5GMOBIX

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

D6.8 - Final report on EU policies and regulations recommendations

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Authors

Authors in alphabetical order		
Name	**Organisation**	**Contributions**
David Fidalgo	AEVAC	Section 4.2.2
Marta Miranda Dopico Irene Saco López Iván Pérez Piñeiro	CTAG	Section 4.4.7, 4.5.2, 4.5.3 review
Oscar Agustín Castañeda Aguadero Janie Baños Polglase	DEKRA	Section 5, 5.1, 5.2
Lidia Buenavida Peña	ERTICO	Section 4.4
Tahir Sari	FORD	Section 4.5.3
Martin Speitel, Claudiu Alin Rusu	FRAUN	Section 2,3 ,4.1.1, 4.1.2 Document organisation
Olga Segou	INTRASOFT	Section 4.5.1
Michel Picard	LIST	Section 4.3
Pieter Nooren	TNO	Section 4.21, 4.2.3
Jorge Alfonso Kurano	UPM	Section 1,6

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ABBREVIATIONS

Abbreviation	Definition
ADAS	Advanced Driver Assistance Systems
AMF	5G Core Access and Mobility Management Function
AV	Autonomous Vehicle
BEREC	Body of European Regulators for Electronic Communications
CAM	Connected and Automated Mobility
CBC	Cross Border Corridor
CE	Conformité Européenne
CN	China
DE	Germany
DNS	Domain Name System
EC	European Commission
EMBB	Enhanced Mobile BroadBand
eNB	evolved Node B
ENISA	European Union Agency for Cybersecurity
EPC	Evolved Packet Core
ES	Spain
ETSI	European Telecommunications Standards Institute
EU	European Union
Euro NCAP	European New Car Assessment Programme
FCC	Federal Communications Commission
FI	Finland
FR	France
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System

gNB	Next Generation Node B
GPRS	General Packet Radio Services
GPS	Global Positioning System
GR	Greece
GRX	GPRS Roaming eXchange
HO	HandOver
HR	Home Routed, for routing data back to the HPLMN from the VPLMN
ICT	Information and Communications Technology
IQN	In-Advance QoS Notification
LBO	Local Break-Out
M2M	Machine to Machine
IP	Internet Protocol
IPX	IP Packet eXchange
ISP	Internet Service Providers
ITS	Intelligent Transport Systems
KR	Korea
M2M	Machine to Machine
MEC	Multi-access Edge Computing
MME	Mobile Management Entity
MNOs	Mobile Network Operators
mmWave	Millimetre Wave
MQTT	IBM MQ[1] Telemetry Transport
MS	Members States
NL	Netherlands
NSA	Non-Standalone (network)

[1] https://www.ibm.com/products/mq (Accessed June 2022)

NRA	National Regulatory Authority
NTN	Non-Terrestrial Network
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency-Division Multiplexing
PDU	Protocol Data Unit
PGW	Packet data GateWay
PLMN	Public Land Mobile Network
PT	Portugal
QoS	Quality of Service
RF	Radio frequency
RSUs	Road-Side Units
RTK	Real-time Kinematic positioning
SA	Standalone Architecture
SAE	Society of Automotive Engineers
SAE L4	Semi-autonomous vehicles LEVEL 4: No human interaction required
SIM	Subscriber identity module
SLA	Service-Level Agreement
SMF	(5G) Session Management Function
TCP	Transmission Control Protocol
TR	Turkey
UDM	(5G) Unified Data Management
UDP	User Datagram Protocol
UE	User Equipment
UPF	User Plane Function
V2X	Vehicle-to-everything wireless communications

VRU	Vulnerable Road User
WP	Work Package
X-border	Cross-border

1. EXECUTIVE SUMMARY

Deliverable *D6.8 - Report on EU policies and regulations recommendations*, closes up the preliminary outlook of *D6.4 – Plan and preliminary report on EU policies and regulations recommendations* summarised in Section 4 of this document, closing the gap between the regulatory authorities or lawmakers and the stakeholders in mobility using 5G technology. The objective is to facilitate the identification of challenges and solutions towards the implementation of appropriate regulations and legislative background regarding the roaming.

These outcomes are the combination of two major actions. First, complementing the survey results described in D6.4 with a further assessment of the questionnaires that provided that overall view of the major issues that are of concern to the relevant stakeholders in deployment of 5G-CAM solutions. And secondly the analysis of the results of the field trials conducted in cross-border scenarios in 5G-MOBIX and other related test-sites.

Section 2 of this document outlines the 5G-MOBIX approach and the purpose of this D6.8 deliverable.

Section 3 of this document describes the overall plan and methodology followed in WP6.4 to make this integration of different inputs in a consistent and meaningful way to achieve the expected objectives of the work.

Section 4 proceeds to detail the major inputs that are used to finalise the WP6.4 activity:

- Results from the preliminary questionnaire analysis – described in section 4.1- show that the main concerns of 5G-CAM were considered to be interoperability, cybersecurity, scalability of the architectures, technical maturity of the different applications, technical priority and investments in CAM development.
- Results from the field trials are detailed in section 4.2, and do confirm several of the main issues identified in the preliminary questionnaire, while providing also solutions to those. Roaming and its implications in terms of service continuity and quality of service guarantee in cross border scenarios are analysed in detail, resulting in 9 cross-border requirements that address specific related technical aspects.
- Recommendations from the ICT sector, road operators and car industry, following an additional assessment of the questionnaire in WP6.4 is presented in section 4.5. This section provides a deeper understanding of the views outlined by the stakeholders in D6.4 and section 4.1, and it results in a number of specific recommendations for the policy makers and regulatory entities.

Section 5.1 and 5.2 finally provides the recommendations for the relevant entities and authorities that can speed up the deployment of 5G-CAM services.

Deliverable D6.8 completes the cycle of requirements gathering, analysis, target group and framework identification that was reported in D6.4. The added value over the previous document comes from the 5G-

MOBIX field trials and the more detailed feedback from relevant stakeholders on key questions posed on the topic. This has resulted in a comprehensive list of recommendations and guidelines which address the identified issues on cross-border scenarios on deployment of 5G-CAM applications, together with a formulation that squarely targets the bodies and entities that are better positioned to implement the solutions explored in the project. These results, in conjunction with the other outcomes from T6, form an integral package that aims to speed up adoption of 5G for CAM scenarios.

2. INTRODUCTION

2.1. 5G-MOBIX concept and approach

5G-MOBIX seeks to demonstrate the usefulness of 5G technology for advanced Connected and Automated Mobility (CAM) technology use cases and validates the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). Towards this, 5G-MOBIX is demonstrating the potential of various 5G capabilities, in real use cases, on European highways and roads and to provide and develop sustainable business models to establish 5G corridors. 5G-Mobix employs essential infrastructural assets and upgrades them while ensuring a seamless operation and coexistence of 5G in a heterogeneous environment with several incumbent technologies as ITS-G5 and C-V2X direct.

5G-MOBIX executed CAM trials along cross-border (x-border) and urban corridors using 5G core technological innovations and qualifies the 5G infrastructure while evaluating the benefits in the CAM context. The project also defines the deployment scenarios and identifies the required standardisation and spectrum gaps.

5G-MOBIX defined the critical scenarios which needed advanced connectivity, provided by 5G network, and the required features to enable the advanced CAM use cases. The matching of the CAM use cases, with the expected benefits of 5G, were tested during trials on the 5G corridors in the different EU countries and as well in Turkey, China and Korea.

The trials allowed the 5G-MOBIX project to conduct evaluations and impact assessments and to define business impact and cost/benefit analysis. As a result of these evaluations and international consultations with the public and industry together, 5G-MOBIX has identified new business opportunities for 5G enabled CAM while providing recommendations and variants for the deployment of the technology.

Through its findings on technical requirements and operational conditions, 5G-MOBIX is expected to actively contribute to standardization and spectrum allocation activities and to provide technical background and guidance in accordance with the requirements of the industrial and public consumers for the regulatory authorities and law makers.

2.2. Purpose of the deliverable

The present deliverable's main purpose is to narrow down the recommendations collected in D6.4 to a comprehensible format and to inform the policy makers, regulatory authorities and law makers towards the common goal of implementation of the appropriate legislative and regulatory context regarding roaming, gap closing and spectrum allocations in the 5G connectivity. These recommendations have the role of providing directions in brief for the authorities and bringing together the goal of the mobility stakeholders using 5G technology with the above stated authorities.

To achieve the resolutions of the D6.8, the following tasks were defined and distributed between the internal and external stakeholders of WP6.4 as well as with partners from other deliverables:

1. Monitor specification, deployment, trial and evaluation activities to identify issues related to deployment and x-border issues (WP2/WP3/WP4/WP5):
   - Transform the expression of issues into topics of discussion with the related above organizations,
   - Provide corresponding recommendation to policy makers and regulators.
2. Analyse the issues detected to transform them first in topics of discussions pushed to the relevant EU bodies (private or public) and to provide directly recommendations to those bodies.
3. Interact with the relevant bodies to push the general matters for the CAM and 5G mobility technology discovered within 5G-Mobix issues and provide expertise and technically relevant recommendations based on the background provided by the project and the relevant stakeholders.

2.3. Intended audience

The current document is publicly disseminated and is available as a free download on the 5G-MOBIX website [1]. It is primarily meant as a handbook that introduces 5G for CAM stakeholder opinions and discusses challenges that can be addressed by proposed recommendations at the regulatory and policy level. Thus, this document aims to serve not just as an internal guideline and reference for all 5G-MOBIX beneficiaries but also for the larger communities of 5G and CAM development, as well as national and EU regulators and other policy makers.

Interested readers may also refer to:

- D6.1 "*Plan and Preliminary Report on deployment enablers*" for discussion on the current state and evolution of 5G for CAM,
- 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,
- D6.4 "*Plan and preliminary report on EU policies and regulations recommendations*" for an extensive analysis of recommendations for policy makers and regulatory entities.

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

3. PLAN AND METHODOLOGY

3.1. Objectives

The deliverable *D6.8 - Report on EU policies and regulations recommendations* shall be an update to the previous *D6.4 - Preliminary report on EU policies and regulations recommendations*. It summarizes the findings in the field tests with a special focus on policy makers and regulatory entities. It is based on the previous work of D6.4, which was mainly based on collections from different stakeholders by interviews, questionnaires and published reports. The source of information was the experience and know-how of the project partners. The collected information comprises some overlapping recommendations, which are used to confirm the findings in previous work.

The focus of D6.8 comes to the roaming issues at X-borders and differences in legal aspects in various areas of legislation for the mobile communication and autonomous vehicles across borders in the European countries.

3.2. Workflow

The deliverable D6.8 will mainly reference the findings and collections of recommendations of D6.4. In addition, the field test results from WP5 will be used to prioritize and select the most relevant recommendation for policy makers and regulatory entities. In addition, the remarks from the review process of D6.4 are incorporated in the final deliverable of T6.4. This will focus on X-Border Issues for roaming among neighbouring countries. Figure 1 illustrates this workflow.

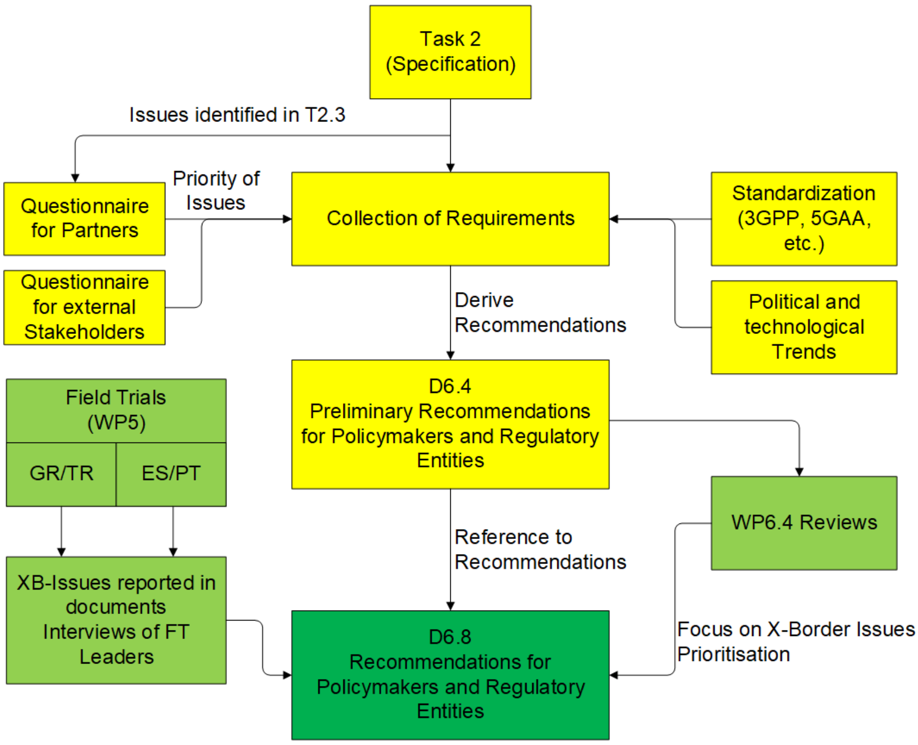

Figure 1: Project plan with subtasks

4. INPUT FROM PREVIOUS AND CURRENT WORK

The deliverable D6.8 main goal consists of summarising the cross-border issues provided by the field trials such as the feedback of WP 3 (deliverable D3.7) which is in the final stage of completion and as well from WP4 and WP5 which provide the technical references and the use case scenario.

