem with application to steer connectivity	4,0	2,5	1,6	4	3,	4,0	0,8	2
XBI_1.3		3) Multi-modem / multi-SIM implementation	3,7	2,8	1,3	4	4,	3,2	1,3	3
XBI_2	SA Roaming interruption	1) Requirements and proposed architecture for inter-PLMN handover with SA networks	4,3	2,9	1,5	5	4,	2,7	1,6	4
XBI_3.1	Inter-PLMN interconnect ion latency	1) Considering the low latency possible with a direct connection (theoretical lower limit).	4,1	2,4	1,7	5	3,	2,2	1,6	2
XBI_3.2		2) Comparing impact when using a shared connection (not optimized for latency, e.g., Internet based), giving a worst-case scenario	2,3	2	1,1	2	2,	1,4	1,8	2
XBI_4.1	Low coverage Areas	1) Satellite connectivity	3,6	3,2	1,1	4	4,	3,1	1,3	4
XBI_4.2		2) Multi-modem / multi-sim	3,7	2,8	1,3	4	3,	3,2	1,2	4
XBI_4.3		3) Small cells deployment	3,4	2,8	1,2	4	3,	1,6	2,1	2
XBI_5.1	Session & Service Continuity	1) Non-connection-oriented protocols such as UDP, when possible;	2,4	1	2,4	3	1,	1,0	1,6	1
XBI_5.2		2) Resilience features related to connectivity management e.g., service discovery;	4,9	3,4	1,4	5	3,	2,9	1,1	3
XBI_5.3		3) Disruption tolerant behaviour in what concerns state management e.g., stateless applications, context migration of state-full applications, imminent HO detection, pro-active IP change notification.	4,7	3,3	1,4	5	3,	3	1,2	3
XBI_5.4		4) Pro-active communications and/or caching of static information	4,1	2,4	1,7	4	1,	1,9	0,8	1
XBI_5.5		5) Information exchange across MEC nodes	4,7	3,2	1,5	5	4,	2,9	1,4	3
XBI_5.6		6) Multi-modem / multi-technology solutions	3,7	2,8	1,3	4	3,	3	1,3	3
XBI_5.7		7) Service continuity with make before break connections coordinated with central application function in SA network	4,9	3,3	1,5	5	4,	2,4	2,0	4
XBI_6.1	Data routing	1) Local breakout versus Home routed for NSA 5G networks	4,4	3	1,5	5	4,	1,9	2,1	4
XBI_6.2		2) Local breakouts for SA 5G networks	4,4	3	1,5	5	4,	1,9	2,4	4
XBI_7.1	Insufficient Accuracy of GPS Positioning	1) Augmenting positioning through the use of compressed sensing techniques on the OFDM signal (improves localization accuracy where only few reference base stations are available)	4,3	3,1	1,4	4	3,	2,8	1,2	4
XBI_7.2		2) Taking advantage of known angle-of-arrival/departure and the sparsity of mmWave channels in the angular domain substantially	4,3	3,1	1,4	4	3,	3,5	1,1	4
XBI_8.1	Dynamic QoS Continuity	1) Graceful degradation mode	4,6	3,5	1,3	4	3,	2,9	1,0	4
XBI_8.2		2) Warning to switch to manual drive or disabling some ADAS functions	3,3	2,2	1,5	4	3,	2,9	1,3	4
XBI_8.3		3) The service degradation is monitored at both ends by ACK messages timestamped. When QoS is not guaranteed, the remote driving application will stop the Shuttle, requiring manual drive.	2,7	2	1,4	3	3,	2,9	1,3	4
XBI_9.1	Data and Protocol Stack Interoperabil ity	1) Use of standard C-ITS messages and commonly agreed data formats for other CAM applications, such as HD-Maps updates.	4,3	1,6	2,7	5	4,	3,6	1,3	5
XBI_9.2		2) Use of message queueing protocols (e.g., MQTT, CoAP) for disseminating the CAM information across different countries.	4,3	1,1	3,9	5	3,	2,5	1,5	4

XBI_10.1	Geo- Constrained Information Dissemination	1) MQTT broker publisher/subscriber architecture based on quadtree tiling schemes for the geo-localized dissemination of standard ETSI C-ITS messages and other relevant CAM information.	 3,9	 2	 1,9	4	 3,	 3,5	 1,1	4
XBI_10.1		2) Use of communications technologies holding geo-localized characteristics by design, such as PC5 or 5G sidelink, in order to implement specific use cases only requiring short-range communications, e.g. platooning.	 4,3	 2,2	 1,9	4	 4,	 2,6	 1,8	4
XBI_11	Law enforcement interaction	1) Active involvement of Law enforcement (customs) agents in the CAM communication (reception of CAM/DENM messages) from both side of the border, and capability to override and issue autonomous driving commands (stop command to incoming vehicle)	 3,4	 2,4	 1,4	4	 4,	 2,2	 2,1	4

NOTE. Corridor Impact:

Score	Definition
1	Has not impact
2	Has little impact, brings awareness to a specific gap
3	Has average Impact - somewhat limits an existing gap
4	It has the potential to simplify CAM deployment
5	Has great Impact - will greatly help 5G for CAM deployment plan

6.3.3. Recommendations at macro-level




Table 30. Recommendations at macro-level.

ID	Area	Recommendation	U	C	F
R1	5G Architecture	Resilience in the 5G architecture needs to be guaranteed to enable a minimum level of connectivity coverage to ensure a secure and safe handover at different borders, and the vehicle architecture should handle this handover in a secure way. Even if the vehicle follows an architecture definition by standards, such as INCOSE, or ensures safety through SOTIF and ISO 26262, any vehicle functionality reliant on infrastructure to support operation will require security in the form of trusted perception from off-vehicle sources (V2X, GNSS, HD maps), for which currently no standard exists. Vehicle resilience should also consider behaviour for collisions/incidents. It is recommended that a set of standards be developed for incident investigation. Standards for teleoperation are also absent, so recommend instigating a set of standards for I2V support for teleoperation, to enable vehicle developers to understand resilience expectations. Recommend review of China standard GB/T 204-14 telematics service/management as a potential basis. There are some working groups in the IEE and ITU working on potential guidelines to tackle trials, and combine the standards from the different stakeholders, however standards to provide guidance in the deployment of the 5G architecture in the context of CAM need to be developed to facilitate collaboration between stakeholders and create a framework to develop, test and scale these deployments. Recommend a standard be formulated for this.	4,4	4,2	1,1
R2	5G Architecture	In the context of 5G architecture Integration there is an urgency to execute a set of integration objectives to support 5G for CAM applications. How quickly do these objectives need to be achieved (to gain society benefits, to justify investment in 5G or route infrastructures etc.)? A competitive landscape here is not likely to lead to an agreed international solution. These are international (and global) issues. A strong regional proposal may well be compelling on a global stage, but the proposal/solution needs to be defined and engineered to have credibility. These issues are more complex than have ever been managed traditionally (international air standards, telecom standards etc.) due to the safety and security implications. European level organizations are required (with agreed authority) to coordinate/invest/provision in these agreements. As importantly such organizations need to be funded to collaborate globally to reach agreement (or identify operational divergence and manage it). Currently there are no minimum capability standards for I2V in support of highly automated vehicles, therefore recommend establish agreed minimum viable infrastructure to support V2X for AV consistently. China activity on GB/T 102-2 Automotive intelligent, networked data structure and transmission format, will provide a potential basis for this standard that should be reviewed. Also, an alignment with e.g., GB/T 204-6 to 11 Technical requirements for security equipment and information security to integrate the 5G architecture would be recommended	4,9	4,5	1,1
R3	Road Infrastructure	There is no minimum standard road condition specification for highly automated vehicles. Highly automated vehicles' vision systems need to identify different road markings and signage markings in different member states. Road designs may need to be changed. Road maintenance standards and maintenance procedures (e.g., road works, snow clearing) are different between member states. Investigate if there are any road infrastructure requirements for highly automated vehicles, and possibility to harmonise road	3,4	2,5	1,4

		<p>markings and signage designs between member states, with minimum maintenance standards and maintenance management procedures. Any potential road modification requirements should be aligned with the Operational Design Domain standards, e.g., ISO/WD 34503 ODD.</p> <p>Similarly, any dependency on road condition should reflect back onto potential updates to this ODD standard.</p>			
R4	Road Infrastructure	<p>Journeys will benefit from continuous rather than patchy 5G coverage. There is not a clear action plan about which roads should be prioritised for continuous 5G coverage and when. Make priority list of roads to become 5G corridors, based on typical road users and potential benefits/business cases. 5G corridors should have by definition continuous 5G coverage.</p>	● 3,6	● 1,5	● 2,4
R5	Business Models	<p>Review OEMs' planned service models for highly automated vehicle updates and find aligned solution if necessary. Clarity needed about which updates will be included in sale price (assume safety related) and which may require subscription service models (assume additional/enhanced functionality). Further offboard support to vehicles, such as aided environment perception, will also need a service model, but there is currently a gap in standards for trusted perception from off-vehicle sources (V2X, GNSS, HD maps) as minimum service. Recommend this to be established.</p>	● 4,0	● 3,3	● 1,2
R6	Business Models	<p>Following on from recommendation 4. Use priority list of roads to become 5G corridors, based on typical road users and potential benefits/business cases, and develop plan for roll out of signalling upgrade, including e.g. GLOSA, using ITS-G5. As already mentioned, it is not still a clear plan to coverage with 5G and ITS-G5, to supports limited local connectivity for local traffic management improvement. Security of connectivity for highly automated vehicles will be covered by PD ISO/TR 4804:2020 Road vehicles (Safety and cybersecurity for automated driving systems. Design, verification, and validation) standard, so compatibility with this for 5G infrastructure in particular is recommended.</p> <p>Also, recommend broader integration of V2I/I2V CEN ISO/TS 19091:2019 Intelligent transport systems Cooperative ITS. (Using V2I and I2V communications for applications related to signalised intersections) standard, particularly for limited local connectivity for local traffic management improvement use cases.</p>	● 3,6	● 2,7	● 1,3
R7	Business Models	<p>MNOs are making significant investments in antenna and connection equipment, which is often duplicated by different operators. Local authorities are running tendering processes for small cell equipment. 5G bandwidth is being auctioned by governmental authorities to MNOs. Both processes are running very slowly, typically taking 12-18 months.</p> <p>This should be coordinated and accelerated.</p>	● 4,9	● 4,2	● 1,2
R8	Network	<p>Using legislation to overcome the difference in local rules and to standardise MNOs services. There should be harmonised EU rules & regulations:</p> <ol style="list-style-type: none"> 1. to facilitate the installation of 5G infrastructure, such as small cell or radio apparatus widely. 2. to define common service level agreement between MNOs for CAM applications. <p>Cross-border harmonisation issues may arise in cases of countries that do not implement the ECC/DEC/(15)01 decision on "Harmonised technical conditions for mobile/fixed communications networks (MFCN) in the band 694-790 MHz including a paired frequency arrangement (Frequency Division Duplex 2x30 MHz) and an optional unpaired frequency arrangement (Supplemental Downlink)" e.g. Bulgaria. Frequency harmonisation is a necessary component of CAM, otherwise there is the risk that automated capabilities will not be available across a hard border.</p>	● 4,9	● 4,6	● 1,1

		3. to have a common slicing strategy for V2X application. Recommendation 7 is quite link to recommendation 8 so it would be recommended to undertake the work scope in sequence.			
R9	Network	<p>A specific plan needs to be in place from any member state prior to the spectrum auctions to enable telco operators to make appropriate plans for 5G deployments. A flexible mechanism should be in place to enable leasing of additional frequencies and the additional licensing processes for the development of infrastructure (e.g., antenna placement etc.) should be fast.</p> <p>The members of state plan need to ensure a share infrastructure to reduce cost and to have a set of commonly defined service level agreement in order to maintain the V2X performance cross regions and borders. Recommendation 7 is quite link to recommendation 9 so it would be recommended to undertake the work scope in sequence.</p>	● 4,6	● 4,6	● 1,0
R10	Network	<p>As 5G connection/ quality can never be 100% guaranteed, the vehicle itself should have safety mechanisms to control the vehicle safely in case of 5G connection missing or deteriorated. It is common functional safety practice. Although stable 5G connection helps to improve CAM safety, the vehicle itself should have redundancy and safety mechanism in case of 5Gservice degradation. Recommend that levels of 5G availability be determined, for which vehicle expectations can be defined. Suggest this is incorporated with development of the standard ISO AWI TR 23254 Intelligent transport systems – Architecture - Use cases and high-level reference architecture for connected automated vehicles.</p>	● 2,6	● 1,5	● 1,7
R11	Stakeholder collaboration	<p>The 5G implementation in a CAM environment represent a complex challenge with a number of noise factors that need to evaluate and prioritizes in order to develop a roadmap to tackle and solve some of these challenges with a comprehensive investment plan. This road map should review each of the areas highlight in these recommendations and provide a 5-year roadmap to ensure that the legal, investment and technology ecosystems in EU has a the capacity and the ecosystems to be ready to implement the 5G in a CAM environment. 5GMobix has highlighted the main challenges that we are facing in order to deploy these technologies and it would be providing a prioritization of these recommendations however there is a wider initiative outside of the scope of 5GMobix to work on a strategic roadmap to prioritise and solve some of these challenges with the right stakeholders in the EU.</p>	● 4,0	● 5	● 0,8
R12	Legal & Standards	<p>Recommend digitalisation of all the regional traffic rules. When the vehicle travels between member states, the relevant digital highway code should be available to the vehicle and applied. This is currently missing. Recommend all member states' highway codes are digitised. Also recommend decision if these should be incorporated with ODD activities or kept separate.</p> <p>Recommend development of a standard for teleoperation of CAM vehicles to avoid any ambiguity about maturity of development or enabling framework. This is currently recognised as a gap.</p> <p>Recommend standard to specify CAM vehicle in-use monitoring, including sensor performance. ITU – Focus Group on AI for autonomous and assisted driving (FG-AI4AD) – Monitoring in use, and others, have identified this gap.</p> <p>Recommend development of a standard for off-vehicle information, such as an initiative to establish 'Trusted perception from off-vehicle sources (V2X, GNSS, HD maps)'.</p> <p>Recommend definition and commissioning of dedicated testbeds for CAM trialling in real world conditions, potentially in tandem with definition of 5G corridors.</p>	● 4,4	● 3,9	● 1,1
R13	Legal & Standards	<p>Recommend harmonisation of EU rules and regulations to facilitate the widespread installation of integrated 5G infrastructure.</p>	● 4,7	● 4,2	● 1,1