Furthermore, the cross-border issues identified in D6.4 are based on internal stakeholder's interviews and questionnaires, and provide detailed feedback from the actors of the cross-border trial sites and partners specialised in all the areas required for the implementation of CAM.

4.1. Cross-border issues identified in D6.4 questionnaires

As a conclusion of the 5G-Mobix European project, the deliverable D6.4 main focus was to resume the existing technical and regulatory issues in a comprehensible format and to communicate them as recommendations for the regulatory authorities.

For the collection of the issues and in order to narrow down the results, the D6.4 partners provided a series of questionnaires to the x-border trial partners and other stakeholders from the involved industries and authorities, regarding the technical background and existing limitations.

The questionnaire was developed and based on the professional background of each possible attendee and the questions focused on the aspects directly related to the area of interest of each questioned individual. Moreover, the questionnaire had a cross sections area for experts from multiple domains, which answered a series of simplified questions, with multiple options of answers and text case answers, which provided more detailed views over the issues.

An extensive answer lists for the focused four questions directed to the main commercial partners can be found in "*D6.4 – Plan and preliminary report on EU policies and regulations recommendations*" Section 5.5: "Four Questions to Stakeholders".

As the final results were still uncertain for the recommendations phase, a second series of targeted questions for stakeholders was developed and launched, the "4 Questions" section was intended for the clarification and the progress of the recommendations section.

4.1.1. Questionnaire results

The questionnaire, realized in cooperation with WP6.1 and WP6.3, is a survey of the stakeholders regarding the level of communications, the motivations and the barriers that must overcome in the vision of various stakeholders from domains such as automotive, telecom, etc., and it was disseminated with the 5G-MOBIX consortium in September 2020 and with external partners and stakeholders in October 2020.

To guide the various stakeholders to the questions of interest for their domain of expertise, the questionnaire was based on a multi-level question system where the aspects such as the "type of stakeholder" (e.g., Automotive Industry, Telecommunication Operator, etc.), "company size" or "area of expertise" of the responder are initially required for the classification of the participants.

After the identification stage, the questions are narrowed to the area of interest and domain of expertise, while the main topics of the questions are based on the major domains of expertise of the attendees (e.g., Technological/Scientific aspects, Regulatory & Compliance aspects, Infrastructure aspects, Security and Privacy aspects, Business aspects).

As a majority of contributors to the questionnaire were from Academia and R&D, a detailed selection of the questions for each attendee research area was implemented with a series of main researches in the CAM and 5G sectors (e.g., Next-generation networking, 5G & Edge Hardware suppliers, Big Data and Software suppliers for telecom/automotive industry) and as well an open field for "other" areas mentioned by the participants: Generic ITS, Human Factors, Education, Testing, 5G non-terrestrial network convergence, Intelligent infrastructure for automated vehicles and Machine Learning.

When asked about the technical or scientific obstacles that 5G-CAM will face, the majority of experts answered that interoperability and cybersecurity are the key concerns as well as the scalability of the architectures to a massive deployment.

Regarding the involvement of Academia and R&D in the 5G-CAM, the attendees most popular choice was the participations in projects. Additionally, one of the experts highlighted the "Development of Standards" as an alternative idea in the field "Others".

Furthermore, the interest of Academia and R&D in the 5G-CAM research was mainly motivated by the "Scientific interest" and due to the interest of the organization that they are part of ("Part of my organisation research").

Out of the 52 contributors, 36 were from Academia and R&D where the most relevant and extensive statistics were based on the answers of the researchers. The extended results can be found in D6.4 – chapter "5.4. Questionnaire Results".

The second-largest group, represented by the automotive industry, was formed by only eight experts, which diminish the statistic relevance of the answers but provided background for the automotive industry on the matter.

The most relevant answers regarding the following were: the technical maturity (remote driving was found as "least mature" and "Automated Fleet Management" and "Continuity of Vehicle-to-Everything" as the most mature), the technical priority (Driving safety" get the highest rating, followed by "Cyber Security, Data Protection") and the motivation factors for new investments in CAM development (with "New Trends" and "Improving the company's position in the market for automated professional vehicles" as favourite answers).

As the dissemination and the internal evaluation of the questionnaire concluded a second round of questions directly targeting the subjects of cross border issues and CAM with 5G was required to improve the relevance of the document and provide most valuable feedback for the policy makers and regulators.

4.1.2. 4 Questions

Apart from the initial questionnaire, four questions were chosen for specific short interviews with stakeholders to augment the questionnaire and provide additional responses from commercial partners and all cross-border trials participants. Additional 12 recommendations were included as a result of the additional questions, with a particular focus on X-border concerns and the 5G-Mobix initiative.

The four questions are:

1. What is your implication in automated driving and the view on 5G in your company or research institutes?
2. Which are the most challenging issues related to 5G for CAM in your perspective and which are the one related to your work or research activity?
3. How would you prioritize these challenges and what can be done from the policy makers and regulatory entities to overcome these challenges?
4. How can 5G-MOBIX influence the regulatory entities and policy makers to overcome these issues?

The questions were openly addressed to the direct stakeholders of the 5G-Mobix European initiative group through a document available to all the internal partners and further distributed to external stakeholders.

When asked which are the most challenging issues related to 5G for CAM, the questionnaire respondents reported the 5G coverage and access, especially in the cross-border corridors.

Other aspects regarded as impending challenges on short term were the definition of boundaries for the responsibility and access of different stakeholders (e.g., safety-related information management), the interoperability of users with different network operators or service continuity, the alignment of spectrum allocation and signalling as well as RSI and road maintenance.

In the long term, the definition of a common roadmap with common investment plans (investments for the infrastructure as well as the development of the environment for business plans enabling the CAM industry) and interoperability, considering the scalability, implementation of security, determine the responsibilities and boundaries of these responsibilities for the stakeholders were the most noticeable answers.

Another important aspect, remarkable between the answers, is the actions focused on business, the development of scalable business models behind 5G coverage in non-urban motorways, including the X-Border scenarios and the process of achieving the end-user trust.

Regarding the prioritisation of the challenges and the requirements from the policy makers and regulatory entities, the focus was on the definition of standards for the safety and efficiency of traffic and the environmental protection, as well as the necessity of commonly agreed test methods, certification programs for conformance and cybersecurity between the states and stakeholders were reported as major factors for the challenges of the respondents.

As well, a general alignment of the radio spectrum, operational deployment (e.g., operational rules, deployment of equipment, time-frame definition and funding allocation) and a minimum service standard, required for the 5G-CAM is to be considered viable for normal and cross-border sectors.

Concerning the strategy to influence and enable the process of proliferation of the regulations for 5G-CAM through the 5G-Mobix project, the responders' main reactions were regarding the prioritization towards the most relevant use cases, and to define the architectures for the real deployment for cross-border validation methods, to make the regulatory authorities aware of the existing issues.

The engagement of the decision-making entities in the process is considered crucial for the wide adoption by the responders, as the policy makers can understand the benefits of the technology in operational design domain.

4.2. Cross border issues found in the field trials

4.2.1. Motivation: cross-border CAM services based on network slicing technology must comply with European rules on net neutrality

This section explores how the provisioning of cross-border CAM services based on network slicing technology relates to the European rules for open internet, including net neutrality. As will be seen below, the cross-border characteristics of CAM services also play into the analysis of net neutrality. This topic has already been identified in D6.4 [2] and it has also appeared in the NL TS (Trial Site) where tests have been performed on 5G network slicing for CAM services. Network slicing is a technical approach to cater for services with high QoS demands from networks that at the same time provide services with other, more moderate demands. Several of the CAM services considered in 5G-MOBIX indeed are described as having very challenging requirements [3]. For example, certain remote driving applications require a guaranteed uplink/downlink data rate of 200/1 Mbps, 4 milliseconds maximal latency and 99.999% reliability. There can be discussion whether these requirements are indeed necessary, but that is outside the scope of this section. As another example, extended sensor applications involving collaborative perception messages need a 10/10 Mbps data rate, 20 milliseconds maximum latency and up to 99.99% reliability. These are more modest requirements, but they are still challenging because of the demands for the uplink data rate and the reliability.

Through network slicing, mobile operators can create separated virtual mobile networks on top of a single physical network infrastructure, both in the radio and the core network. Different slices can have different performance characteristics, for example in bandwidth, latency, reliability and the types and numbers of devices they can handle. In the experiments in NL TS, network slicing has been used to implement QoS guarantees for the traffic flows in CAM services, by introducing a priority for the slice carrying the CAM traffic above a second slice that carries the regular internet traffic. The architecture and technical approach for the network slicing has been described in D3.7 section 3.6 [4]. The network slicing, and in particular RAN slicing, has been shown to be effective in guaranteeing bandwidth and latency for the remote driving application, see D5.2[2].

The handling of traffic flows and use of priorities must comply with European rules for open internet, see D6.4 [2] section 3.2.8. In summary, EU Regulation 2015/2120 [5] sets the rules for open internet, including net neutrality. BEREC has published Guidelines [6] that provide guidance on the implementation of the rules. The Regulation and the Guidelines emphasize the open access of consumers to the global public internet. To this end, they contain detailed rules and guidance aimed at protecting Internet Access Services. The general rule is that Internet Service Providers (ISP)s must treat all traffic equally, which seems to be at odds with the 5G view to provide tailored connectivity to verticals and applications. In a further refinement of the general rule, the Regulation and Guidelines do offer room for traffic management and differentiation between traffic flows, subject to specific conditions. There is also the option to provide so-called Specialised Services in parallel to Internet Access Services, again subject to specific conditions. As will be seen below, both the rules for IAS and for SpS are relevant in the regulatory assessment of network slicing for CAM services.

4.2.2. Key questions on compliance in cross-border situation

The EU Open Internet Regulation and the BEREC Guidelines apply in all EU Member states, which provides a solid common basis for the assessment of slicing for CAM in cross-border situations. However, the final assessment of cases is the responsibility of the NRAs and is therefore done on a per-country basis. BEREC has an important role in promoting the consistency in the assessments made by individual NRAs. For cross-border scenarios for network slicing it is thus seen that two or more NRAs are involved in the regulatory assessment, with guidance from BEREC that can help in achieving consistency across Europe. This shows that there are two key points to consider when using network slicing in cross-border CAM:

1. The compliance of network slicing for CAM with EU Regulation and Guidelines in individual Member State cases. This is an obvious basic requirement. The result of the assessment depends on the CAM

[2] "D5.2 - Report on technical evaluation", August 2022.

services but, as will be seen later in this section, it also depends on the generic performance of the mobile networks involved.

2. Handling of potential differences between Member States in a cross-border case. A consistent assessment of network slicing for CAM in the Member States involved may still lead to different outcomes, as the generic performance mobile networks on both sides of the border may differ. The question is therefore how NRAs and mobile operators can handle potential differences. This would be a key point if the assessments lead to outcomes where the network slicing is allowed on one side of the border but not on the other side. Such outcomes could have a large impact on the CAM service provided by mobile operators and CAM application providers.

4.2.3. Structured analysis of compliance of network slicing for CAM with EU Regulation and Guidelines

Below, we use the framework developed in a separate study [7] to analyse the two key questions from the previous section. The analysis framework involves three main steps, two of which have already been covered by earlier 5G-Mobix results:

1. Determine the connectivity requirements of the services and applications in the use case. For this step, we can readily reuse the results from D2.5 referred to earlier in this section: a remote driving application requires a guaranteed uplink/downlink data rate of 200/1 Mbps, 4 milliseconds maximal latency and 99.999% reliability.