		<p>Recommend the EU 5G EMF limits standard be developed together with the European public health organisations. Public Health organisations typically take the lead on public health matters associated with radiofrequency electromagnetic fields, or radio waves, including in relation to 5G. A typical position is that "The overall exposure [from all mobile network EMFs, including 5G] is expected to remain low relative to guidelines and, as such, there should be no consequences for public health." A consensus will be needed between all member states' public health organisations.</p> <p>Only DSRC currently has EU approved for V2X applications. To ensure the success of 5G-based CAM applications, recommend C-V2X be approved by the EU.</p>			
R14	Legal Standards &	<p>This class of technical definition is largely being addressed in other forums. The correct choice of an appropriate set of extensible standards and rules still has to be made in the context of the working objectives and safety criteria for the system/infrastructure. The UN Economics and Social council and the World forum for Harmonization of Vehicle Regulations has approved in June 2020 the resolution (ECE/TRANS/WP.29/2020/79). The two new UN Regulations, adopted by UNECE's World Forum for Harmonization of Vehicle Regulations, require that measures be implemented across 4 distinct disciplines:</p> <ol style="list-style-type: none"> 1.Managing vehicle cyber risks. 2. Securing vehicles by design to mitigate risks along the value chain. 3.Detecting and responding to security incidents across vehicle fleet. 4. Providing safe and secure software updates and ensuring vehicle safety is not compromised, introducing a legal basis for so-called "Over-the-Air" (O.T.A.) updates to on-board vehicle software. <p>The regulations will apply to passenger cars, vans, trucks, and buses. They will enter into force in January 2021.Despite this and having some guidance related to 5G deployment for connected vehicles and data there is still significant work to be done to have a more harmonized set of standards and guidance's on:</p> <p>GDPR: Recommend developing a standard to ensure all data sharing complies to GDPR, referring to AP-C100-17 Privacy Impact Assessment (PIA) for Cooperative Intelligent Transport System (C-ITS) data messages. Also develop guidelines to encourage widespread data sharing while complying to GDPR.</p> <p>Data Structure & Transmission: Recommend investigating the potential to standardise CAM data structure and data transmission format. The China standard 'GB/T 102-2 Automotive intelligent, networked data structure and transmission format' should be reviewed as a potential basis for this.</p> <p>Ethics: Recommend investigating potential alignment on Ethics of AI in CAM applications, referring to:</p> <ul style="list-style-type: none"> - IEEE P2846: Assumptions for Models in Safety-Related Automated Vehicle Behaviour, - BS 8611: Robots and robotic devices. Guide to the ethical design and application of robots and robotic systems, - IEEE P7001 - Draft Standard for Transparency of Autonomous Systems, - CAN/CIOSC 101: Ethical design and use of automated decision systems. <p>Security: Strongly recommend applying existing security standards to CAM across all member states, including but not limited to:</p> <ul style="list-style-type: none"> - SAE J2945/5: Service Specific Permissions and Security Guidelines for Connected Vehicle Applications, - SAE J3005-2 Diagnostics: Permanently or Semi-Permanently Installed Diagnostic Communication Devices, Security Guidelines, 	<div> <div></div> 5,0 </div> <div> <div></div> 3,9 </div> <div> <div></div> 1,3 </div>		

		<ul style="list-style-type: none"> - BS EN 17529: Data protection and privacy by design and by default, - ISO/TR 4804: Road vehicles — Safety and cybersecurity for automated driving systems — Design, verification, and validation, - ISO/TR 21186-3: Cooperative intelligent transport systems (C-ITS) — Guidelines on the usage of standards — Part 3: Security, - ISO/DAPS 5112: Road vehicles — Guidelines for auditing cybersecurity engineering, - ISO/IEC 27007: Information technology — Security techniques — Guidelines for information security management systems auditing, - ISO/IEC 27034: — Information technology — Security techniques — Application security, - ISO/IEC 19790: Information technology — Security techniques — Security requirements for cryptographic modules, - ISO 20828: Road vehicles — Security certificate management, - ISO/TS 21185: Intelligent transport systems — Communication profiles for secure connections between trusted devices, - ISO/TS 21177: Intelligent transport systems — ITS station security services for secure session establishment and authentication between trusted devices, - ETSI - TS 102 731: Intelligent Transport Systems (ITS); Security; Security Services and Architecture. 			
R15	Stakeholder collaboration	<p>Collaboration between the stakeholders is key in the implementation and deployment of these technologies, however if there is not a roadmap of implantation and harmonization of legislation, standardisation, and guidance it would be a challenge to ensure that the collaboration is unbiased and fair for the ecosystem. After reviewing all the challenges on the 5GMOBIX we would recommend that to ensure a more robust collaboration between different stakeholders a roadmap to implement the necessary legal and collaborate framework to ensure collaboration need to be created at European level. That body should be leading the standardization and legislation road map and develop a collaboration framework to provide guidance to the members of state, develop a fair competitiveness amount the stakeholders and ensure the security and safety of the EU Citizens as well as managing the investment plan to ensure the acceleration of the technology deployment and positioning Europe as a technology leader in 5G for CAM.</p>	 5,0	 4,5	 1,1

6.3.4. Macro-level Recommendations Implementation Approach

The macro-level recommendations prioritise and group the recommendations that the Commission needs to develop an action plan at European level to achieve the 5G CAM deployment. Based on the prioritisation criteria and the evaluation of the 15 macro-level recommendations, this chapter is aiming to provide an approach and guidance to the implementation of the recommendations based on utilisation vs cost. The evaluation (see in the figure bellow) highlights that there are two distinctive groups of recommendations that need to be prioritised to develop policies and initiatives to reduce the technological gap (move from TLR 6 to TRL 8) and align the industry to create a legal and operational framework to deploy 5G for CAM in Europe.



Figure 3. Macro-level recommendations. Utility vs Lifecycle Cost Score.

The recommendations with more significant impact (highlighted in red above) define the areas where the technological gap, value add for the industry and stakeholders are more significant. Implementing these recommendations has a higher cost as the gap in technology development and legislation is greater.

Also, these recommendations are time critical. The time to market criticality defines the necessity for the stakeholders and market to implement and deploy these recommendations; in order to be competitive and

allow stakeholders to deploy their services for the end users. In our evaluation criteria and conversations with the industry, these recommendations were also highlighted as critical and necessary to solve between 2021 and 2025.

Industry experts highlight that in 2025 vehicle manufactures would need to have a legislation and collaboration framework to allow deployment of their products. However, if the networks and governments in Europe do not have some of the infrastructure and legislation in place it could have socio-economic impact to the European region. The European market would become less attractive to the industry and would make the EU a follower of policies and frameworks created by the USA and China.

The recommendations highlighted in yellow highlight that that road infrastructure is also highly important for the deployment of the 5G for CAM. These recommendations are quite dependent on the 5G network deployment, architecture, and legislation.

Even the utility vs cost is greater in the application of these recommendations, which are dependent on those highlighted in red.

Implementation Approach:

Most of the feedback received from industry experts as well as the internal 5G MOBIX issues in the corridors, highlighted that there is a need for more collaboration between the stakeholders in order to reduce the technological gaps and accelerate legislation to create a European framework for collaboration.

The main key recommendation evaluation also highlights that in order to be competitive with other markets and provide the value added to the end customer, there is a need for investment in a vehicle that accelerates those European ecosystems and closes the technological gap. That would allow us to be leaders in the deployment of 5G for CAM.

In addition, to implementing recommendations, we should also create what we call the 5G for CCAM task force which will define and implement a plan of action over the next 2 years.

We have defined a two-stage approach highlighting the steps needing development in order to implement these recommendations into solutions that can be deployed at scale in the European Union.

Phase A: Design and define the European framework of collaboration to ensure the acceleration of 5G deployment for CAM.

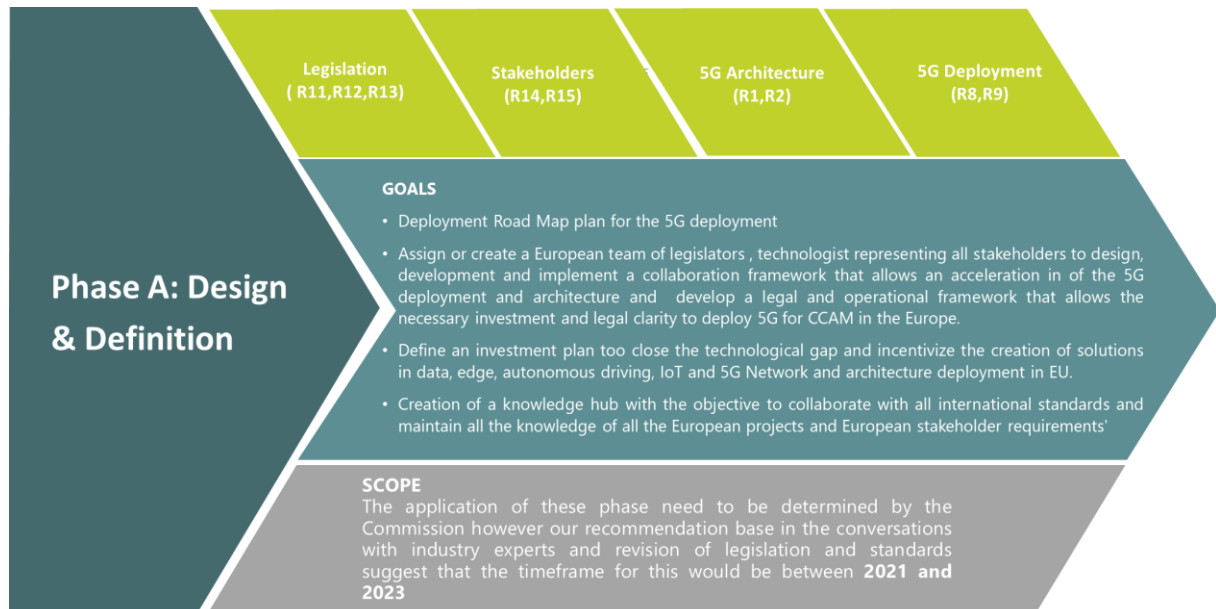


Figure 4. Phase A: Design and Definition.

Phase B: Implementation of the European framework of collaboration to ensure the acceleration of 5G deployment for CAM

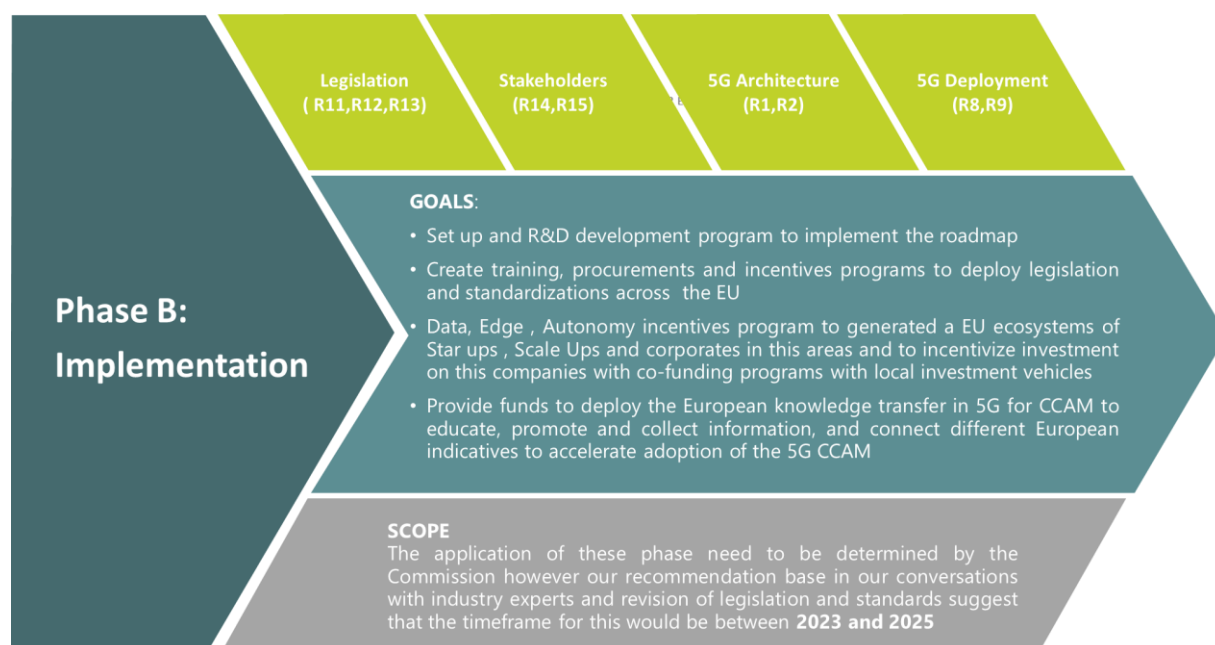


Figure 5. Phase B: Implementation.

6.3.5. Recommendations for additional research

Based on the preliminary analysis performed in the previous chapters, 5G-MOBIX identified key innovations in main areas that can combat specific gaps and issues in 5G for CAM. The required innovations² are included in the following tables. The selection of time horizon is indicative and has been assessed by the 5G-MOBIX consortium. Continuing analysis during the project lifecycle will produce a coherent technical and research.

Table 31. Fundamental innovations required for Enhanced Mobility.

Area of Work	High Mobility	
Target	Ensure that disruptions to services are minimal in high mobility scenarios, focusing on issues of roaming, coverage, handover and definition of boundary conditions.	
Action	Time horizon	
1. Research in the optimisation of handover used in SA and NSA deployments and their effects on URLLC/eMBB/mMTC services.	2020-2023	
2. Research in the optimisation of roaming mechanisms in SA and NSA deployments	2020-2023	
3. Trialling scenarios of mixed traffic (automated & legacy), scaled to larger traffic volumes. Consider boundary conditions that might exist with respect to the network and with traffic management.	2020-2025	
4. Optimisation of coverage.	2020-2025	

² In order to maintain research coherence, 5G-MOBIX adopts the template used during preliminary stages of the Transport Research and Innovation Mobility Package <https://ec.europa.eu/transport/sites/transport/files/swd20170223-transportresearchandinnovationtomobilitypackage.pdf>

Table 32. Fundamental innovations required for Service Continuity.

Area of Work	Service Continuity	
Target	Ensure service continuity and high availability (5-nines for non-critical, 7-nines for critical services)	
Action		Time horizon
1. Improvements in lifecycle management and service placement through an ETSI-compliant Management and Orchestration (MANO) framework.		2020-2023
2. Health monitoring & Fault Management in order to ensure that reliability and availability criteria are met. Validation of CAM cases in fault injection scenario.		2020-2023
3. Resource utilisation & performance optimisation in order to ensure that critical services are never resource-starved, even in highly dynamic scenarios. Scalability and Reliability KPIs validation.		2020-2023
4. Monitoring for CAM Billing & Accounting: In elastic provisioning scenarios, resource-based or instantiation-based billing models can be foreseen. In any case, a monitoring framework needs to be in place to ensure fair billing and account management.		2020-2023
5. Standardised specifications for CAM Services need to include not only baseline technical information, but also boundary conditions with respect to resources that define when a service is operating within its normal parameters.		2020-2023

Table 33. Fundamental innovations required for CAM Cybersecurity.

Area of Work	Cybersecurity	
Target	To create a holistic cybersecurity framework that is aligned with the ENISA guidelines for secure connected and automated vehicles	
Action		Time horizon
1. The starting point should be a holistic risk assessment that includes all digital assets in a 5G/CAM scenario, including all infrastructures (5G/Edge), RSU/OBUs, Vehicles, and data flows.		2020-2023
2. Advanced methods like anomaly detection and hardware root-of-trust should be utilised along traditional perimeter defences (e.g., firewalls, intrusion detection etc.).		2020-2023
3. Critical validation in CAM "Cyber Range" testbeds with penetration testing. The effects of cybersecurity measures to latency and CAM performance must be assessed.		2020-2023
4. Definition of cybersecurity liabilities and cyber insurance.		2020-2025

Table 34. Fundamental innovations required for Improved Planning & Financing.

Area of Work	Planning & Financing	
Target	To improve planning of infrastructure and optimise costs. Cooperative planning and cost/benefit approaches should be complemented by cash flow monitoring.	
Action		Time horizon
1. Cost optimisation using simulation tools to assess coverage, should be available to all actors in the ecosystem. Advanced simulation to include traffic patterns and telecommunication KPIs.		2020-2023
2. Billing & Accounting for CAM services so that every user or industry can track both their expenses and their revenues. As CAM services can create a highly dynamic ecosystem, all users should be able to track money flows.		2020-2023
3. Cooperative funding between multiple industries that benefit from CAM (e.g., insurance, logistics etc.) and not only from the traditional CAM actors (e.g., ICT, road operators, telcos etc.).		2020-2025
4. Connecting road operators with other travel and logistics hubs (e.g., borders, ports, airports etc.).		2020-2025

Table 35. Fundamental innovations required for Data Access Democratization.

Area of Work	Data Access Democratisation	
Target	Improve cooperation among actors and commercialisation of new CAM cases by removing data barriers.	
Action		Time horizon

1. Use of AI and analytics for operational insight: this needs to be complemented with efforts to ensure data quality and responsible AI practices.	2020-2023
2. Setting a framework for standardised data formats can increase cooperation among actors.	2020-2023
3. Access of non-ICT stakeholders to a data economy can incentivise multiple industries to invest in 5G for CAM.	2020-2025
4. Ensure data protection across borders and actors. Setting common guidelines for 5G for CAM for each actor, including cases where Joint Controllers are required.	2020-2023
5. Foster a data economy by combatting GDPR fragmentation and promoting a "GDPR as an innovation framework" policy, showing how GDPR can be leveraged instead of being perceived as a barrier.	2020-2025
6. Improve access of public authorities and LEAs to data: specifically address requirements set by the NIS and Open Data Directives.	2020-2025

Table 36. Fundamental innovations required for CAM Data Pilots.

Area of Work	CAM Data Pilots	
Target	Improve experimentation with CAM Big Data.	
Action		Time horizon
1. Ethical Data Proxies		2020-2023
2. Ensuring Data Quality		2020-2023
3. Access of third parties to the data economy, to build Mobility-as-a-Service applications		2020-2025
4. Business plans and sustainability for services relying on CAM data		2020-2023
5. Improve access of public authorities and LEAs to CAM data for crime investigations		2020-2025

Table 37. Fundamental innovations required for Next Generation Traffic Management.

Area of Work	Next-generation traffic management	
Target	Improve experimentation with CAM Big Data.	
Action		Time horizon
1. Data interoperability between TM centres and connected vehicles, among Traffic Managers and among TM centres and other stakeholders like municipalities, transport companies (e.g., ridesharing platforms, logistics/freight, demand-responsive transport etc.)		2020-2025
2. Smart re-routing of traffic in case of a scheduled event (e.g., sports, concerts, road works etc.) and unscheduled (e.g., accident, failure of infrastructure, extreme weather etc.)		2020-2023
3. Reconciling TM-optimal with user-optimal routes		2020-2025

7. CONCLUSIONS

The fifth-generation cellular wireless, 5G, is born as a revolution in comparison with 4G; new aspects like wider channels, lower latency, and the ability to connect a lot more devices at the same time and in a limited area are some contributions of this new technology to the current wireless world.

The connected and automated mobility (CAM) demands huge data amounts, a reliable responsiveness, and the capacity for connection of several multiple sensors and video devices. All these requirements pose a challenge for wireless communications and 5G networks can offer a response for these dares thanks to services like enhanced mobile broadband (eMBB) which provides data rates of 1 Gbps, ultra-reliable low-latency communications (URLLC), end-to-end latency of less than 10 ms and massive machine-type communications (mMTC) which allows the connection of a huge number of devices. The diversity of Use Cases related to CAM makes it difficult to present the general requirements, but, in general terms, low latency, high bandwidth, appropriate coverage and high reliability are the most important to consider.

With the aim of accelerating its deployment, the “5G Strategic Deployment Agenda for CAM” sets the “shared view of a wide group of industry stakeholders supporting the objectives of the 5G Strategic Deployment Agenda (SDA)”. The 5G SDA for CAM revolves around the deployment objectives, cooperation models and regulatory innovations as its main elements and envisions that deployment of 5G is a major enabler for commercial as well as safety services, due to improved speed and reliability.

At the infrastructure level, and beyond the spectrum frequencies, automating driving requires additional infrastructure to be a safe mobility system from point of view of the telecommunication network, RAN (Radio Access Network), MEC (Multi-access Edge computing), Core and transport network are the main components in 5G networks. Their characteristics and configurations are detailed in this deliverable, as well as the currently available frequencies and possible agreements between telecom operators.

In relation to the latter, the main options are:

- Passive sharing, in which the equipment shared is limited to the passive network elements.
- Active sharing extends the list of shared equipment to include the transport infrastructure, baseband processing resources, and potentially the radio spectrum.

Among other advantages, significant savings at both investment and operational levels can be achieved through these models. However, there is still reluctance on the part of MNOs to incorporate these models into their strategies. But not only MNOs and end users are part of the 5G value chain; numerous stakeholders from the Automotive and 5G Industries have interests in this market, as well as Road Operators and all of them are framed in the legislation and regulations developed by Policy Makers and Standards Developing Organizations. This provides an insight into the complexity of the 5G for CAM value chain.

In economic terms, given the difficulty of reflecting technology deployment costs due to the emerging state of the same and the strict confidentiality agreements with which telecommunication operators play, bibliographic costs were presented.

The issues, barriers and challenges have been identified by the consortium, so the 5G partnership has provided recommendations to overcome them based on its previous experience and that gained in the 5G MOBIX project up to date. These recommendations have been validated through macro-level recommendations from external stakeholders who are directly involved in the 5G for CAM technology under study at the industrial level. In addition, the identification of possible activities to encourage deployment has begun from two points of view:

- from "Local to Project", which aims to create concrete links with innovations that can benefit from and to 5G-MOBIX and that are developed at a national level for each of the countries represented by the consortium.
- from "Project to Global", which aims to support the market take-up of the innovations and services that are demonstrated in the project use cases. This support will be done by reaching concrete agreements to support the post-project exploitation plan, considering innovators, technology adopters/customers, and private investors. Concrete recommendations on how to deploy the innovations according to the targeted use-cases or to address the project's issues are also expected.

The result of this work initiated in the present document will be presented in the, as already mentioned, in D6.5. To finish, based on the preliminary analysis performed, 5G-MOBIX identified key innovations in several areas that can combat specific gaps and issues in 5G for CAM and the predictive plan for the deployment of 5G technology for CAM is presented. WP6 plans to reiterate and validate this view with the participation of related stakeholders during the project lifetime.

8. REFERENCES

- [1] EC, "Discussion within the European ITS Committee on Cross-border testing," [Online]. Available: <https://ec.europa.eu/transport/sites/transport/files/its-committee-cross-border-testing-scoping-document.pdf>.
- [2] X. C.-P. V. S. Konstantinos Samdanis, "From Network Sharing to Multi-tenancy: The 5G NEtwork Slice Broker. NEC Europe Ltd. Germany".
- [3] [Online]. Available: <http://www.techplayon.com/5g-network-sharing-concept-benefits-and-architectures/>.
- [4] "Techplayon," [Online]. Available: <http://www.techplayon.com/5g-network-sharing-concept-benefits-and-architectures/>.
- [5] "GSMA," [Online]. Available: https://www.gsma.com/futurenetworks/wiki/infrastructure-sharing-an-overview/#_ftnref3.
- [6] Booz&Co, "Sharing Mobile Networks Why the Pros Outweigh the Cons".
- [7] [Online]. Available: <https://www.nokia.com/about-us/news/releases/2020/03/04/nokia-telenor-and-telia-create-the-worlds-most-advanced-shared-wireless-network-in-denmark/#:~:text=This%20trial%20highlights%20that%20through,to%20businesses%20and%20consumers%20quickly.&text=Netwo>.
- [8] 5GPPP, "5G PPP Automotive Working Group «Business Feasibility Study for 5G V2X Deployment» pp. 7, version 2.," February 2019. .
- [9] B. B. E. C. D. C. E.-F. C. Systems, "5G for Cooperative Connected and Automated Mobility.," in *9th ETSI ITS Workshop.* , Berlin, 7 March 2018.
- [10] 5GAA, "CITS Vehicle to infrastructure Services: how C-V2X technology completely changes the cost equation for road operators. White Paper.".
- [11] ENISA, "Report on Recommendations for the Security of Connected and Automated Mobility," 2020.
- [12] "5G SDA for Connected and Automated Mobility in Europe.," 2019.
- [13] I. Skog, "In-Car Positioning and Navigation Technologies - A Survey.," in *IEEE trans on Intelligent Transportation.* , 2009.
- [14] K. Jo, "GPS-Bias Correction for Precise Localization of Autonomous Vehicles," in *IEEE*.
- [15] J. Borenstein, . H. R. Everett, . L. Feng and D. Wehe, "Mobile robot positioning sensors and techniques," *J. Robot. Syst*, vol. vol. 14, p. pp. 231–249.
- [16] X. F. C. L. J. W. L. L. D. D.]Yahui Liu, "An Innovative Information Fusion Method with Adaptive Kalman Filtering for Integrated INS/GPS Navigation of Autonomous Vehicles".