2. Develop the 5G architecture options to support the connectivity requirements. For this step, we reuse the architecture for network slicing detailed in D3.7, which already provides the (in this case single) option to be considered, see Figure 2 (taken from D3.7 [4]).

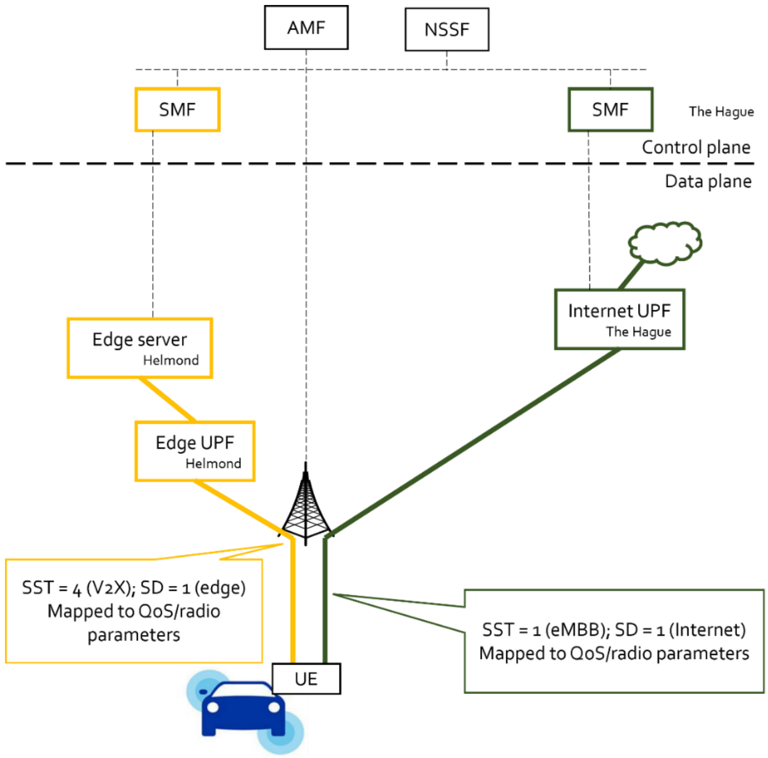

Figure 2: Network slicing architecture for CAM services in NL TS

3. Evaluate the alignment of the combination of services, applications and architecture options with net neutrality rules. The remainder of this section focuses on this step.

To make the network slicing architecture more suitable for the regulatory analysis, we first map it to the archetype options in the consolidated 5G architecture, see Figure 3, which is a slightly adapted version of Figure 28 in the study [7]. As explained there, the consolidated architecture model contains several parallel network slices. Some, but not all slices provide connectivity to the internet. The internet is a prominent example of a Data Network (DN). The internet itself is made up of many interconnected IP networks, with geographical scales that vary from global to national and regional. In the case of local access to the internet, one or more networks in the internet extends up to the geographical locations at the edges of the 5G mobile network. Apart from the internet, there are also other IP-based DNs, such as the edge and central clouds used in CAM services autonomous driving use.

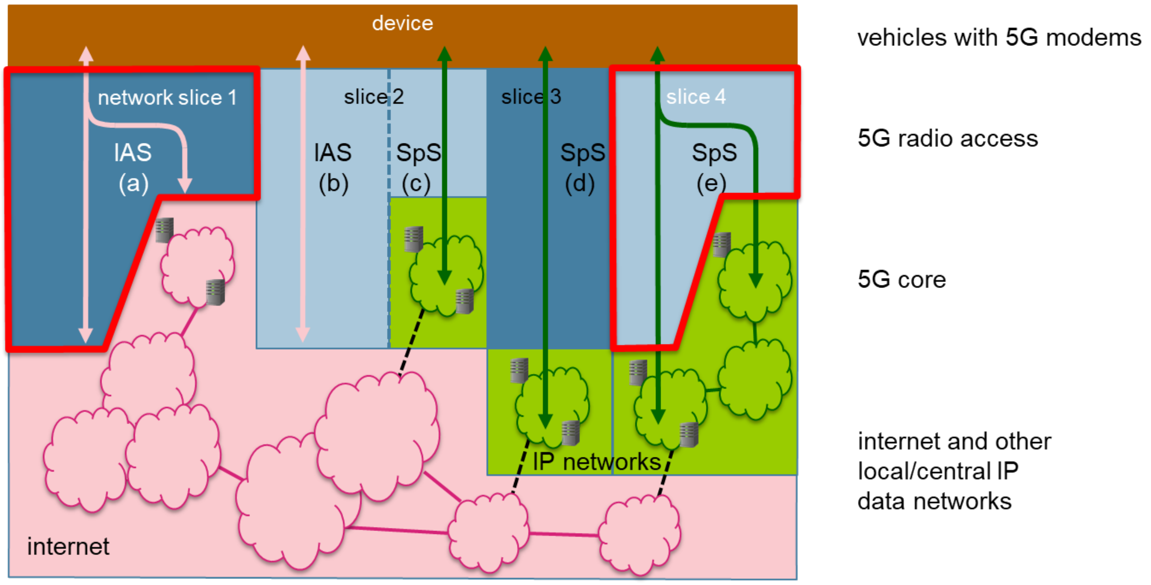

Figure 3: The network slicing architecture for CAM considered here maps to two archetype slices in the consolidated architecture

The two slices we have from the NL TS architecture in Figure 2 map to two of the archetype options in the consolidated architecture, see Figure 3.

- The slice carrying the internet traffic, indicated by the green lines in Figure 2, maps to the "network slice 1" archetype in the consolidated architecture. The handling of the traffic in this slice will need to comply with the rules for the Internet Access Service (IAS) from the EU Regulation. This part of compliance is not considered further here as it is not specifically related to the CAM services that are central to 5G-MOBIX. The considerations for the IAS are similar to those for other IAS services and are well known (but not trivial).
- The slice carrying the traffic for the automated driving application maps to the "network slice 4" archetype. The combination of the automated driving application and the traffic carried in the slice qualifies as a Specialised Service (SpS). This is because there is no connectivity to internet, only to CAM application servers in the edge or central cloud. The EU Regulation makes a binary split between IASs and SpSs, therefore the absence of internet access automatically leads to qualification as a SpS. The BEREC Guidelines [6] further explain that a potential application-level connection between CAM application servers and servers on the internet do not lead to disqualification as SpS, as this does not constitute internet access from the user entity (in this case a modem in a vehicle).

The first conclusion in our compliance assessment is that the automated driving application and the handling of its traffic in the dedicated slice need to comply with the rules for SpSs.

As a second step, we have a closer look at the rules for SpS that the automated driving application and the handling of its traffic must comply with. The rules can be divided in two parts: requirements for the SpS itself and requirements for the impact of SpS on IAS.

A. Requirements for the SpS itself

The BEREC Guidelines break the requirements on SpSs themselves down in three parts:

1. *They are services other than IAS services*. It is clear that the CAM SpS considered here satisfies this requirement: it does not provide connectivity to internet.
2. *They are optimized for specific content, applications or services, or a combination thereof*. It is straightforward to argue that CAM SpS considered here has been optimized for the specific remote driving application.
3. *The optimization is objectively necessary in order to meet requirements for a specific level of quality*. This last part is typically more complex to analyse, see study ation is the quality that can be achieved over the standard best-effort delivery in IAS.As explained in the BEREC Guidelines, the benchmark for assessing the necessity of the optimization is the quality that can be achieved over the standard best-effort delivery in IAS.

Zooming in on the third part, we see that, in principle, a characterisation of the quality achievable over best-effort internet requires a quantitative assessment of the performance of IAS, based on measurements or insights in the network dimensioning in the operator network. The tests performed in the NL TS do not provide this type of information. Indeed, it is important to note that the performance of the CAM service in the tests degrades when polluting traffic is added, which does not prove that CAM service cannot be run over public internet, as polluting traffic may exaggerate the effect of typical internet use.

Taking another perspective, we see that, given the very strict requirements of the automated driving service, in particular the uplink data rate, delay and reliability, it is unlikely that the service can be realistically provided with the required quality via a regular IAS today.

For services with less strict requirements, the assessment becomes less straightforward. In itself, it would be attractive if the services can be delivered over IAS. The question which then follows is at what point it would not be allowed to provide the CAM service as an IAS: if it can be provided over the IAS provided by one operator? Or over the IASs of all operators in a country? In the whole of the Member State or in certain regions? One can think of two main approaches to deal with this more subtle situation:

- A regulatory approach or interpretation, such as: allowing the provision as SpS across the Member State as long as there are substantial regions or networks where the CAM service cannot be delivered with the required quality over IAS. The technical and process advantage of this is a uniform treatment across the Member State and networks. A disadvantage may be that SpSs might be allowed to a degree that is not intended by the EU Regulation.

- A technical approach, such as: have a flexible provision of the service by providing it as an SpS where needed, and providing it over an IAS where feasible. The obvious disadvantage here is increased technical complexity, the regulatory advantage is the promotion of IAS as a generic carrier of services, which seems to be intended by the EU Regulation.

The second conclusion in our assessment is that the automated driving application and the handling of its traffic in the dedicated slice indeed comply with the rules for SpS.

For services with less strict requirements, the assessment may not be as straightforward as the provision over IAS may be a realistic alternative. This also opens up the issue of potential differences between the IAS performance in different regions or operator networks.

B. Requirements for the impact of SpS on IAS

The Regulation makes it very clear that the offering of SpS should not be at the cost of the quality of IAS: "Providers … may offer or facilitate such services only if the network capacity is sufficient to provide them in addition to any internet access services provided. Such services … shall not be to the detriment of the availability or general quality of internet access services for end-users." For mobile networks, a specific note has to be made: a temporal negative impact of SpSs on the quality of IASs is acceptable, as the number of users in a (radio) cell may be difficult to anticipate. The impact should be unavoidable, minimal and of short duration though. Despite this note, the analysis of compliance with the overall requirement is typically complex (see study [7], Table 7). Figure 4 shows the relatively simple situation we have in our case with the IAS and the CAM SpS.

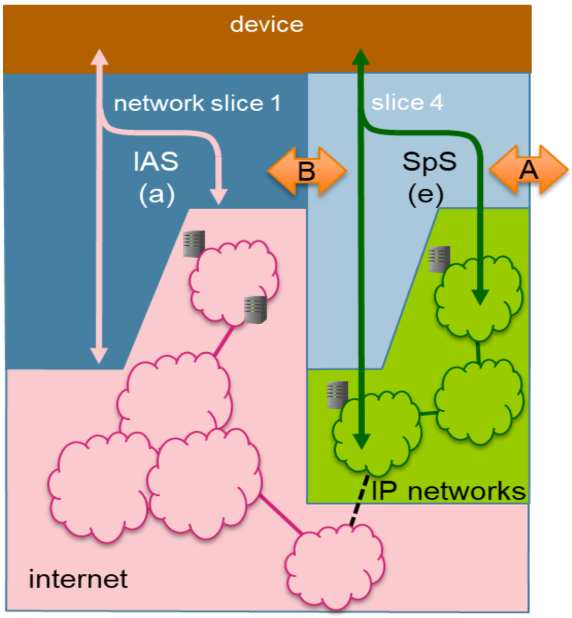

Figure 4: The impact of the CAM SpS on the quality of IAS

Compared to the initial situation with only the IAS present, adding the CAM SpS changes the overall availability of resources for the IAS. The precise impact depends on:

- The provision of additional resources in the network (arrow A). If the resources added are larger than the expected maximum used by the SpS, then the IAS does not suffer. In the NL TS tests, the IAS was still available during activation of the CAM SpS, although at a somewhat smaller maximum capacity. In operational situations, it can be estimated from measurements or from the changes in network dimensioning whether sufficient resources have been added. In practice, this may be a complex exercise [7].
- The distribution of the available resources between the IAS and the SpS (arrow B). In the NL TS, the traffic flows of the CAM SpS take absolute priority over the IAS traffic. This means that the SpS can consume all resources, at the cost of the IAS. Note that the aim in the NL TS was to test whether the slicing priority mechanism behaved as expected and not to try and mimic an operational implementation of coexisting services. For an operational implementation, further measures would be needed to manage the use of resources by the services. For example, a Session Admission Control (SAC) mechanism for CAM sessions could be used to limit the number of parallel CAM sessions and their combined resource usage, to ensure that sufficient resources remain available for IAS. As another example, in radio resource portioning, a different technical approach, each slice is provided with its own radio resources which would thus intrinsically protect the IAS performance from the CAM SpS. A SAC mechanism would in that case still be useful to ensure that CAM sessions cannot crowd out one another.

The third conclusion in our assessment is that the impact of the SpS on the performance of IAS can be analysed, based on measurements or network dimensioning, for an operational situation. For the specific situation in the NL TS, it is not very useful as the network dimensioning is too basic for that.

Handling of potential differences between Member States in a cross-border case

A cross-border situation in itself does not introduce new points for regulatory assessment to the table because, as explained earlier, the EU Open Internet Regulation and the BEREC Guidelines apply in all Member States. However, cross-border situations can bring additional complexities because of the larger number of mobile networks involved and the larger potential for differences in network performance between networks and across borders. This is illustrated in Figure 5, which shows a cross-border situation with two Member States with three mobile networks each.

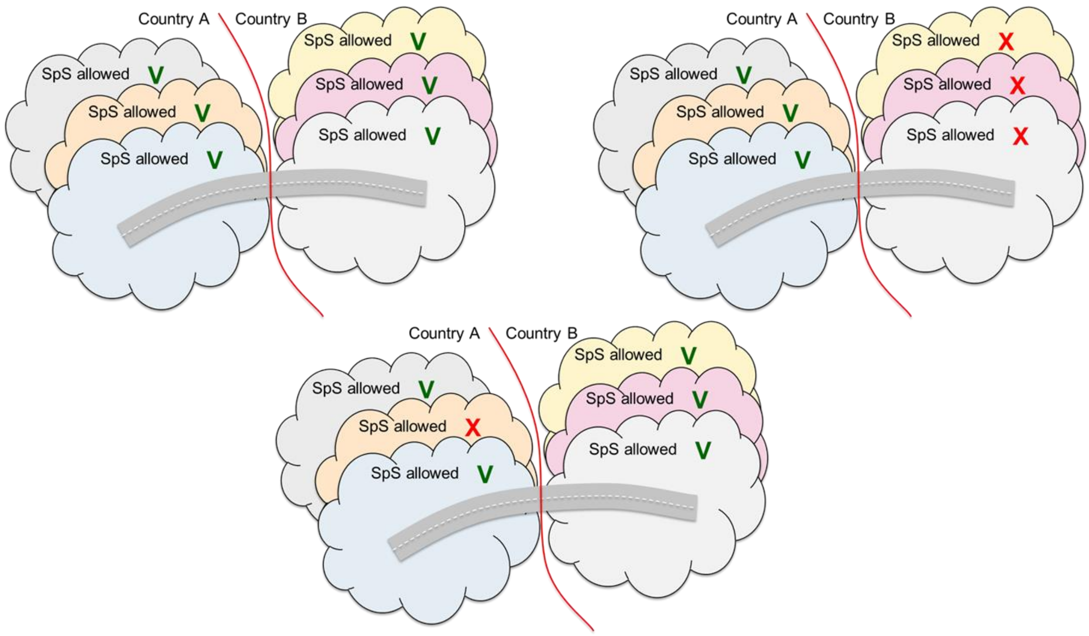

Figure 5: Three scenarios for regulatory status of a CAM SpS in a cross-border situation

- The most straightforward situation is shown in the top-left scenario: the CAM SpS is allowed to be provided in parallel to IASs in all networks in both sides of the border.
- In the top-right scenario, the SpS is allowed in all networks in country A, but not in country B. A cause for this may be a difference in the overall network performance on the two sides of the border. For example, if the performance of the networks in country B is across the board substantially better than in country A, this may imply that the CAM service can adequately be carried over IAS in country B, while it cannot meet the service requirements when carried over IAS in country A. The regulatory implication would then be that the CAM service is allowed to be provided as a SpS in country A (and also must be provided as a SpS to meet the technical requirements), while it is not allowed to be provided as a SpS in country B.
- In the bottom scenario, the CAM service is allowed to be provided as a SpS in all networks, except one network in country A. Again, the cause for this may be the better overall performance and capacity of that network.

We see that in the latter of the three scenarios, the logic in the regulatory assessment of individual networks leads to a situation with cross-border differences, which make it, to some degree, more difficult to come to seamless cross-border services. As in the national situation with differences between networks or geographic regions, one can think of an adaption of the regulatory approach, where one zooms out from the performance of the individual network or even the performance of networks per Member State. In the extreme case, one would then come to a single outcome for the whole of the EU on whether a specific CAM service is allowed to be provided as a SpS. The other approach is to stick to the more detailed network or member state-level assessments and leave it up to the CAM providers and mobile network operators to resolve the different provisioning models in their service provisioning, including their effort on seamless cross-border handovers.

4.3. WP5 results

This section aims to describe the requirements to be addressed to MNOs and the policy makers for guaranteeing the smooth running of cross-border operations. These requirements result directly from the cross-border issues experienced by one or more trial sites (including CBCs) during soft or hard border crossings. In addition, the cross-border issues have been delved into deeply in order to identify one or more possible ways (from both a technical and a regulatory standpoint) to address them and so to fulfil the related requirements. These possible solutions would be considered as the beginnings of an answer that need to be further investigated.

4.3.1. Cross-border requirement 1: Ensure continuity of roaming

Coming from: GR-TC CBC, ES-PT CBC, FI TS, NL-TS, FR TS, DE TS

Roaming interruptions should be considered as the first concern for MNOs to ensure an effective implementation of the CAM solutions in the NSA networks as well as in the SA networks. Indeed, 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 the steering of roaming that is currently implemented by MNO's, trying to steer the UE to a preferred network and by doing so deny certain roaming requests. In addition to this, currently roaming for SA networks has only been defined for basic roaming. No handover is specified, and furthermore, the equivalent of the S10 interface for Evolved Packet Core (EPC) (i.e. N14) has not been referenced as a roaming interface. Consequently, the same connection issues occurred on both NSA and SA networks during the tests performed by the trial sites.

Solutions to be considered:

- In the 5G NSA architecture, a S1 handover[3] is a normal handover procedure used within one PLMN when there is no X2 interface between the involved eNBs. It can furthermore happen that it also includes a change of MME, in which case the S10 interface[4] is also used. As an inter-PLMN handover always goes along with a change of MMEs, we can consider that it is possible to use the same mechanism. Same information as for an X2 handover is exchanged between source and target eNB but the MMEs are relaying it. The source eNB asks the target one to accept the UE and the target eNB provides its configuration information. This information is provided to the UE so it can adapt, if needed, to the target eNB settings and quickly connect to it. Nevertheless, it has to detach from the source eNB and then synchronize with the target one where it then performs the random-access procedure. Once this is done, communication is resumed as the source eNB transferred all RAN context information to the target one. Furthermore, the S10 interface can be used to conduct the core context transfer and routes are adapted towards the new serving target eNB.

- In the 5G SA architecture, the N2 handover procedure works in a similar way compared with the S1 handover previously described for NSA. Thus, in addition to facilitating the exchange of context data between the home and visited AMFs, the N14 interface plays a similar role as the S10 by acting as relay to exchange information between the source and target gNBs. The source gNB requests the target gNB to reserve resources for the UE. When the target gNB accepts it, the source gNB sends a "handover command" to the UE with information about the target network so that the UE can proceed and connect to the new network.

- "Release with Redirect" using the S10 interface is used where the UE needs to re-attach and re-authenticate to the new NSA network. This procedure is normally related to idle mode mobility, as it does not transfer context information between the source and target eNB. It therefore results in a service interruption as the UE attaches to the target gNB in idle mode and has then to transition to connected mode. The S10 interface connects two MME's and is most commonly used in a PLMN network, connecting for instance different regions in a country. In the core network, context information is exchanged between the source and destination core through the S10 interface. The UE does therefore not have to initiate the procedure to establish a packet data network connection as the session is resumed.

- In the "Release and Redirect" procedure in a 5G SA network, the N14 interface between home and visited AMFs is used in a similar way as with the S10 interface in NSA network, as it allows the visited AMF to

[3] A handover procedure using the S1 interface that is very similar to the handover procedure using the X2 interface, except the involvement of the MME in relaying the handover signalling between the source eNB and the target eNB.
[4] S10 interface is a control interface between different MMEs, used during inter-MME tracking area updates and handovers to retrieve data about user identity (IMSI), security information (security context, authentication vectors) and active SAE bearers (PDN gateways to contact, QoS, etc.) from the former MME to which the user was registered.

retrieve context information from the home AMF. In addition, the visited core is made aware of home UPF and UE IP address to speed up the re-establishment of the user plane in the new network.

4.3.2. Cross-border requirement 2: Improve inter-PLMN interconnection latency

Coming from: GR-TC CBC, ES-PT CBC

MNOs also have to fix the interconnection latency. Currently, operators interconnect using a GPRS Roaming eXchange (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. This latency issue must be solved by MNOs.

Solutions to be considered:

- Internet-based interconnection (e.g., IP Packet Exchange (IPX)) is the main solution followed by MNOs for roaming purposes. An efficient service guarantee can be offered by complying with service level agreements (SLAs). However, the Internet-based interconnection links between two MNOs do not necessarily follow the optimum routing path in terms of number of hops, since the traffic may reach its destination MNO via far-away nodes, still affecting the interconnection latency.

- Direct interconnection (via leased lines) is one solution that can be followed by MNOs for roaming purposes, especially for services that require low latency, such as CAM ones. The direct interconnection can secure the number of hops between two interconnected parties securely leading to low interconnection latency and better treatment of traffic management. However, this solution should only be applied at a regional level between operators, especially for big countries where operators have centralised core services. It means that each operator needs to keep traffic in a specific region (i.e. at the border) and create interconnects with the regions opposite to the border.

4.3.3. Cross-border requirement 3: Remove low coverage areas

Coming from: GR-TC CBC, FR TS, CN TS

On the other hand, MNOs must also tackle the problem of Low Coverage Areas. As a matter of fact, 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 take into account the max 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 incentive 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, which is threatening the CAM applications' continuity.

Solutions to be considered:

- Multi-SIM approach can address service continuity challenges for V2N connectivity in any geographical location where connectivity to two (or more) PLMNs is possible using a device containing a SIM (physical or embedded) associated with each PLMN and a central system steering to the most optimal PLMN. This location could be within national borders with coverage from multiple PLMNs of the same country, or in cross-border areas where there is an overlap of coverage from PLMNs of neighbouring countries. The multi-SIM solution could provide redundancy and/or minimise interruption time when moving between PLMNs with overlapping coverage areas. This is possible through a multi-SIM device either selecting the 'best or high priority connection or link (passive mode), or then the device utilising multiple connections in the same session (link aggregation or link bonding).

- Being able to provide continuous service and assist automated vehicles is challenging in rural or remote areas, including cross-border corridors, that are often left uncovered or late to be covered by terrestrial networks. In such coverage gap situations, NTN (non-terrestrial network) can be an attractive solution to ensure ubiquitous service offering thanks to its universal coverage. Different approaches can be used to decide when a vehicle should switch to NTN network. One of such solutions can be Predictive QoS.

- A vehicle's trajectory on the road/highway may cross the serving areas of different cross MEC systems of different PLMNs both within nation's border and at cross-border areas. In this context, a possible solution for service continuity in terms of MEC service discovery and migration can be based on enhanced DNS support through association of MEC with DNS edge servers for low latency applications[5].

- From a regulatory perspective, it is also possible to act on this requirement by thinking on a way to facilitate, foster or even enforce a minimum coverage rate specifically for the cross-border areas. For example, in some EU countries, the administrative burden for getting operational permit (i.e., for deploying a new base station) is considerably lightened when the new base station is located far away from permanent living places, which is typically the case in the cross-border areas.

- A last promising means of fulfilling the requirement is to use the mmWave bands (24.25GHz-52.6GHz), which can provide as high as 10 Gbps data rate, can be attractive for CAM services particularly those needing exchange of large volume data (e.g., collective perception). It is most likely that mmWave spectrum bands will be attributed to verticals allowing different actors (e.g., a road operator) to install 5G networks. Hence, mmWave 5G network would provide improved quality and service continuity in high dense or low network coverage areas (including at the cross borders).

[5] DNS-based solutions are surveyed in this ETSI ISG MEC white paper (Accessed June 2022): https://www.etsi.org/images/files/ETSIWhitePapers/etsi-wp39-Enhanced-DNS-Support-towards-Distributed-MEC-Environment.pdf

4.3.4. Cross-border requirement 4: Ensure session and service continuity

Coming from: GR-TC CBC, ES-PT CBC, FI TS, FR TS, NL TS, DE TS, CN TS

Concerning session & service continuity, another issue also raises: When directing the UE to new closer by 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. 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. 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, and so as to reduce the impact of mobility and ensure service continuity.