- [17] E. M. N. a. H. F. D.-W. Salah Sukkarieh, "A High Integrity IMU/GPS Navigation Loop for Autonomous Land Vehicle Applications".
- [18] S. F. K. K. M. D. F. M. a. A. M. S. Kuutti, "A Survey of the State-of-the-Art Localization Techniques and Their Potentials for Autonomous Vehicle Applications," *IEEE Internet of Things Journal*, vol. vol. 5, no. no. 2, p. pp. 829–8.
- [19] R. K. a. S. P. I. K. Jain, "Driven by Capacity or Blockage? A Millimeter Wave Blockage Analysis," in *30th International Teletraffic Congress (ITC 30)*, IEEE, Vienna, Sep. 2018.
- [20] S. S. MOSTAFAVI, *Vehicular Positioning Using 5G and Sensor Fusion*, Stockholm, 2019.
- [21] "Transforming Transport," [Online]. Available: <https://transformingtransport.eu/>. [Accessed April 2020].
- [22] Transforming Transport Consortium, "D3.13 Policy Recommendations," 2019.
- [23] Transforming Transport Consortium, "D2.4 Lessons learned from cross-pilot analysis," 2019.
- [24] The European Parliament and the Council of the European Union, "Directive (EU) 2019/1024 of the European Parliament and of the Council of 20 June 2019 on open data and the re-use of public sector information," *Official Journal of the European Union*, vol. L 172/56, 2019.
- [25] The European Parliament and the Council of the European Union, "Directive 2003/98/EC of the European Parliament and of the Council of 17 November 2003 on the re-use of public sector information," *Journal of the European Union*, vol. L345, pp. 90-96, 2003.
- [26] "EU Guidelines for responsible AI," [Online]. Available: <https://ec.europa.eu/digital-single-market/en/news/ethics-guidelines-trustworthy-ai>. [Accessed April 2020].
- [27] "Digital Single Market: Shaping Europe's digital future," [Online]. Available: <https://ec.europa.eu/digital-single-market/en>. [Accessed April 2020].
- [28] The SHIELD Consortium, "SHIELD: Securing against intruders and other threats through a NFV-enabled environment," [Online]. Available: <https://torsec.github.io/shield-h2020/>. [Accessed April 2020].
- [29] "nIoVe - A Novel Adaptive Cybersecurity Framework for the Internet-of-Vehicles," [Online]. Available: <https://www.niove.eu/>. [Accessed April 2020].
- [30] "H2020 Caramel - Artificial Intelligence-based cybersecurity for Connected and Automated Vehicles," [Online]. Available: <https://www.h2020caramel.eu/>. [Accessed April 2020].
- [31] The Headstart Consortium, "Headstart - Harmonised European Solutions for Testing Automated Road Transport," [Online]. Available: <https://www.headstart-project.eu/about/>. [Accessed April 2020].
- [32] The ANASTACIA Consortium, "ANASTACIA - Advanced Networked Agents for Security and Trust Assessment," [Online]. Available: <http://www.anastacia-h2020.eu/>. [Accessed April 2020].

- [33] "The DIAS platforms," [Online]. Available: <https://www.youtube.com/watch?v=uetFO7y8WPA&t=5622s>. [Accessed April 2020].
- [34] FOT-Net and CARTRE, "FESTA Handbook v7," 2018.
- [35] 5GAA, "Whitepaper on CV2X roadmap," 2019.
- [36] NGMN, "V2X Whitepaper v1.0," 2018.
- [37] "Internet Of Business," [Online]. Available: <https://internetofbusiness.com/worldwide-connected-car-market-to-top-125-million-by-2022/>.
- [38] "3GPP," [Online]. Available: <https://www.3gpp.org/specifications/releases>.
- [39] "Land Mobile, Wireless Communications for Business," Sam Fenwick, 19 December 2018. [Online]. Available: <https://www.landmobile.co.uk/news/release-15-delayed-3gpp-5g>.
- [40] C. Sbeglia, "RCR Wireless News," 26 March 2020. [Online]. Available: <https://www.rcrwireless.com/20200326/5g/3gpp-delays-5g-updates-covid-19>.
- [41] "OOKLA 5G MAP," [Online]. Available: <https://www.speedtest.net/ookla-5g-map>.
- [42] M. Bayern, "Tech Republic," 12 March 2020. [Online]. Available: <https://www.techrepublic.com/article/37-of-mobile-operators-will-deploy-5g-standalone-within-two-years>.
- [43] *Vehicle Positioning Using 5G Millimeter-Wave Systems*, October 2016.
- [44] Uplink Contention Based SCMA for 5G Radio Access, 2014.
- [45] Towards a Cost Optimal Design for a 5G Mobile Core Network Based on SDN and NFV, December 2017.
- [46] *SDN Enabled 5G-VANET: Adaptive Vehicle Clustering and Beamformed Transmission for Aggregated Traffic*, July 2017.
- [47] Radio Propagation Path Loss Models for 5G Cellular Networks in the 28 GHz and 38 GHz Millimeter-Wave Bands, September 2014.
- [48] *MEC-aware Cell Association for 5G Heterogeneous Networks*, 2018.
- [49] Latency Critical IoT Applications in 5G: Perspective on the Design of Radio Interface and Network Architecture, February 2017.
- [50] Coalitional Game for the Creation of Efficient Virtual Core Network Slices in 5G Mobile Systems, March 2018.
- [51] *5G-MiEdge: Design, Standardization and Deployment of 5G Phase II Technologies*, 2017.
- [52] "EXCITING Panorama tool," February 2020.. [Online]. Available: <https://panorama.euchina-iot5g.eu/exciting>.
- [53] "Dragon Star: "HORIZON 2020 - What's in for China?" ,,," February 2020. [Online]. Available: <http://www.dragon-star.eu/h2020-and-china>.
- [54] "5GCROCO," February 2020. [Online]. Available: <https://5gcroco.eu/>.

- [55] "GSMA and CAICT "5G in China: Outlook and regional comparisons", February 2020. [Online]. Available: <https://www.gsmaintelligence.com/research/?file=67a750f6114580b86045a6a0f9587eao&download>.
- [56] "5G PPP, 5G Infrastructure Public Private Partnership," February 2020. [Online]. Available: <https://5g-ppp.eu/>.
- [57] "cablefree," [Online]. Available: <https://www.cablefree.net/wirelesstechnology/4glte/lte-4g-5g-radio-access-network-ran/>.
- [58] GSMA, "Operator Requirements for 5G Core Connectivity Options May 2019," May 2019.
- [59] "ETSI," [Online]. Available: <https://www.etsi.org/technologies/multi-access-edge-computing>.
- [60] X. C.-P. V. S. Konstantinos Samdanis, From Network Sharing to Multi-tenancy: The 5G Network Slice Broker. NEC Europe Ltd, Germany.
- [61] 5. MOBIX, "H2020-ICT18-5GMOBIX D6.2 Foster Adoption New Business Models for 5G & CCAM," 2020.
- [62] "5G Observatory," [Online]. Available: <https://5gobservatory.eu/market-developments/5g-services/>.
- [63] "Europarl," [Online]. Available: [https://www.europarl.europa.eu/RegData/etudes/IDAN/2019/631060/IPOL_IDA\(2019\)631060_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/IDAN/2019/631060/IPOL_IDA(2019)631060_EN.pdf).
- [64] "Ookla 5G," [Online]. Available: <https://www.speedtest.net/ookla-5g-map>.
- [65] 5GAA, "Timeline for deployment of C-V2X," 2019. [Online]. Available: <https://5gaa.org/news/5gaa-releases-updated-white-paper-on-c-v2x-deployment-timeline>.
- [66] R. E. & E. ... S. f. 5GAA., "Study on the Deployment of C-ITS in Europe: Final Report Framework Contract on Impact Assessment and Evaluation Studies in the Field of Transport MOVE/A3/119-2013-Lot N° 5 "Horizontal", 2016.
- [67] R. E. & Environment, "Cost Analysis of V2I Deployment. Final Report. Report for 5GAA," 2020.
- [68] S. a. Q. o. L. P.). Colin BLACKMAN and Simon FORGE (Policy Department for Economic, "Methodology of Investment in 5G network".
- [69] 5. P. A. W. Group, " Business Feasibility Study for 5G V2X Deployment. Version 2.," February 2019.
- [70] "EuropaRL," [Online]. Available: [https://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL_IDA\(2019\)631060](https://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL_IDA(2019)631060).
- [71] GSMA, "The 5G Guide: A reference for Operators.," April 2019.

9. ANNEXES

9.1. Prioritisation of the recommendations.

The results of the prioritization analysis are presented below:

9.1.1. Microlevel prioritisation

Table 38. Micro-level recommendations. Score.

ID	Utility Score	Lifecycle Cost factor	FINAL SCORE
DEP1	3,5	3,4	1,0
DEP2	3,0	2,0	1,5
DEP3	4,3	3,5	1,2
DEP4	4,3	3,6	1,2
DEP5	4,0	3,0	1,3
DEP6	4,7	3,2	1,5
DEP7	4,0	2,6	1,5
DEP8	3,5	2,5	1,4
DEP9	3,7	2,4	1,5
DEP10	3,2	2,5	1,4
DEP11	4,7	3,3	1,4
DEP12	3,0	2,4	1,3
DEP13	3,5	3,4	1,0
DEP14	3,7	2,1	1,7
DEP15	4,0	3,0	1,3
DEP17	4,2	2,2	1,9
DEP18	3,8	1,7	2,3
DQ-V1	4,0	1,8	2,2
DQ-V2	3,8	1,8	2,1
DQ-V3	3,5	1,5	2,3
DQ-V4	2,7	1,0	2,7
DQ-V5	4,2	3,7	1,1
DPM1	3,8	2,9	1,3
DPM2	3,3	1,8	1,9
DPM3	4,0	3,7	1,1
DPM4	4,0	3,5	1,1

ID	Utility Score	Lifecycle Cost factor	FINAL SCORE
AI1.1	4,7	2,3	2,0
AI1.2	4,7	2,9	1,6
AI1.3	4,7	3,1	1,5
AI2	4,7	3,4	1,4
AI3	4,7	3,2	1,5
AI4	4,7	3,2	1,5
AI5	4,7	3,2	1,5
AI6	3,3	1,6	2,1
AI7	3,0	2,7	1,1
AI8	4,2	2,6	1,6
AI9	4,2	2,2	1,9
AI10	4,2	2,3	1,8
AI11	4,3	2,0	2,2
AI12	3,8	1,8	2,1
AI13	4,0	2,4	1,7
AI14	3,7	2,9	1,3
AI15	4,5	2,6	1,7

ID	Utility Score	Lifecycle Cost factor	FINAL SCORE
AI & CAM1	2,8	1,8	1,6
AI & CAM2	4,2	2,2	1,9
AI & CAM3	2,5	1,7	1,5
AI & CAM4	4,0	2,8	1,4
AI & CAM5	3,8	3,1	1,2
AI & CAM6	3,8	2,6	1,5
AI & CAM7	4,0	3,1	1,3
AI & CAM8	3,2	2,0	1,6
AI & CAM9	3,3	2,2	1,5
AI & CAM10	3,2	1,7	1,9
AI & CAM11	3,2	1,7	1,9
AI & CAM12	3,7	2,5	1,5
CB 1	4,0	3,1	1,3
CB 2	4,0	2,4	1,7
CB 3	3,8	3,1	1,2
CB 4	3,7	3,0	1,2
ROAD 1	4,2	2,5	1,7
ROAD 2	4,2	3,2	1,3
ROAD 3	3,2	1,7	1,9
ROAD 4	3,3	2,5	1,3
ROAD 5	3,5	1,7	2,1

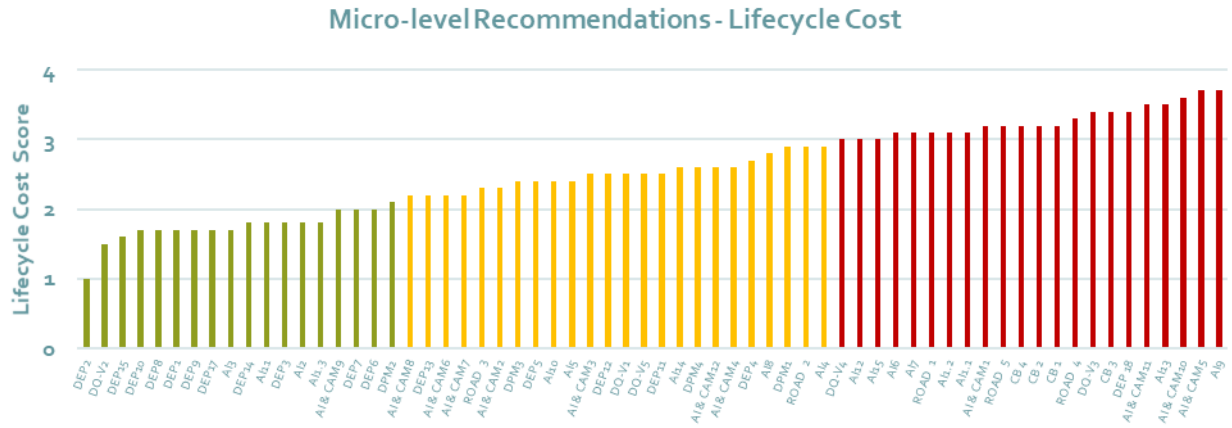


Figure 6. Micro-level recommendation vs Utility.