Solutions to be considered:

- The solutions presented in the previous requirement, related to the low coverage area issue, as well as those presented to address the roaming continuity issue, would contribute to ensure the session and service continuity but they need to be complemented by one or more of the solutions presented below.

- An application-based solution, during which an edge-based application server continuously compares the GPS coordinates of the OBU and issues an "imminent HandOver (HO) detection" alert once it is determined that the OBU has a trajectory towards national borders, and an imminent HO to a neighbouring network is expected. Once this alert is triggered, the server may proactively notify the OBU that it will soon receive a new IP address (once it crosses the border and the network triggers a data session reconnect) from a designated IP pool of the neighbouring network (if known) and communicate the IP address of the neighbouring edge node hosting the application instance in the neighbouring country. This is the new IP address that the OBU should transmit its data after the HO. This mechanism should enhance service level continuity, as the OBU will be pro-actively notified regarding its own IP and the edge servers IP, eliminating any search period in the neighbouring network.

- Another similar solution to allow for the transition between different edges without the application disconnecting is to use the proposed scheme where the application receives a notification from the application function when a new edge is to be used. The UE will need to set up an extra Public Data network (PDN) session allowing to connect to the new edge and the application at the vehicle will need to reconnect to the application running at the new edge. After this is completed, the old PDN session to the previous edge can be closed. The application functions would be running near the 5G Core having a connection with the Network Exposure Function (NEF)[6] to receive location updates of the UE. In comparison to the previous solution, we do not need GPS information from OBU and we only use 5G network information (from NEF). The other main difference is that the UE initiates the new data session and not the network.

- It is also possible, when the service requires a low latency connection with a MQTT server (i.e., upon a handover event), to create and deploy two instances of the MQTT server, one at the MEC of the home and another one at the visited PLMNs. The home MQTT is directly publishing the messages in the visited one (and vice versa), managing both MQTTs with the same information in every moment avoiding its segmentation in two MQTT servers upon the HO event. This solution should be considered as a required addon in any cross-border context and should not be limited to the MQTT protocol.

- In the same vein, and in complement to the previous solution, it is also possible to use two instances of the MQTT client, what we call the "double MQTT client solution". Typically, upon a handover event, an MQTT client is required to gracefully tear down its session with the MQTT server at the home PLMN and then establish a new one with the MQTT server at the visited network, resulting in a service disruption. The double MQTT client solution employs two client instances A and B with A being connected to the home PLMN server. Upon a handover event, client B initiates the session establishment procedure with the visited PLMN server, while A is in the process of tearing down the original session.

- When the service is rather requiring a high throughput, (but not very strict latency requirements), it is possible, upon a handover event, to create and deploy two instances of the same application, one is a server behind the MEC (connected via high-speed fibre) of the home and another one is at the visited PLMNs. Hosting the application in a server, instead of the MEC, would avoid the MEC saturation and give the service provider direct control over its application. Moreover, duplicating the server applications enables to manage the different regulatory issues in both PLMNs, if needed, and contributes to minimising the latency.

4.3.5. Cross-border requirement 5: Improve data routing

Coming from: GR-TC CBC, ES-PT CBC, NL TS

In addition, data routing issues have also consequences on service continuity and need to be solved by MNOs. When roaming normally, the data traffic will be routed to the home network and connect to the data network at home. Crossing the border will then lead to higher latencies. As an alternative it is also possible

[6] 5G Network Exposure Function (NEF) facilitates secure, robust, developer-friendly access to the exposed network services and capabilities of your 5G network, enabling third-party developers and enterprises to create and tailor their own composite or specialized network services on-demand, and helping you drive service innovation along-with and through an extended ecosystem.

that the UE uses a local breakout roaming, connecting to the closest edge which will result 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.

<u>Solutions to be considered:</u>

- It is possible to use a "Local Breakout" for NSA 5G networks: the user plane (UP) traffic of a roaming UE is served directly by the visited PLMN, while authentication and handling of subscription data is managed by the home PLMN. Specifically, only signalling data is routed to the home PLMN, which allows more efficient routing in terms of latency, whereas the IP address of a roaming user is obtained from the visited PLMN.

- In the opposite way, in "Home routed" for NSA 5G networks, the home PLMN provides the IP address for the roaming users and the user plane (UP) traffic of the roaming UE is always served by home PLMN, thus giving more control over the users' traffic. The MME in the visited PLMN contacts the HSS in the subscribers' home PLMN to obtain subscriber data. When the subscriber is accepted by the visited PLMN, the user plan to the packet data gateway (PGW) is established in the home PLMN where the subscriber's IP address is anchored. The main drawback of this model is the high latency incurred, since UP traffic must be tunnelled towards the home PLMN.

- In the same vein as for NSA 5G network, there is also an option to use "Local Breakout" for SA 5G networks. In this case, the UE sets up a PDU session with a UPF in the visited network. To setup a Local Breakout PDU session, the SMF in the visited network needs to contact the UDM in the home network over the N10 interface. All the other roaming interfaces (N8, N12, N21, N24, N27, N31 and N32) are also needed, with an exception for the N9 and N16 interface since the data stays local.

- In the same vein as for NSA 5G network, it is also possible to use "Home routed" roaming for SA 5G network. In this case, the data is routed back to the data network at the home PLMN. The data is routed from the UE to the UPF of the visited PLMN and from there to the UPF of the home PLMN over the N9 interface. While the latency of a home routed session will most likely increase significantly, this is probably the only data session that can continue to exist when a handover takes place from the home PLMN to the visited PLMN. In addition, it is also possible to have multiple sessions in parallel so next to a "Home routed session" an additional "Local Breakout" session can be set up to a local data network.

4.3.6. Cross-border requirement 6: Improve accuracy of GPS positioning

<u>Coming from:</u> NL TS

The weaknesses related to the positioning of the vehicle has also to be tackled. Today, the positioning provided by the Global Navigation Satellite System (GNSS) cannot meet the stringent CAM requirements (i.e., down to 20-30 cm accuracy) when a vehicle is moving indoors, such as, for example, in tunnels, indoor parking's/garages or lower decks of multi-level bridges. Moreover, GNSS has also strong limitations in dense urban environments and suffer from a refresh rate too low to be used in safety critical applications. Without accurate geo-positioning, CAM applications that require external information based on absolute position cannot merge this information onto local maps with relative positions (i.e., distance to other vehicles/obstacles, lane positions and so on).

Solutions to be considered:

- Augmenting positioning through the use of compressed sensing techniques on the OFDM signal (improves localization accuracy where only few reference base stations are available), taking advantage of angular information for angle of arrival/departure and sparsity of mmWave[7] channels.

- Other technologies such as Real-time Kinematic positioning (RTK) or combination of GNSS positioning with inertial system can also be used for providing higher accuracy of positioning, but these technologies have not been investigated in the project.

4.3.7. Cross-border requirement 7: Refine dynamic QoS continuity

Coming from: FR TS, DE TS

The QoS continuity can also raise some concerns. Indeed, when the vehicles move from one MNO to another in a cross-border area, a sudden drop in the network connection quality, in terms of bandwidth and latency may happen. This is usually due to an increased distance between the base station of the different MNOs and fading antenna coverage to avoid overlaps. Specifically in a roaming situation when the sessions and applications are resumed, a conservative approach could be more reliable as an eager communication rate can lead to performance degradation at the application level, in terms of steady framerate, high fidelity and continuous QoS, hindering the full potential of CAM solutions.

Solutions to be considered:

- A possible option to be considered can be the Adaptive QoS bitrate and framerate: depending on different thresholds mapping good and poor network performance for the intended application demand, the bitrate and the framerate are set to the nominal values (high fidelity) or downgraded to ensure that a suitable representation is sent in any situation guaranteeing a functional operation of the CAM application. The conservative approach starting with a low fidelity and upgrading to high, when possible, makes application resume faster and more reliable.

[7] Millimeter waves (mmWaves) are frequencies starting at 24 GHz and beyond. Because of its high frequencies, mmWave would lead to very high-speed and reliable 5G networks at the expense of a limited range of only 300 to 500 feet and difficulties to penetrate buildings. Until recently, mmWaves were only used by satellite and radar systems, usually operated by the military and aerospace industry.

- On the other hand, Predictive QoS is a solution that adapts application data rates based on predicted communication quality. Quality prediction is based on machine learning algorithms that trained using various information including quality, bandwidth, spectrum, cell occupation, uplink and downlink data rates, delay, user's position, speed, orientation collected from the cellular network, applications, and users. The predicted quality is then informed to users/applications via so-called In-Advance QoS Notification (IQN), in which the QoS prediction module suggests vehicles to adapt its e.g., video data rate to a given value etc. Upon reception of an IQN, the user/application adapts its data rate accordingly avoiding unnecessary packet loss and throughput degradation.

- Another solution can be used by the slicing feature of 5G networks. Indeed, it is possible to partition data and services in different slices to guarantee service performance in one network and across networks when roaming. Network slicing has been specified in 3GPP in various normative documents on the requirement level, on the architecture level, on the procedure level and at the management level [8]. Further information about these standards can be found in Chapter 3 of Deliverable D3.7. Two slices are created, one slice for regular Enhanced Mobile Broadband (EMBB) data and one slice for remote driving service, including uplink video and control data. Priority mechanisms should prevent the disturbance of remote driving data because of generated load in the regular EMBB slice. However, if the EMBB regular traffic is in trouble, it will be difficult to downgrade it further by prioritizing remote driving traffic. In that case, it can only be possible to warn the driver and maybe provide him with a temporary solution to give him the time to find a parking, for example. In addition, it is also important to remind that the priority mechanism between both slices must respect the European rules for open internet, including net neutrality, such as explained in Section 4.2.1..

- A last option can be to define and agree at EU level on common rules for maintaining a minimal level of QoS, particularly, at the cross-border areas in order to guarantee the safety (at least) of the CAM solutions and so ultimately the safety of EU citizens.

4.3.8. Cross-border requirement 8: Contextualise the geo-constrained information dissemination

<u>Coming from:</u> ES-PT CBC, FR TS, NL TS, DE TS, KR TS

The last issue is about the appropriateness of traffic information received by a connected vehicle when it is travelling close to the border. Usually, it needs to receive traffic information directly related to its surroundings (and not the whole flow of CAM messages) through the edge computing node to which it is connected. In addition, in a cross-border area, the vehicle may also want to receive some data from neighbouring geographical areas covered by a MEC node located in another PLMN, but again, not all CAM information exchanged through the neighbouring MEC is of interest to that specific connected vehicle. For

[8] The 5G-Mobix use of slicing technology follows these and other 3GPP standards.

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 only the relevant CAM data to the appropriate vehicles.

Solutions to be considered:

- A possible way to address this requirement is to combine the standard ETSI Cooperative Intelligent Transport System (C-ITS)[9] messages with an MQTT broker and a subscription system including a geographical topic. First, the information of standard ETSI C-ITS messages is disseminated via Uu interface[10]. Then, using a MQTT broker and publisher/subscriber architecture, the broker filters the information and forwards to the vehicles only messages from the infrastructure that are relevant for their driving direction and their current location/area. Brokers in contiguous areas, for example in a cross-border scenario, exchange the information produced in their areas. Therefore, a broker can forward relevant information from other broker to a vehicle in its area if the conditions are the right ones (e.g., a vehicle driving towards the border will receive information from the other side of the border).

- Another option is to use the PC5 interface[11] holding geo-localized characteristics by design. The Road Side Units (RSUs) broadcast infrastructure information (i.e., ITS messages) which is received only by the UEs in that PC5 coverage area, without the need of an MQTT broker. This solution is also used in specific use cases only requiring short-range communications, e.g., platooning. In a cross-border scenario, the information is received independently of the actual border side or registered MNO. If the UE is in the PC5 coverage area, it will receive the information. It is worth noting that using the PC5 interface can also address some other cross-border requirements such as the continuity of roaming and the removal of low coverage area.

4.4. Interviews with field trial leaders

This section explored the challenges faced by the trial sites during the 5G-MOBIX project. Individual interviews with the trial site leaders were performed to identify the challenges and issues faced before, during and after testing.

[9] Intelligent Transport Systems (ITS) embrace a set of communications-related applications intended to increase travel safety, improve traffic management and maximize the benefits of transportation to both commercial users and the general public. In Cooperative ITS (C-ITS), vehicles communicate with each other and with roadside infrastructure, greatly increasing the quality and reliability of information available about the vehicles, their location and the road environment.

[10] Uu interface, or UMTS air interface, links the User Equipment to the UMTS Terrestrial Radio Access Network.

[11] A PC5 interface enables the direct communication between vehicle and other devices (V2V, V2I). In this case, the communication with the base station is not required.

A guided interview was performed with the leader around three topics (two topics for the sites that do not include a cross-border site): technical challenges, cooperation issues and 5G-MOBIX role.

The individual answers can be found below and at the end a brief analysis to highlight the most relevant issues and recommendations were performed. The text below corresponds to the answers given by the trial site leaders.

4.4.1. Chinese trial site:

<u>Technical challenges</u>

- What technical challenges do you face related to 5G for CAM in your work or research activity?

The 5G-MOBIX project's main objective is to explore the potential and commercial value of cross-border 5G technology for CAM. How to simulate the problem solving of 5G cross-border issues in the Jinan site is the main technical challenge faced in their work or research activities. We employed multiple 5G MNOs to simulate the related scenarios, such as China Mobile and China Unicom.

To tackle the technical challenges above, we tried to deal with two technical issues specific to the cross-border sites: Low coverage Areas for XBI_4 and Session and Service Continuity for XBI_5. These issues are solved with the 5G-MOBIX's Considered Solutions: CS_4(Multi-modem / multi-SIM connectivity - Passive Mode),CS_5 (Multi-modem / multi-SIM connectivity-Link Aggregation), CS_6 (Release and redirect using an SA network), CS_9(Satellite connectivity), CS_10 (Satellite connectivity), CS_11 (Imminent HO detection & Proactive IP change alert), CS_12 (Inter-PLMN HO, AF make-before-break, SA), CS_13 (Double MQTT client), CS_14 (Inter-MEC exchange of data), CS_15 (Inter-server exchange of data), CS_16 (LBO NSA), CS_17 (HR NSA), CS_18 (LBO SA), CS_19 (HR SA) and CS_20 (Compressed sensing positioning).

- How would you solve or mitigate these issues?

The trial site has two sections, Jinan-1-SDAS and Jinan-2-SDHS, for three Use Cases. Jinan-1-SDAS has deployed with the 5G shared MEC solution provided by China mobile. Jinan-2-SDHS has deployed with China Unicom's 5G Standalone Architecture solution. Namely, two 5G MNOs were employed to simulate the Cross Border Corridor problems. In addition, we used the solutions CS_4(Multi-modem / multi-SIM connectivity - Passive Mode), CS_5 (Multi-modem / multi-SIM connectivity-Link Aggregation) , CS_13 (Double MQTT client) and CS_14(Inter-MEC exchange of data) provided by the 5G-MOBIX project, which can be used in the other sites.

- How could policy makers help in solving these issues?

The policy makers in the CN site include: MNOs, Road manager and city (park) manager. They support in simulating the cross-border sites with different MNOs: the SDAS (park/site manager) provided the test zone for Jinan-1-; the SDHS (road manager) provided an expressway for Jinan-2; two MNOs (China Mobile and Unicom) built the 5G network.

- Would regulatory guidelines or policies have helped with the issues encountered?

The Chinese government has made 5G guidelines and policies to promote 5G development and helped solve the issues encountered, such as building the 5G base station.

Cooperation issues

- What cooperation issues have you identified in your trial site?

According to the dynamic zero-COVID policy of China, we have many cooperation issues on our site. Firstly, the CN team worked in different cities, such as DUT researchers in Dalian city, the SDIA, CNHTC and SDHS researchers in Jinan city and DATANG in Beijing city. Thus, it is not easy to make face-to-face communication for dealing with the problems. Also, it is more difficult to make international communication with the EU partners, and the EU partners cannot visit and make further cooperation.

- Who are the key stakeholders involved?

The key stakeholders involved are: MNOs (China Mobile and China Unicom), 5G providers (DATANG and ZTE), Road/Park managers (SDHS and SDAS), and the vehicle provider (CNHTC).

- How would you solve or mitigate these issues?

We tried to make online meetings and forums to solve cooperation issues. In addition, we tried to have as many face-to-face meetings as possible.

- How could policy makers help in solving these issues?

The policy makers did what they could to help in solving cooperation issues. They applied and provided the cooperation fund. Furthermore, they offered the equipment and places.

5G-MOBIX role

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Technical

5G-MOBIX played an important role in the solution or mitigation of these issues. They provided the XBI-CS solutions to tackle many problems in cross-border scenarios. These solutions helped solve XBI_4 and XBI_5 issues.

Policy recommendations

DUT and other China partners expect to make further cooperation with the China government and the EU policy. We are glad to share innovative findings concerning the CAM use cases on 5G technology between China and Europe partners.

4.4.2. Finland trial site:

Technical challenges

- What technical challenges do you face related to 5G for CAM in your work or research activity?

One of the main issues that arise during the development of the project is related to the supply chain, time and availability of components. The timeline of the project happened at the same time as two major events that have had a global impact (COVID 19 and tensions with China).

Due to these circumstances, there was a shortage of 5G chip sets that affected the initial deployment and the second one when the replacement was needed. Therefore, the activities to be performed were delayed.

Another issue is that the technologies tested are not commercially mature (5G Standalone Mode technologies).

- How would you solve or mitigate these issues?

A way to help mitigate these issues, is not to leave policy makers alone in the market.

- How could policy makers help in solving these issues?

Ensure there is a constant or sufficient supply of key components for the rollout of 5G in the EU market. The European Union is already taking measures to ensure that there is no shortage. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_729

5G-MOBIX role

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Policy recommendations

For the regulators, there is a need to supply sufficient spectrum licenses for testing, it will also be helpful to relax some constrains that allow experimentation (as these are limited to specific test sites). Testing needs to be done without disrupting commercial networks, but there should be areas where testing could be done.

In CAM continuation of services (coverage) policy operators have to ensure the continued coverage along the way. Operators are giving coverage to different places and policy makers need to assure that there is no "blank space" in the coverage. The service should be standardized, even if the customer is from one operator, they should have coverage with the others (car with multiple connections to different operators).

There is a big challenge in rural areas, where the coverage of 5G is low and there may not be many transport means. There is no sense in having many operators to cover these areas, therefore sharing the infrastructure between operators or a "neutral host" to have the infrastructure would be the solution.

4.4.3. France trial site:

Technical challenges

- What technical challenges do you face related to 5G for CAM in your work or research activity?

Beginning in 2018 there have been a few challenges when performing the project activities in the site. There was a lack of public 5G network in the site at the beginning of the project until the end of 2020. Another challenge was that the system on the terminal side was not robust enough. The 5G mmWave is not mature enough at the moment. In addition, testing started in 4G networks instead of 5G.

- How would you solve or mitigate these issues?

Regarding the network, finding an area where there are available test networks ready to test. We also build our own device; and were in constant contact with the chip manufacturer to help solve arising issues.

- How could policy makers help in solving these issues?

Support from policy makers for the deployment of public network (spectrum allocation). It was under deployment and therefore not available at the beginning of the project.

- Would regulatory guidelines or policies have helped with the issues encountered?

In France, it is mandatory to have a network coverage on the roads, network operators must cooperate in order to provide coverage on the roads.

5G-MOBIX role

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Technical

We built our own device and were in constant contact with the chip manufacturer to help solve arising issues.

Policy recommendations

There is a need to increase 5G coverage in the motorways and areas where there is none and the policy makers can play a relevant part in this. However, the network can be deployed not only by public operators but also needs to be commercially viable.

4.4.4. German trial site:

Technical challenges

- What technical challenges do you face related to 5G for CAM in your work or research activity?

The main issues faced in the German trial site are not specifically technical, but they do affect the technical development of the work done under the project. The first one is in relation to COVID 19, the situation is changing rapidly and there are new generation chips that will arrive later (delays).

The second one is regarding the bureaucracy. If there is a need to use the public infrastructure, the timing and steps to request it is not clear. In addition, it is not independent of the political circumstances (willingness from some policy makers to advance and invest in these technologies, versus not interested parties). Also, there is not a clear figure (department, body) from the government who is responsible for public testing and use of public infrastructure (recently appointed but strained).

- How could policy makers help in solving these issues?

More independence for this new figure in charge of the licences. And a clearer strategy that can be implemented federally and "locally".

5G-MOBIX role

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Policy recommendations

The use cases on platooning depend on the vehicles being equipped with short range communications (5G application) architecture and the coverage or On-Board Unit that is 5G capable. The application used is able to work in both situations. The decision now is to select crucial sites where the infrastructure, and sensors RSU, are needed and can be most beneficial (black points). Due to the maintenance of road infrastructure being challenging and the cost high, private companies could do a better job on identifying locations where to deploy this technology.

Therefore, a decision at EU level should be taken rating the value of the deployment of this infrastructure or the value to invest in the vehicles (On Board Units).

4.4.5. Korea trial site:

Technical challenges

- What technical challenges do you face related to 5G for CAM in your work or research activity?

There were no major issues at the Korean trial site. One of the challenges was linked to the remote-control access; the team on the trial site developed the vehicles only for this project and had some issues when accessing the in-vehicle network. To solve the issue, the team signed a Memorandum of Understanding to receive the documentation on the in-vehicle networks.

On the site, Millimeter Wave (mmWave) 5G network developed by ETRI was used, the challenge was in the coverage of the network. We worked on setting the parameters properly, making sure the components would be available and working with three receivers, in order to face the challenge.

When handover issues arise (mmWave system missing) we relied on the On-Board Unit.

5G-MOBIX role

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Technical

Deployment of OBUs for automotive proposes. LG (Korean company) has OBUs prepared (prototype/sample). In addition, three mobile operators offer coverage in Korea (5G stations deployed in cities, highways… less in rural areas).

Policy recommendations

The government (Ministry of infrastructure, Land and Transport) has available public road testing in some cities to test vehicles. There are also 5G networks open to testing functionalities. In addition, there is, in place, an agreement between the researchers and the automotive OEMs.

4.4.6. Netherlands trial site:

Technical challenges

- What technical challenges do you face related to 5G for CAM in your work or research activity?

Regarding the 5G functionality for CAM, there is a lack of mature equipment (5G stand-alone equipment / built network) for the purpose of these type of trials. The standards are ready but the functionality is not yet there.

Another challenge is the dependency on one supplier (QUALCOMM/Huawei), not many suppliers in the market currently (it could also be a problem in the future). There were also delays in the supply of some components due to COVID.

On the public roads, the network was installed for the project.

No real OEMs are involved in the project (on this trial site) and therefore the service might not be "adjusted". Furthermore, parties involved that are not in the consortium, but involved in the project, as suppliers that are investing their own money and time (there is an interest).

All the challenges faced led to more testing done than what was planned.

- How would you solve or mitigate these issues?

Regarding the maturity and availability, is it key to build the functionality for the project, not for public use (low TRL level/prototype).

5G-MOBIX role

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Policy recommendations

Encouragement of CAM projects and testing. In addition, the improvement of traffic safety comes with a high cost but because it is a public matter, there should be an investment coming from the public.

As there are no European suppliers (integrators of chips but not suppliers) to mitigate the current issue and possible future challenges, it would be a good idea to invest in this matter.

4.4.7. Spain - Portugal cross border trial site

Technical challenges

- What technical challenges do you face related to 5G for CAM in your work or research activity?

General:

Lack of alignment in scope between technical centres and partners like telecommunications companies. Also, opposite interests when deploying/setting-up new technologies, between commercially interesting and technically viable.

Had to face in parallel many great challenges in a moment when the 5G is still a very innovative technology with hardly any experience in any field:

- The deployment of a national 5G network infrastructure for the pilot.
- The adaption of the connected devices used in automotive (OBUs, RSUs...) to the new channel of communication using prototypes of modems that are still under development.

- The design of innovative use cases that 5G has enabled.

Initially, the main challenge was the 5G module configuration to connect to the 5G trial networks, but that was solved after some weeks of work. The second problem is to have good measurements for the trial running, since the network performance is still unstable.

Function/vehicle:

From the automotive technology centre perspective, the major challenges faced are the preparations of the OBUs for enabling 5G capabilities, and the validation of the OBUs 5G behaviour which is becoming complicated due to the lack of powerful tools. The high latency in the 5G network to share information V2V and I2V.

- Are any technical issues specific to the cross-border sites?

General:

- The complexity of the relationships grows exponentially in cross-border scenarios. Lack of common authority between both countries.
- The interconnection between 5G networks from different PLMNS.
- The behaviour of the autonomous function under the handover process.
- The handover is still not working properly, especially from the home to the visited network direction.

Function/vehicle:

- The network handover increases the latency problems during this process.
- The challenging validation of 5G behaviour in OBUs regarding the handovers and network changes between countries.