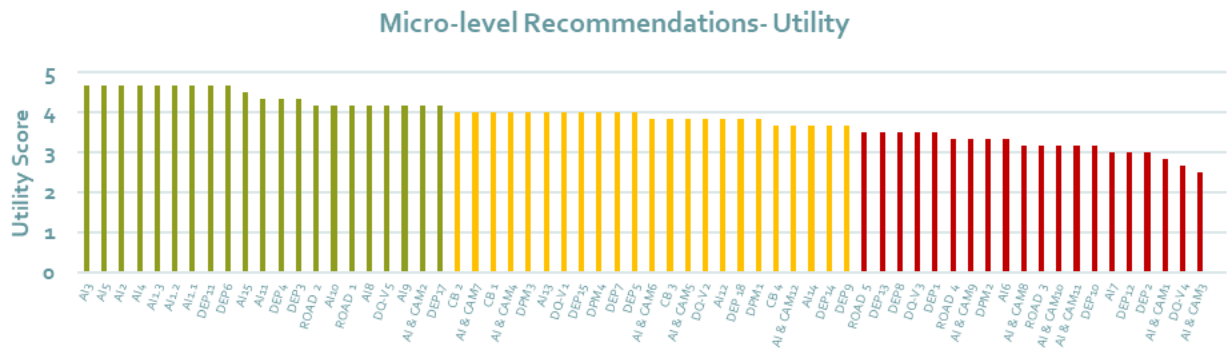


Figure 7. Micro-level Recommendations vs Lifecycle cost.

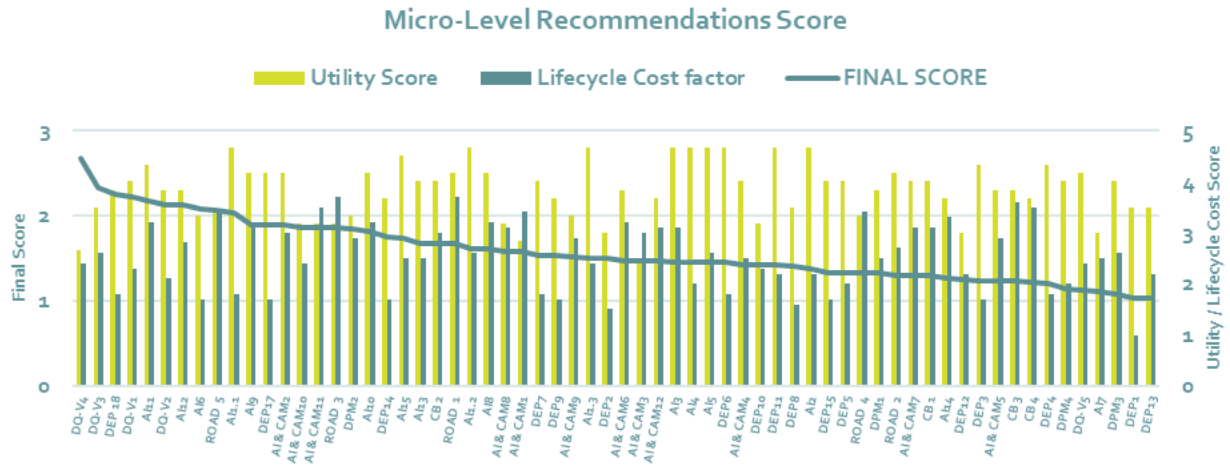


Figure 8. General Micro-level recommendations score.

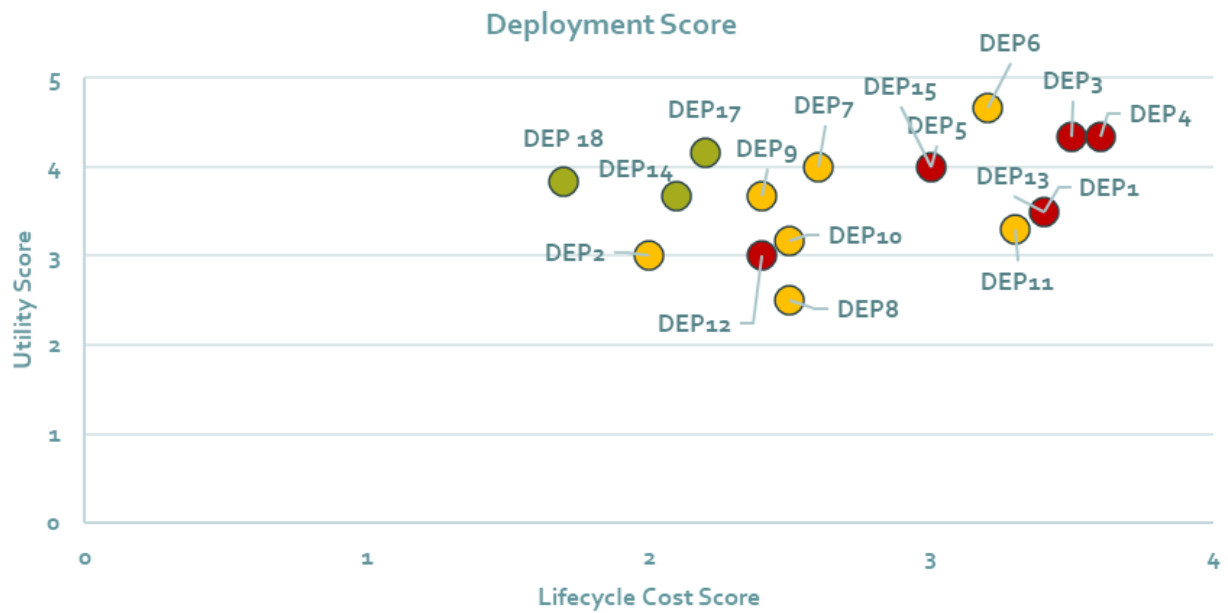


Figure 9. Deployment recommendations score.

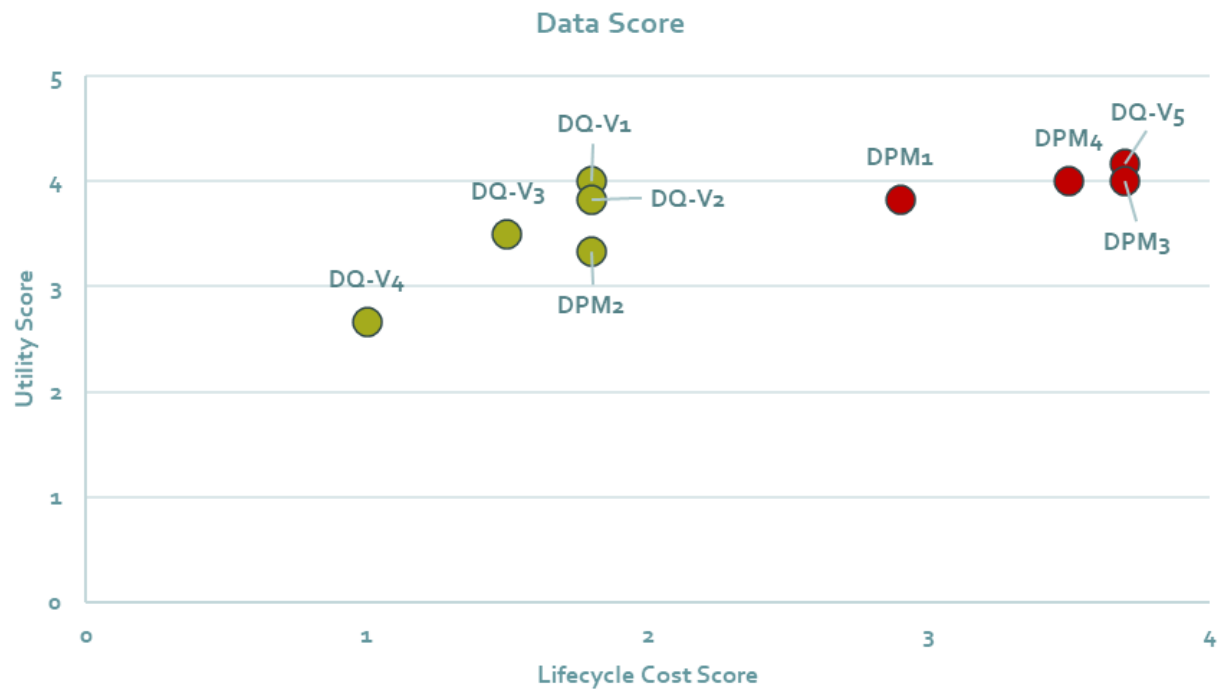


Figure 10. Data recommendations score.

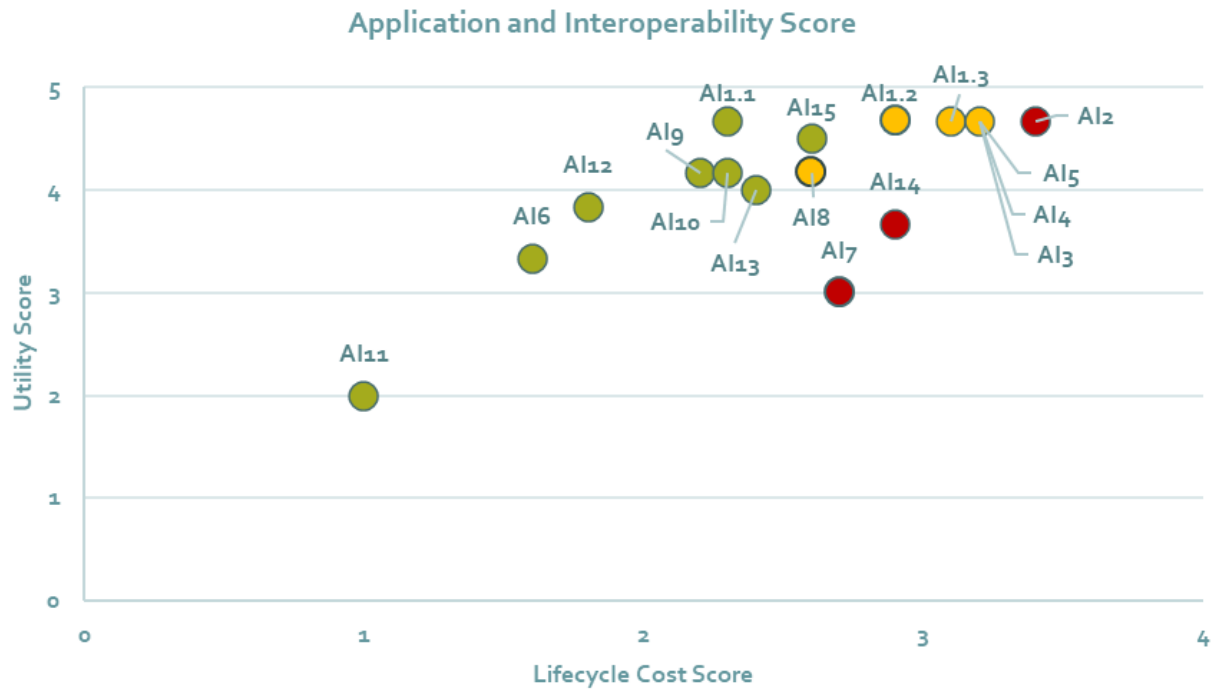


Figure 11. Application and interoperability score.

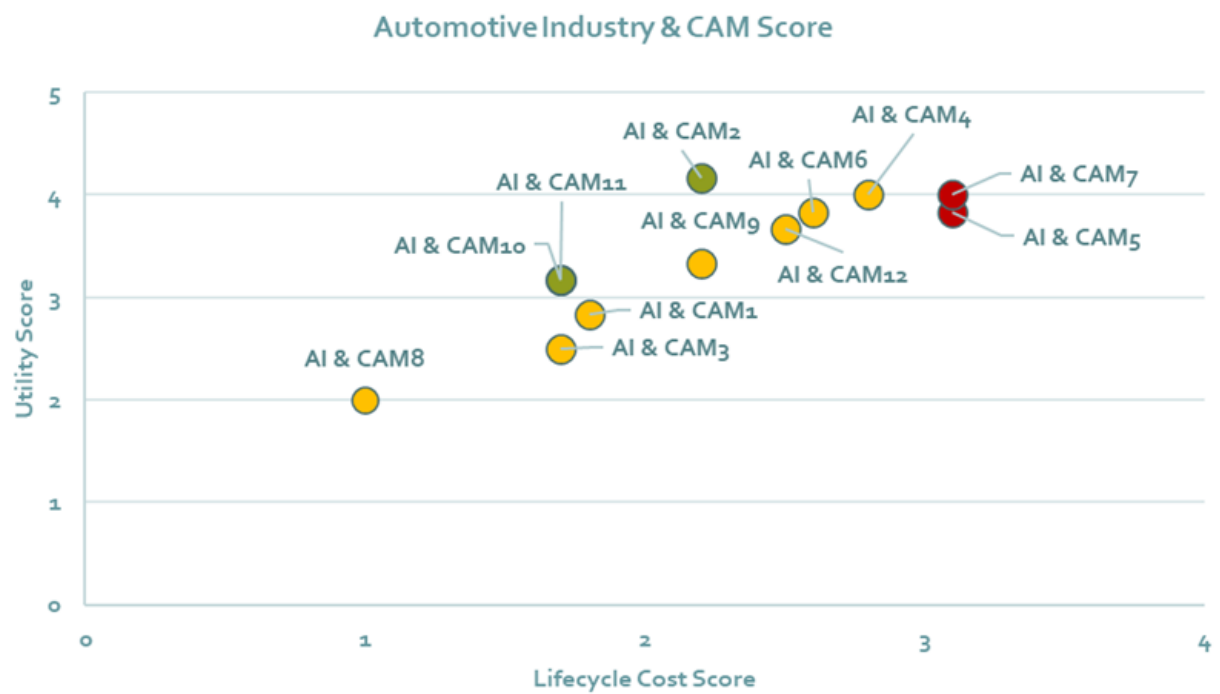


Figure 12. Automotive Industry and CAM score.

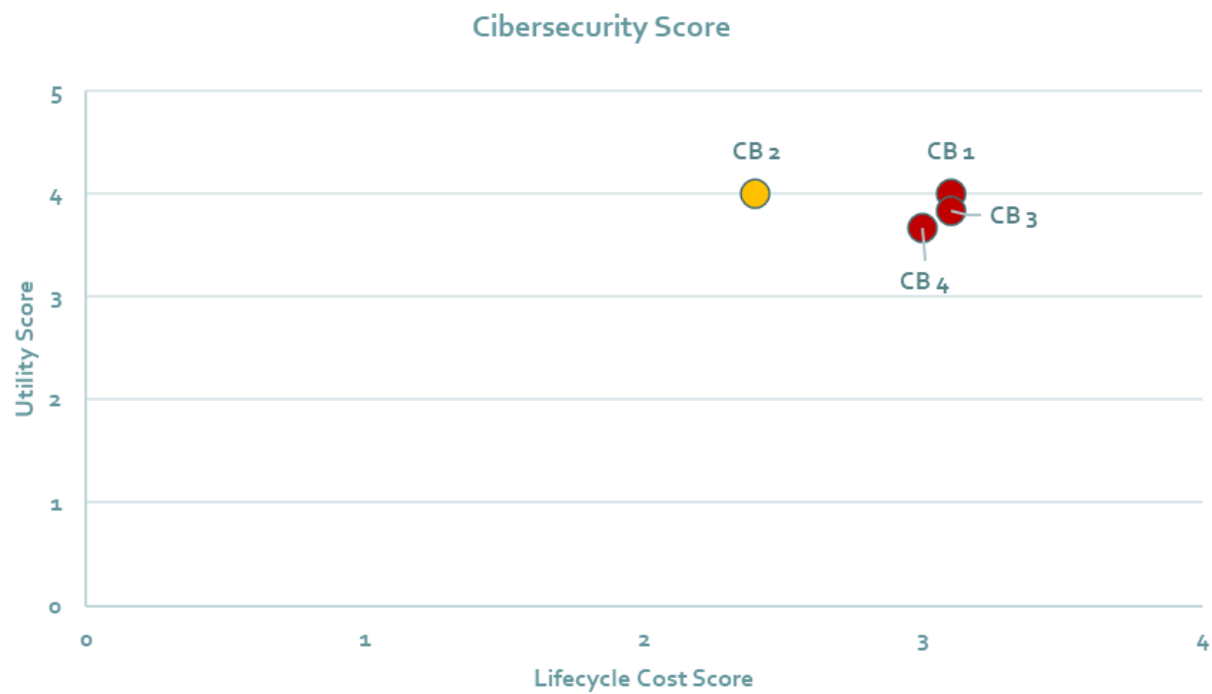


Figure 13. Cybersecurity score.

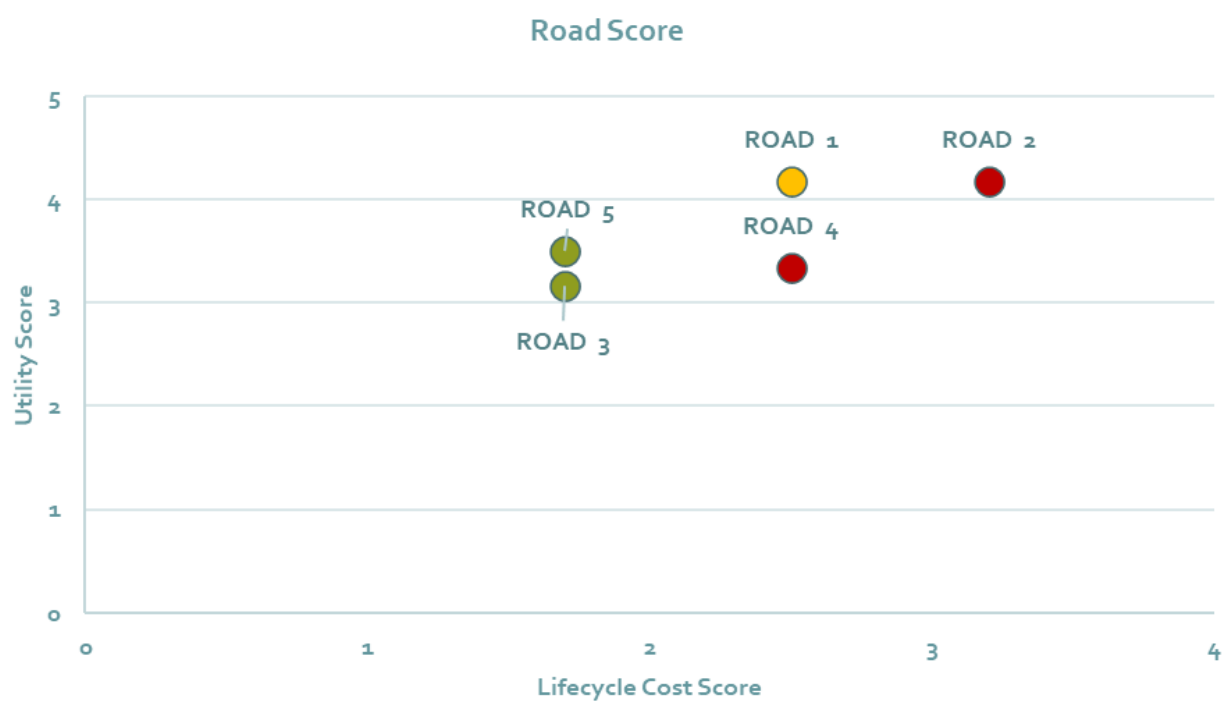


Figure 14. Road score.

9.1.2. Cross-border environment solutions prioritisation

X-border Solution ID	UTILITY SCORE	Lifecycle Cost factor	FINAL SCORE	X-border Solution ID	UTILITY SCORE	Lifecycle Cost factor	FINAL SCORE
XBI_1.1	● 4,3	● 2,9	● 1,5	XBI_5.6	● 3,7	● 2,8	● 1,3
XBI_1.2	● 4,0	● 2,5	● 1,6	XBI_5.7	● 4,9	● 3,3	● 1,5
XBI_1.3	● 3,7	● 2,8	● 1,3	XBI_6.1	● 4,4	● 3	● 1,5
XBI_2	● 4,3	● 2,9	● 1,5	XBI_6.2	● 4,4	● 3	● 1,5
XBI_3.1	● 4,1	● 2,4	● 1,7	XBI_7.1	● 4,3	● 3,1	● 1,4
XBI_3.2	● 2,3	● 2	● 1,1	XBI_7.2	● 4,3	● 3,1	● 1,4
XBI_4.1	● 3,6	● 3,2	● 1,1	XBI_8.1	● 4,6	● 3,5	● 1,3
XBI_4.2	● 3,7	● 2,8	● 1,3	XBI_8.2	● 3,3	● 2,2	● 1,5
XBI_4.3	● 3,4	● 2,8	● 1,2	XBI_8.3	● 2,7	● 2	● 1,4
XBI_5.1	● 2,4	● 1	● 2,4	XBI_9.1	● 4,3	● 1,6	● 2,7
XBI_5.2	● 4,9	● 3,4	● 1,4	XBI_9.2	● 4,3	● 1,1	● 3,9
XBI_5.3	● 4,7	● 3,3	● 1,4	XBI_10.1	● 3,9	● 2	● 1,9
XBI_5.4	● 4,1	● 2,4	● 1,7	XBI_10.2	● 4,3	● 2,2	● 1,9
XBI_5.5	● 4,7	● 3,2	● 1,5	XBI_11	● 3,4	● 2,4	● 1,4

Figure 15. Cross Border Solutions. Score.