- How would you solve or mitigate these issues?

General:

They try to get all the possible data that the 5G modem can provide so that they can monitor the device's behaviour, but for many cases, this information is not enough.

Task Force meetings and continuous communication with network partners to get the support and information to solve, fix and improve all the issues.

With more debugging from the network teams, collecting traces and analysing them. General network traffic needs to be monitored. Handover protocol needs to be optimized.

Function/vehicle:

Being patient and doing as much repetition of the autonomous driving manoeuvres as needed to get "valid" handovers to evaluate the CAM in such a scenario.

- How could policy makers help in solving these issues?

General:

More support and help from policy makers to promote these kinds of studies could help to improve and get better results faster in the future.

Function/vehicle:

Promoting projects like 5G-MOBIX, were based on the first trials, a high-level requirement can be defined to the network providers.

- Would regulatory guidelines or policies had helped with the issues encountered?

Maybe by enforcing better network coverage and higher reliability (with more base stations covering the CAM corridor), the desired performance will be easier to achieve.

Cooperation issues

- What cooperation issues have you identified in your trial site?

General:

Situations where technology does not work as intended and partners do not agree determining the root cause. Different criteria and requirements at project level depending on the partner, which generates conflicts and interferes with the development, progress, and achievement of the objectives of all partners involved and encourages individualism.

Most of the partners have too much work but few PMs, causing the lack of resources when the project needs them. Involvement of the partners in other projects, causing delayed collaboration when the project needs them. Throughout the whole project duration, some cooperation issues have appeared in form of delays in getting results of performing actions that have resulted in global delays for all the partners in the consortium. Also, lack of participation in deliverables and meetings attendance.

Sometimes it is difficult to debug the technical issues with the network providers and operators. The handover process needs to be closely reviewed by network operators. Many difficulties from local authorities to cooperate on the tests.

- Who are the key stakeholders involved?
  - Mainly telecommunication companies (NOKIA ES and NOKIA PT essentially) and any other "user" of the communication, with lack of deep knowledge in networking.
  - Coordination partners (PT)

- Local governments, automotive, local traffic regulators, investigation centres, universities, and network providers in both countries.

- How would you solve or mitigate these issues?

It could be useful to have an external observer, or third party, to determine the root of the technical issues. There should be a figure of a technical leader and not just a management leader at the project level. More support from the network providers/operators during configuration tests and trials is needed.

Some of the issues can be solved by first discussing directly with partners affected, and then escalating these issues to the overall project coordination head. Furthermore, communication with the project leader about the situation would be beneficial as he has the authority to take corrective decisions.

It is also very relevant to get policy makers involved.

- How could policy makers help in solving these issues?

Policy makers could provide resources to grant external technical supervision. Also, promote the R&D projects by establishing friendly procedures to get the approval for testing. Putting in place more aggressive penalties in case the results are not the expected ones. By promoting and facilitating necessary means for 5G projects.

It is difficult to see how they could influence the cooperation issues, but maybe by stressing, even more, the need for these 5G corridors to be fully operational in the near future.

<u>5G-MOBIX role</u>

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Technical:

Showing the state of the art nowadays for the technology and the minimum requirements to operate with it. Although sometimes the results obtained may not be as ideally or theoretically expected, the learning and knowledge achieved during the process will allow further research in the field of 5G and its impact on CAM from a more mature and realistic point of view. The experience accumulated during 5G-MOBIX shows that it is a time-consuming task to well configure and put into operation all the necessary network components in order to perform inter-PLMN handover at the application layer for CAM services. As a result, a detailed guideline should be produced to speed up the deployment and operational execution of these network services in the future.

Establishing starting points to improve interoperability between networks and delays in 5G communication.

Policy recommendations:

Including the requirements mentioned above, the validation criteria need to be approved by an independent validation centre before deploying this technology. And also, by promoting more tests on certain locations to make possible the application of 5G to transport.

4.4.8. Turkey - Greece cross border trial site

Technical challenges

- What technical challenges do you face related to 5G for CAM in your work or research activity?

Two steps preparation was needed before the test could start. An agnostic network test was performed by network related partners to check the installations. The application partners then could go ahead and test if everything is ready. Extra technical fine-tuning was required as there are different sensitivities.

We defined some policies and frameworks for the network but integration was not enough. There was a need of external access to the network and the firewall did not allow it, we had to adjust it.

In the platooning use case, specifically for the autonomous truck routing, the tool to see the trucks in the map (maps locations) had some integration problems.

- Any technical issues specific to the cross-border sites?

There were some crowded areas on the border with queues; therefore, the handover points/places in the area had to be changed. During the handover, even though the coverage could be extended in the area there were still challenges. Any changes that were implemented in one side (i.e. Turkish side), the other side also needed to apply them (timing was key).

Even though permission was granted to do the public testing, officers in locations asked for further notice.

- How would you solve or mitigate these issues?

To solve the problems related to the network, additional definitions and changes were made in the network.

- How could policy makers help in solving these issues?

Support from the officials (public authorities) is needed as some issues on site might arise.

It is helpful to previously have some EU-funded project-related experience. Provide a specific procedure for these specific situations.

Cooperation issues

- What cooperation issues have you identified in your trial site?

Timing and communication between both sites were key to preventing (and mitigating) any issues that might arise in the cross-border trials. The synchronization between both sites had to be planned, in order to do so, weekly meetings were held, all actions needed to be verified, and all partners needed to be involved.

As all partners involved worked together and the communication was constant, no major issues in regards to cooperation arise.

5G-MOBIX role

- What could be 5G-Mobix's role in the solution or mitigation of these issues?

Technical

It is very relevant to share a detailed description of the experiences faced in the project. Good compass for future projects and real-life deployment.

Policy recommendations

Clear procedure to follow and to allow this type of testing.

4.4.9. Highlights from the interviews

After the interviews with each trial site leader and considering all the issues and challenges faced by them in their sites during the development of the 5G-MOBIX project, the following issues should be highlighted.

COVID-19

Even though it is a temporary issue that will not affect projects and development/deployment of these technologies in the future, it had a significant impact on the testing that occurred during the 5G-MOBIX project. Most of the testing performed had to be postponed.

Another issue that derived from the pandemic was the shortage of components available. Due to the lockdowns and reduction in production and deliveries, the components needed for testing the 5G-MOBIX use cases were not available on time and more delays occurred. On the components, it is also relevant to highlight that there are no European suppliers (integrators of chips but not suppliers) and therefore there is a dependency.

Availability of infrastructure

In most trial sites, the infrastructure was not available before the project started and therefore it was deployed during the project that provoked more delays. It was however available and ready at a few of the sites, which made the trials run smoother. In addition, the process of getting permission to use the current infrastructure was either long and complicated or not clear.

Network coverage

Even though there are a few examples where there was pre-existing regulation that facilitated network coverage (Finland: all clients (cars) should be able to be covered by all the operators. France: mandatory to have network coverage on the roads, network operators must cooperate in order to provide coverage on the roads); in most sites, it was not the case.

One of the objectives of the interviews was to identify the challenges/issues that were faced in the trial sites, summarized above.

The other objective was to identify the solutions that could already be implemented by the public authorities, which will help develop and deploy 5G for CAM in the future.

The process and body that grants permission for testing on public roads should be clearer and easier. Moreover, a specific department/body/agency should be in charge of granting licences (for public testing) and all the government bodies should be aware of their work and the extent of the licences they grant. If local authorities, like border police, are not aware of the extent of the licence granted by their government, then it is not very useful to request a licence in the first place. In addition, the licences should be less limiting and restrictive.

Public authorities should also enforce better network coverage and infrastructure. They should provide 5G guidelines and policies to promote 5G and its development. They also will need to rate the value of the deployment of the infrastructure or the value to invest in the vehicles (On Board Units). Furthermore, in rural areas as there is not so much coverage yet, shared infrastructure should be promoted as there is no use for many operators to cover these areas, it is best if shared or neutral host are in charge of them.

The European Commission is already encouraging CAM by funding related projects and keeping the topic in the discussions; however, it would be helpful if the results of the different projects are considered in the policymaking and the recommendations implemented.

In addition, more investment is needed in safety and a European supply chain (as currently there are no European suppliers, and integrators of chips but not suppliers).

Overall, public authorities need to create a standard regulation at EU level, which will help mitigate the challenges that were mentioned above.

4.5. Recommendations from the ICT sector, road operators and car industry

4.5.1. ICT Sector

In order to create a fast-growing market of 5G for CAM services, there needs to be improved cooperation when it comes to the standardisation of interfaces and data formats to ensure interoperability but also data portability. Furthermore, the specifications for 5G services need to be standardised and include their QoS requirements and the limits under which the services are expected to degrade or fail.

The concerns over the use of data-intensive services based on Artificial Intelligence and highly-automated ITS are highly relevant to the future of CAM. Improved and complex functionalities may require the use of massive data collection over periods of time. This needs to be performed under the confines of the GDPR and the new ePrivacy Regulation. More guidance is also provided by the Commission on how data should be stored, transferred, shared etc. within the "Guidelines 01/2020 on processing personal data in the context of connected vehicles and mobility related applications"[12] provided by the European Data Protection Board. The guidelines provide an overview of the rights of the data subject, the obligations of data controllers, as well as the provision of data to third parties. It also exemplifies cases studies such as:

- Provision of a service by a third party
- eCall
- Accidentology studies
- Tackle Auto theft

It is also important to note, that the connected vehicle, as well as all devices that connect with it, are considered as per the guidelines as "terminal equipment" and as such, it must align with the protections under the ePrivacy Directive. This is particularly important for subscribers of 5G-CAM services, since it prevents lock-in conditions for the end user/driver.

The need for ethical data proxies can be a potential solution to the challenge of sharing data among different parties, as data intermediaries that provide encryption, anonymization/pseudonymisation on the fly, and manage who is authorised to access this data and under authenticated access only. This is particularly relevant in the Cross-Border setting, in order to adhere to the principle of data minimisation and becomes even more critical in hard border cases, where GDPR-level protection may not be applicable. This recommendation is aligned with the new proposal for the EU Data Governance Act that was recently put on a vote in the EU Parliament and is awaiting approval by the Council of Europe as well as its official publication in the Journal of the European Union.

This new proposed regulation[13] for Data Governance sets down rules for the reuse of data by the public sector and enables the creation of sector-specific data spaces. This can enable all related 5G-CAM stakeholders to exchange and reuse data. It further hopes to incentivise individuals to share their data and promote "data altruism", which requires a root of trust to be established. To uphold trust, the European Commission has proposed a set of measures such as the creation of Data Intermediaries. Data

[12] https://edpb.europa.eu/our-work-tools/our-documents/guidelines/guidelines-012020-processing-personal-data-context_en (Accessed June 2022).

[13] Proposal for a Regulation of the European Parliament and of the Council on European Data Governance (Data Governance Act) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0767 (Accessed June 2022)

Intermediaries will have to comply with a set of strict requirements to ensure neutrality and will be able to handle safe sharing of data among individuals, public and private organisations. This role can be undertaken by Cloud providers, data brokers, etc. This legislation also protects individuals from data sharing abuses and provides new rules for the transfer of their data, so they can effectively switch between different service providers, thus avoiding lock-in conditions from the standpoint of application providers and industry. The possible democratisation of data access can in turn lead to the development of more intelligent CAM services. This is corroborated by the results of a public consultation on trust of automated vehicles[14], where 98% of Industry actors found value in the re-use and sharing of CAM data.

Based on trial site interviews and results from public consultations[15], on the side of the Telco operators, there seems to be a need for flexible spectrum licensing and payment methods as these can potentially affect the investment in new infrastructures. Clarity in the process and the persons involved from the side of the National Authorities was also mentioned as a requirement. 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 the leasing of additional frequencies and the additional licensing processes for the development of infrastructure (e.g., antenna placement etc.) should be fast.

Particularly in the cross-border case, recommendations are focused on harmonisation and roaming. The European Commission has adopted multiple decisions to harmonise the frequency bands required for 5G Deployment. However, cross border harmonisation issues may arise in the case of hard borders where non-EU countries are not required to implement these decisions. For example, 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. The latest effort by the Commission, includes a decision for harmonisation on the 26GHz band, which the Member States are required to implement.