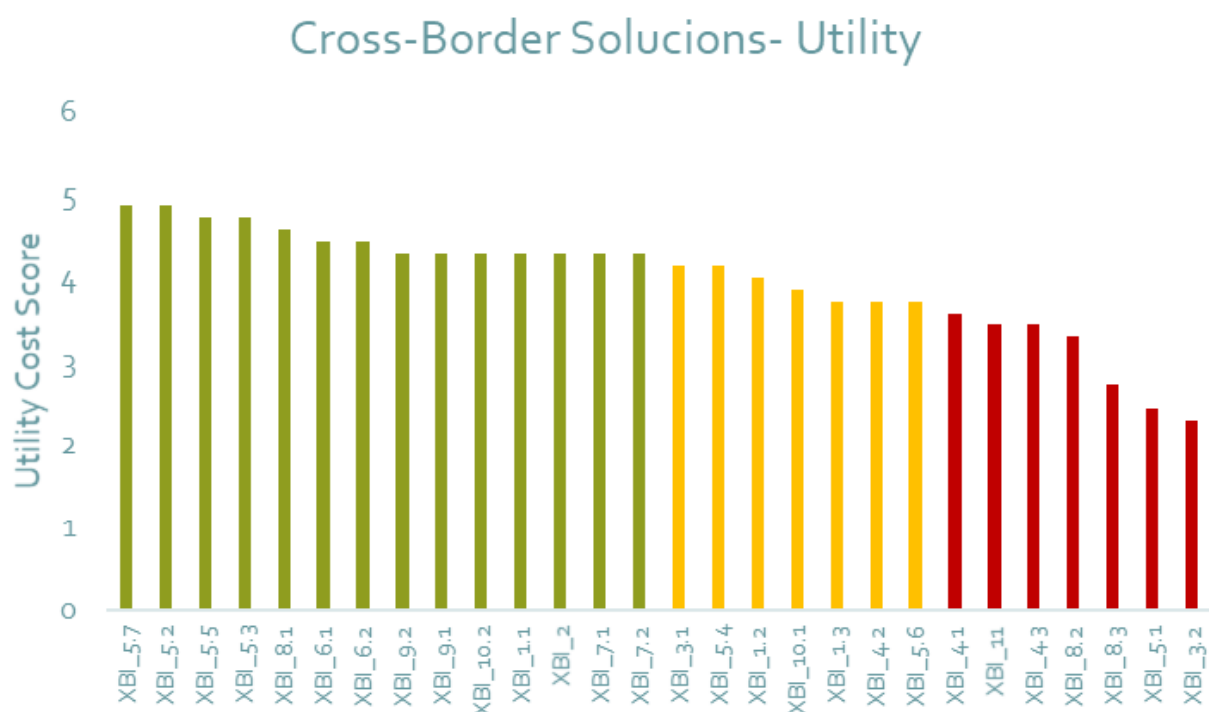


Figure 16. Cross-Border Solutions- Utility. Score from ES-PT CBC

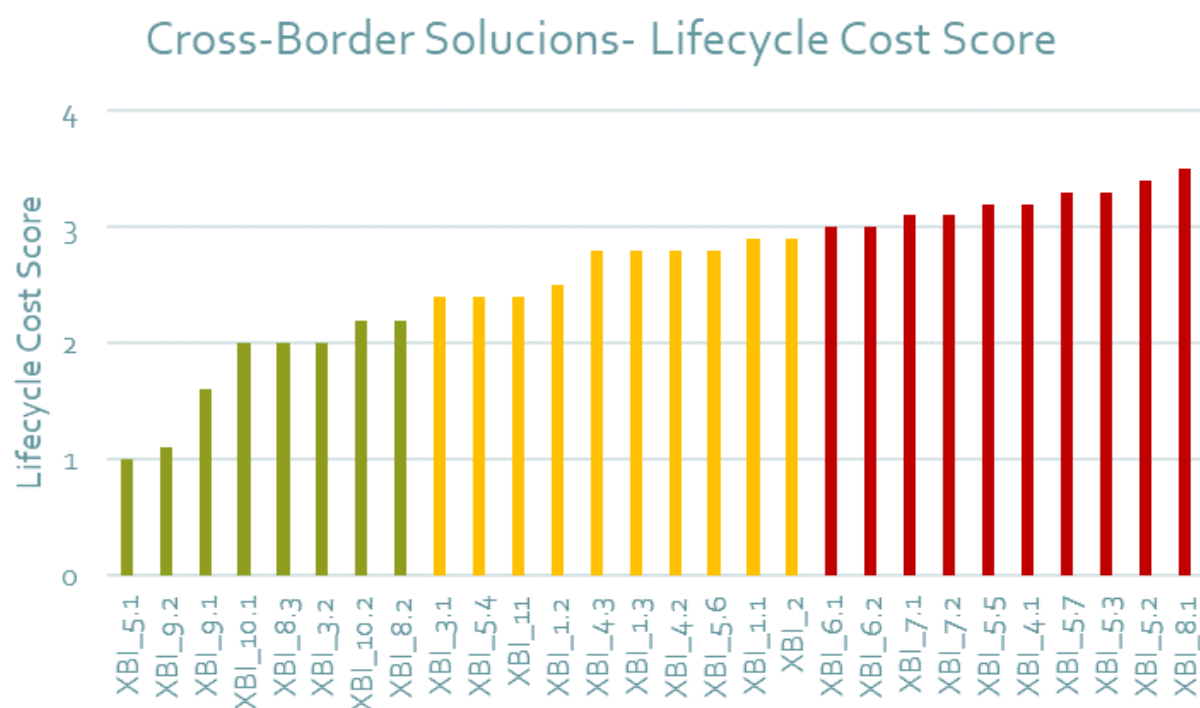


Figure 17. Cross-border solutions-Lifecycle cost. Score from ES-PT CBC

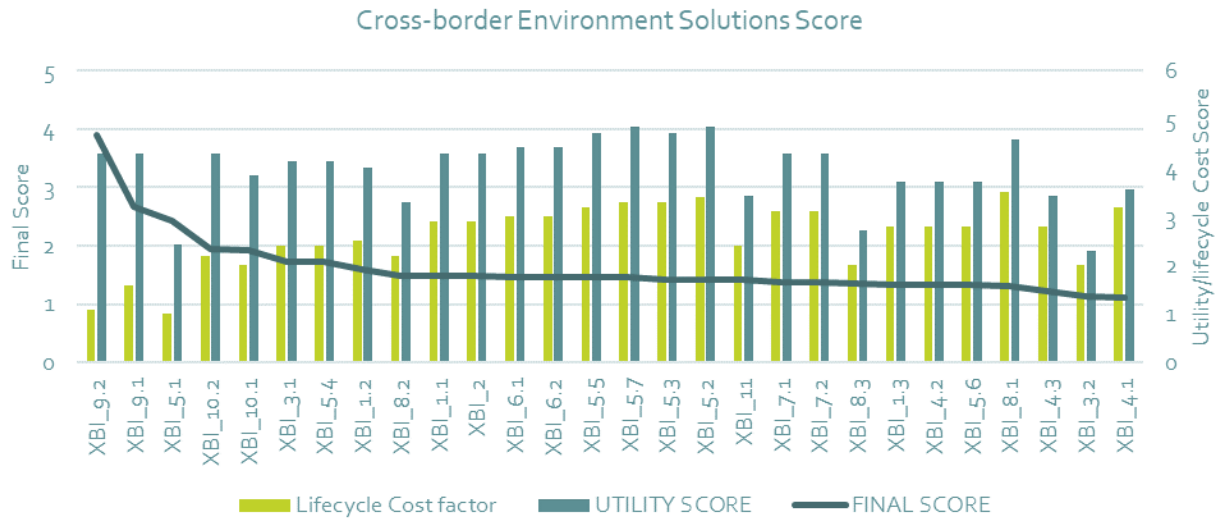


Figure 18. Cross Border Environmental Solutions. Score from ES-PT CBC.

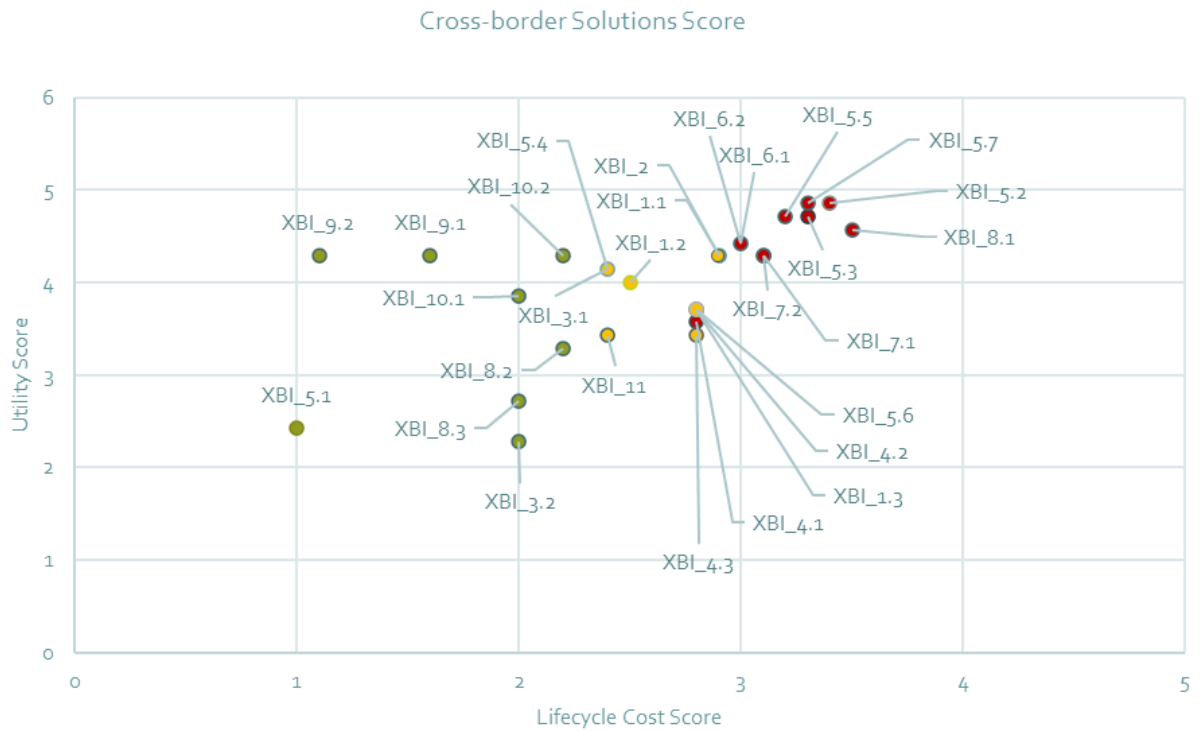


Figure 19. Cross Border Solutions. Score from ES-PT CBC.

X-border Solution ID	UTILITY SCORE	Lifecycle Cost factor	FINAL SCORE	X-border Solution ID	UTILITY SCORE	Lifecycle Cost factor	FINAL SCORE
XBI_1.1	4,0	2,6	1,5	XBI_5.6	3,9	3	1,3
XBI_1.2	3,3	4,0	0,8	XBI_5.7	4,7	2,4	2,0
XBI_1.3	4,0	3,2	1,3	XBI_6.1	4,0	1,9	2,1
XBI_2	4,4	2,7	1,6	XBI_6.2	4,6	1,9	2,4
XBI_3.1	3,4	2,2	1,6	XBI_7.1	3,4	2,8	1,2
XBI_3.2	2,6	1,4	1,8	XBI_7.2	3,7	3,5	1,1
XBI_4.1	4,0	3,1	1,3	XBI_8.1	3,0	2,9	1,0
XBI_4.2	3,7	3,2	1,2	XBI_8.2	3,9	2,9	1,3
XBI_4.3	3,3	1,6	2,1	XBI_8.3	3,7	2,9	1,3
XBI_5.1	1,6	1,0	1,6	XBI_9.1	4,9	3,6	1,3
XBI_5.2	3,1	2,9	1,1	XBI_9.2	3,7	2,5	1,5
XBI_5.3	3,7	3	1,2	XBI_10.1	3,9	3,5	1,1
XBI_5.4	1,6	1,9	0,8	XBI_10.2	4,6	2,6	1,8
XBI_5.5	4,0	2,9	1,4	XBI_11	4,6	2,2	2,1

Figure 20. Cross Border Solutions. Score from GR-TR CBC.

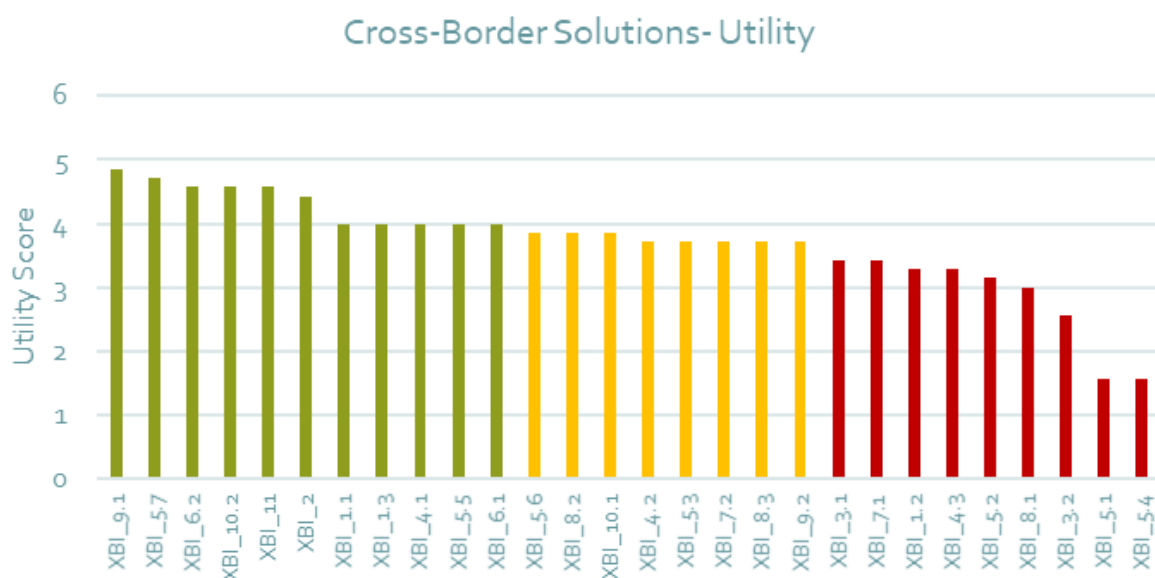


Figure 21. Cross-Border Solutions- Utility. Score from GR-TR CBC.

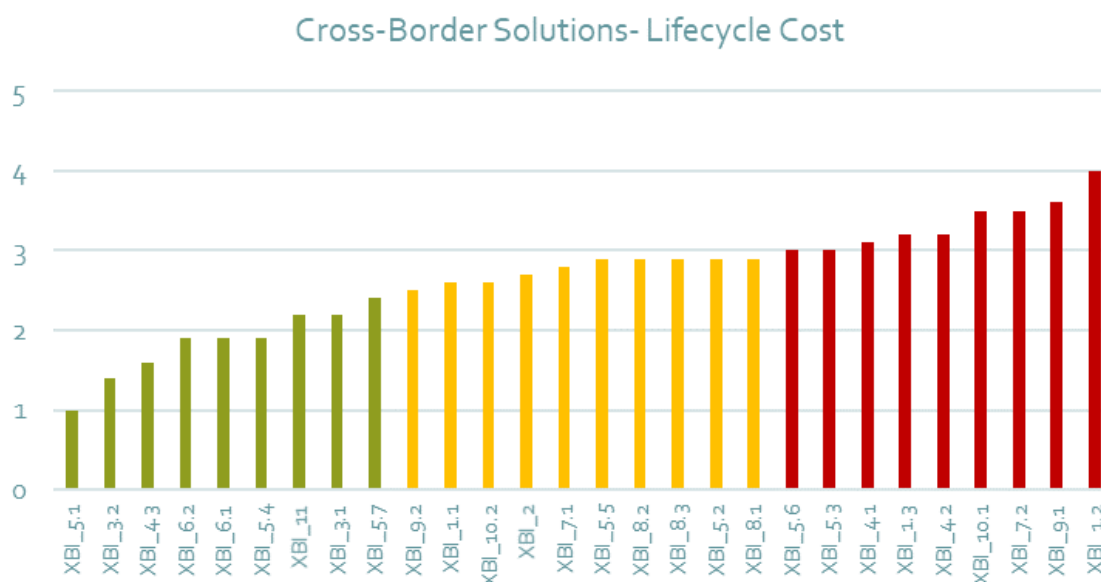


Figure 22. Cross-Border Solutions- Lifecycle Cost. Score from GR-TR CBC.

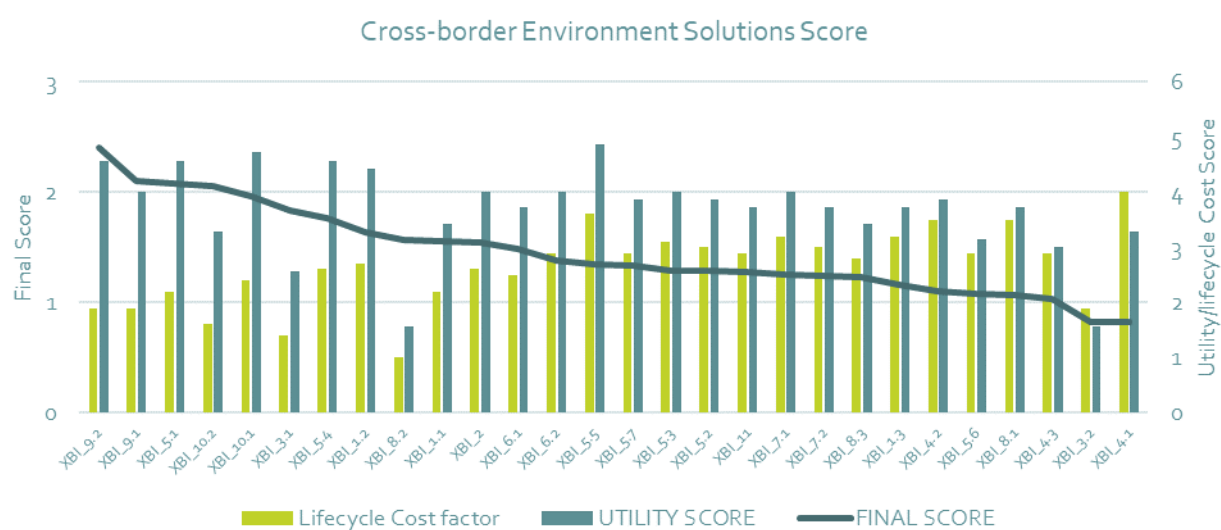


Figure 23. Cross-Border Environmental Solutions. Score from GR-TR CBC.

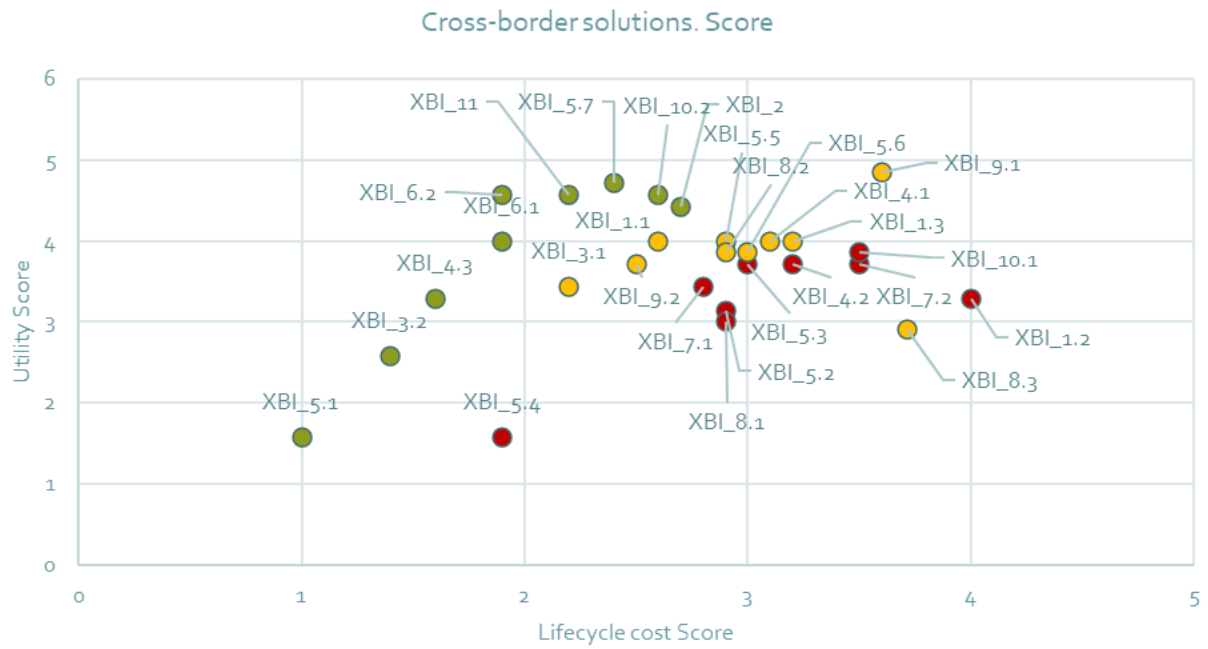


Figure 24. Cross Border Solutions. Score from GR-TR CBC.

9.1.3. Macro-level recommendation prioritisation.

ID	Utility Score	Lifecycle Cost Score	FINAL SCORE
R1	4,4	4,2	1,06
R2	4,9	4,5	1,08
R3	3,4	2,5	1,37
R4	3,6	1,5	2,38
R5	4,0	3,3	1,21
R6	3,6	2,7	1,32
R7	4,9	4,2	1,16
R8	4,9	4,6	1,06
R9	4,6	4,6	0,99
R10	2,6	1,5	1,72
R11	4,0	5	0,80
R12	4,4	3,9	1,14
R13	4,7	4,2	1,12
R14	5,0	3,9	1,28
R15	5,0	4,5	1,11

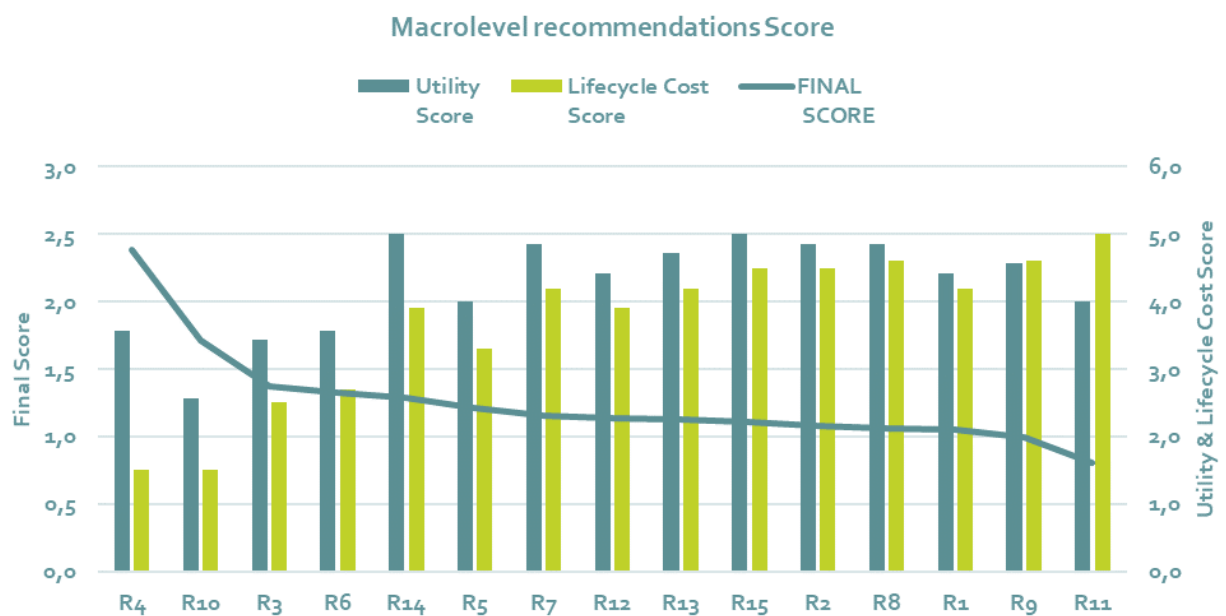
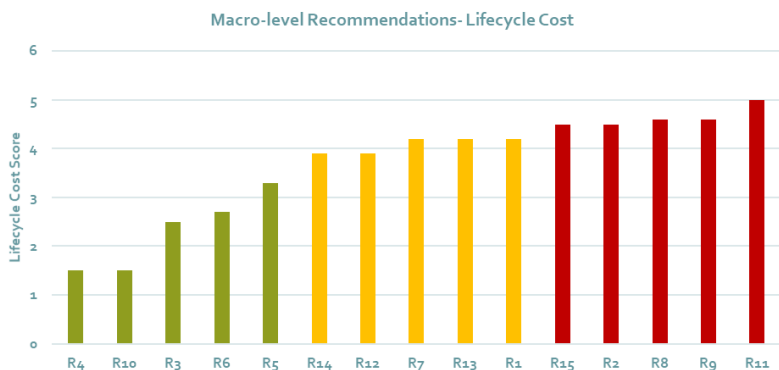
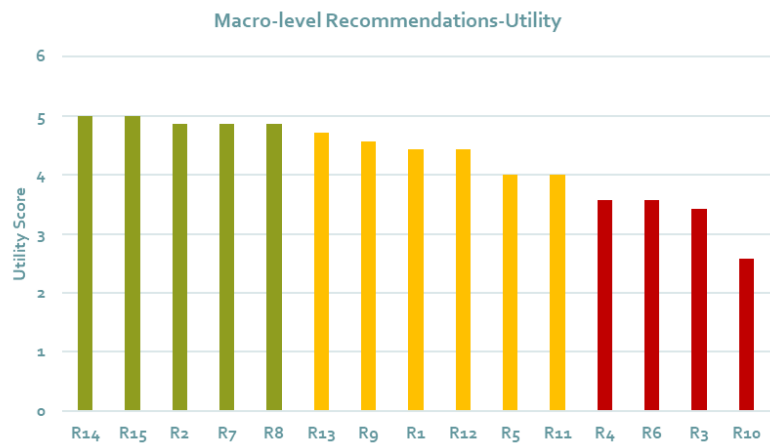


Figure 25. Macrolevel recommendations Score.

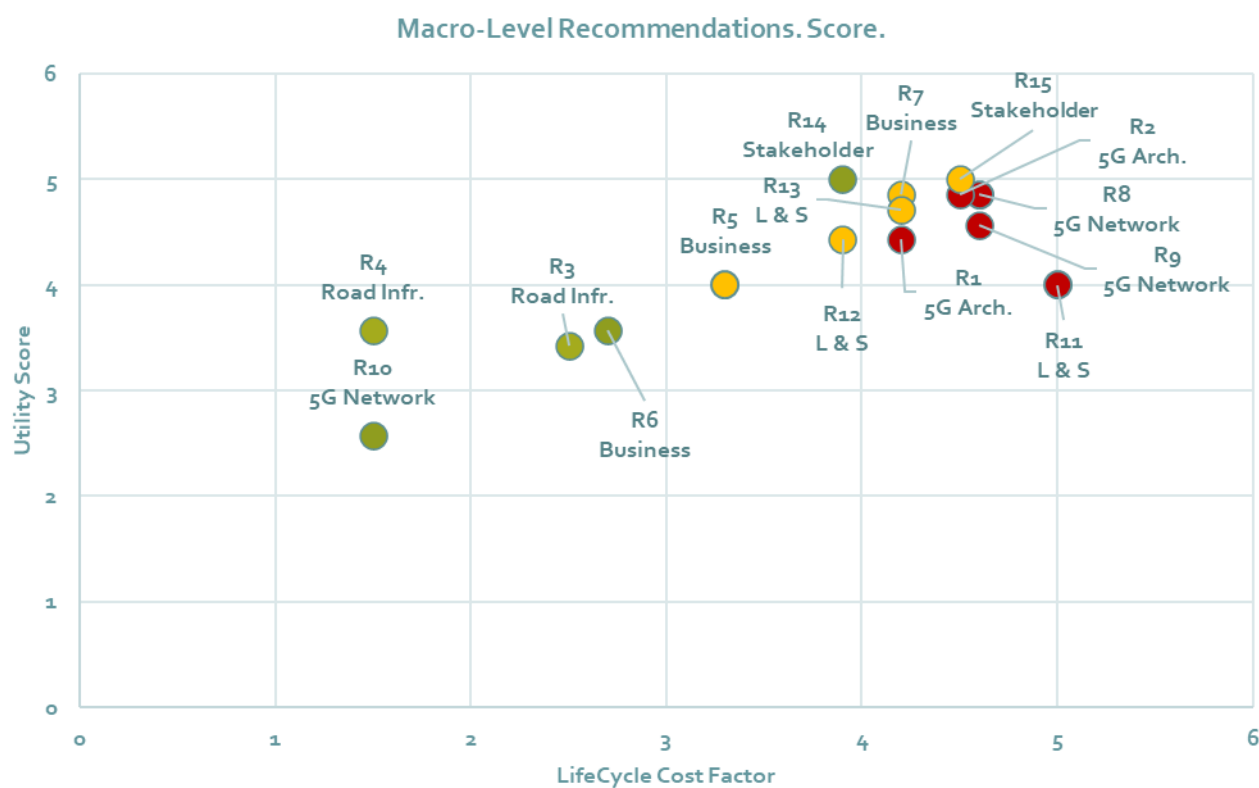


Figure 26. Macro-level Recommendations Score.