In the case of Roaming, it remains to be clarified whether the extent of current Roaming regulation is applicable for M2M communications and what the definition of "fair use" entails. There needs to be harmonisation in the way Roaming is implemented, billed and taxed. The negotiation policies among telcos regarding roaming need to be simplified. Transparent mechanisms will also need to be in place (such as notifications) so that the driver is always apprised of a switch between networks. ENISA has also

[14] https://digital-strategy.ec.europa.eu/en/summary-report-open-public-consultation-connected-and-automated-mobility-cam (Accessed June 2022)

[15] Results of Public Consultations on the granting of rights of use for radio frequencies in the 700 MHz, 2 GHz, 3400-3800 MHz and 26 GHz Frequency Bands, Hellenic Telecommunications & Post Commission.

recommended[16] the use of national roaming to prevent outages and service interruptions. This can greatly enhance 5G coverage, especially in rural areas, secondary roads, etc. However, national roaming is not available in all EU Member States. National electronic communication regulators are key stakeholders in order to help implement national roaming policies.

Furthermore, as exemplified by the EU Cybersecurity Toolbox[17] as well as the European Commission's proposed Chip Act, there need to be sufficient reliability and security in the supply chain. The Cybersecurity Toolbox proposes that National Authorities be granted additional power to monitor procurement processes and exclude suppliers that may prove to be compromised in terms of cybersecurity. The Chips Act[18] is proposed as part of EU policies on Digital Sovereignty, to combat interruptions to the supply chain due to semiconductor shortages. The importance of this Act is also verified by the trial sites that experienced shortages and delayed roll-out, as corroborated by trial leader interviews.

4.5.2. Road Operators

The introduction of automated vehicles in public road networks presents a new challenge for road operators in the relation between infrastructure and road users. Although the rules and context of vehicle operation is expected to remain the same, the automation of driver tasks must include all the safety and compliance demands a human driver should abide to. Some rules can be computationally modelled, and some others fall into the behavioural and cultural domain.

The road environment community of stakeholders has also evolved into a more shared space, where soft modes and new mobility forms are increasing the complexity of the road and the coexistence of different classes of vehicles and pedestrians. Road Operators are committed to the introduction of high-level automation in both vehicles and infrastructure but given top priority and concern to all matters having an impact on road safety.

Considering the regulatory issues that may have a strong influence in supporting cross-border automated vehicles in the next generation of connected mobility and the policy measures that may be taken to support them, the main issues and suggestions for policy recommendations from a Road Operator perspective are depicted below in detail.

- Higher levels of automation, that have road infrastructure requirements such as surface marking or telecommunications support, should require validation to be active. The validation could be achieved by including AD levels in HD Map information or by broadcasting

[16] ENISA report "National Roaming for Resilience" https://www.enisa.europa.eu/publications/national-roaming-for-resilience (Accessed June 2022)
[17] EU Cybersecurity Toolbox: https://digital-strategy.ec.europa.eu/en/library/eu-toolbox-5g-security (Accessed June 2022)
[18] EU Chips Act: https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en (Accessed June 2022)

allowed AD levels in I2V services (e.g., 'SAE Level Guidance' service defined in C-ROADS Release 2 aims to provide information on which SAE levels are not-suitable for a specific road section, noted that this should be understood as a guidance service, not as a strict regulation, for in vehicle's own decision-making processes). Common guidelines must exist to define the compliance of vehicles with infrastructure conditions (e.g., adoption of guidance/regulation services), including cross-border borders.

- Extended sensors allow the increased visibility and awareness of a vehicle's surroundings, shared information measures where levels of reliability and precision related to the different data elements provided by sensors are included (e.g., CPS) and security mechanisms (e.g. adoption of EU CCMS) to ensure that all data exchanged is reliable and not susceptible to manipulation by third parties should be agreed. Policies regarding the handling of Road Infrastructure sourced sensor information and shared vehicle awareness information must define the priority and validity of overlapping or conflicting data.
- Safety and reliability of AV handling and manoeuvre is heavily reliant on global positioning systems and HD Map information, which do not have enough precision for kinetic calculations. For most high-precision AV functions, local positioning systems and HD Maps should be adopted, supported by infrastructure location reference services.
- It is not expected that vehicles can include all traffic laws and regulations in their AV functions. Specifications and specific regulations must be developed in a common format to describe the general laws and regulations, as well as the laws and regulations applicable locally for specific conditions. Ongoing standardisation works on Management of Electronic Traffic Regulation (METR) should be covering this aspect. Specifications should take the Vienna convention and existing related standards as a base for an I2V service or HD Map data layer to allow the vehicles to receive traffic law compliance instructions for ADAS systems.
- From a traffic management point of view, platooning is a specific vehicle formation that already exists with human driving. The rules for platoons of vehicles, for example in emergency and military formations, restricts the flow of traffic for remaining drivers. C-ROADS Release 2 contains the "Platoon support information" service whose purpose is to provide road operator-based guidance and information on the unsuitability of "platooning" on specific road or lane segments on their network, considering different vehicle classes, overall road conditions and the current traffic situation, but as SAE level guidance, this is information for the vehicle's decision support system, not regulation. Specific regulations must be created for the existence and limits of automated platooning, and the ADAS for all vehicles member of a platoon must comply with manoeuvre enforcement measures that reduce the impact for remaining road users.
- Road traffic is based on the principle that each vehicle has the responsibility to perform according to the rules of traffic while ensuring observance to safety conditions in the surrounding. Remote driving allows for an operator to replace the driver, being limited to the capabilities of the vehicle sensors and communications, much like the highest level of SAE driving. Specific regulations must

be created to define the conditions in which remote driving is allowed and to assure the liability for operators in case of incident or non-compliance to traffic laws.

- The rise of automated interaction with vehicles driving components, along with the meaningful interference of digital telecommunication services in ADAS, shall require the creation of specific regulation for black box information and road accident recording. As such information is not only required for legal and liability purposes, but also as a key factor to improve the resilience and reliability of AV. Such work is currently underway[19] within UNECE WP.29 on Data Storage System for Automated Driving (DSSAD).
- The technology of AV for higher levels of SAE autonomous driving and remote driving can, and should be, used as additional safety measures regarding human failure. Systems such as detection of illegal substance abuse or sudden illness or driving monitoring systems can be regulated as future mandatory base functions of AV, along with the support for contingency stops and automated malfunction response manoeuvres with or without road infrastructure support.
- The coexistence of AV with other conventional vehicles on the road requires the creation of specific regulations regarding the need to support additional safety measures in AV, prioritization of road traffic, maximizing road safety and performance. Using high level automated functions in environments with presence of pedestrians and/or vulnerable road users (VRUs) shall require certification/validation or rating of safety levels for a vehicle to operate in automated mode as well.
- To reach the full potential of CAM technologies in road vehicles, the conventional vehicles must become, more and more, connected vehicles. This technology should not only benefit new vehicles manufactured with specific applications for connected mobility. In particular for awareness and safety functions, there must be a development policy that allows this technology to be available for conventional vehicles by retrofitting them with connected V2X systems.
- The communication in V2V and V2I must safeguard all aspects related to privacy and secure data handling, making available only the relevant data to the involved parties under the principle of driver consent. Some AV functions rely on the detection and tracking of specific vehicles, by recording and processing data that is needed to remain trackable for a certain span of time. Specific regulation must be developed to handle the ability of automated systems to perform data processing in closed context, assuring the privacy of tracked and recorded data.
- Higher level functions of CAM like overtaking or lane merging, in mass transit or high-performance roads, once it will be regulated, may require arbitration between the involved parties depending on the implementation model. Road Operators may provide such arbitration and manoeuvre coordination. For that purpose, it shall be necessary to create specific regulation that, considering a same legal status for V2X messages and traffic signs, provides a framework for infrastructure action and vehicle abidance by ADAS, including the possibility of non-compliance by any party involved and observing liability aspects in the case of Real-Time Multi-tier Processing and remote driving, recommendations include:

[19] https://globalautoregs.com/rules/252-data-storage-systems-for-automated-driving (Accessed June 2022)

- Define whether road operators in each country are willing to act as mediators and take responsibility for the management of such warnings. (As a current example, the position of some road operators (e.g. Sweden) is that they want to interfere as less as possible).
- KPI verification of sensor operation. Some of the usual KPIs are vehicle manoeuvres, safety measures, environmental impact or network efficiency within the car. Checking the data at the beginning of the process ensures that the system works properly.
- Raising the level of data processing. With traditional data storage methods, the results must be stored on a NAS-based system and then transferred to workstations. This process has two drawbacks:
  - Large amounts of data must be moved, which requires considerable bandwidth and operating time.
  - Individual workstations do not offer the massive computing power required to return results quickly enough.
  - Employ work environments that allow processing and storage to be scaled to hundreds of petabytes (e.g., open-source Hadoop for programming distributed applications that handle large volumes of data)
- Harmonisation in data standards. More sensors that can cover a type of information. The final decision will be based on the action that indicates the largest number of sensors in case of inconsistency. However, much work remains to be done in this regard in terms of ethics and prioritizing actions when lives are at stake. Furthermore, there is a need for further harmonisation in data standards, interoperability and ensuring data quality, observing also that in case that not only metadata is shared (e.g. as it is the case when using CPMs) but going further and sharing raw sensor data, IPR aspects should be taken into account.

In the case of Autonomous Vehicle Regulation Compliance and QoS Support, recommendations include:

- Definition of an international regulation and an associated set of drivers who must outperform both the on-road equipment and the ADAS in order to guarantee the quality of the service.
- Definitions, associated measurement methods and guidance objectives for road-centred parameters.
- Definition of the exact metrics (e.g., minimum performance, maximum latency, etc.) that information has to transfer during the handover procedure in cross-border environments. Quality of these metrics should rely on both MNOs and OEMs as network and vehicle application owners respectively, ensuring that handover must operate independently of the equipment, vehicle and external factors. It must be possible to ensure that the minimum requirements are met in order to be able to switch from assisted driving to manual driving without risk to users.

4.5.3. Automotive OEMs

This section aims to describe the requirements of automated vehicles for cross-border operation by identifying the possible regulatory issues that automated vehicle may encounter during soft or hard border crossings and then proposing solutions from the perspective of OEMs. In 5G-MOBIX project, we study five different use cases comprised of advanced driving, vehicles platooning, extended sensors, remote driving and vehicle QoS support that are classified under 3GPP TS 22.186 R16. In this section, we provide the regulation issues that are already identified with additional concerns and respective solutions, as discussed with 5G-MOBIX partners.

- EU policies in support of the reduction of technological expenses in vehicles. Perception and localization related capital expenditures (CAPEX) are standing as an obstacle for autonomous vehicles to be readily available on the market. Road operators may provide this information. Thus, cost/benefit balance can be ensured for OEMs.
- Compliance with at least FCC and CE marking regulations. This should guarantee that the vehicle is able to operate legally in most of the countries.
- Definition of associated set of test cases that an autonomous vehicle has to pass in order to be authorized to drive on public roads.
- Use of geo-fencing to restrict the AD functions to operate only on the operational design domain where they have been authorized.
- Regulations allowing Platooning applications in hard-border crossings to be switched to remote driving by an operator or a cloud, because at hard-border settings platooning should be dissolved for security controls.
- Vehicles on-the-road should share their safety distance level for emergency braking situations or other applications and corresponding information.
- Regulations and homologation processes in different countries should be unified. Compliance to several regulations can be costly from the perspective of OEMs.
- There should be unified messaging list for each CAM application, and each vehicle should transmit and receive these messages among themselves. Moreover, since not all CAM applications are supported by each vehicle, the ability to support related CAM application should also be provided as a separate message.
- In case of different traffic laws of neighbouring countries, autonomous vehicle should be capable to adapt its driving condition with the help of the information provided by RSUs and HD maps.
- To increase the speed of the security control process in border settings, additional sensors to monitor the goods on vehicles may be mandatory. Sharing related vehicular information in advance may decrease the inspection time.
- Enabling regulation for the use of Autonomous cars for on-demand transport services in a sustainable Mobility-as-a-Service scheme – this can alleviate impact of epidemic and pandemic occurrences such as Influenza or COVID-19.

- CAM applications that are ensuring safety of VRUs should be mandatory for all vehicles, because in regions where mostly high-level AVs exist, pedestrians tend to expect AVs to brake automatically. Thus, in case of duality, fatal accidents could emerge as expectations of pedestrians would not meet the ability of vehicle.
- All AVs must be able to perform safe stop in case an unknown environment is encountered.
- All AVs should be reachable by traffic management centres in order to exchange information to optimize traffic and there should be a specific messaging list for this purpose.
- All hardware and software components of AVs should be compliant in a global manner. For example, allowed frequencies for radar and LIDAR sensors should not vary from one country to another as vehicles cross the border.
- Align infrastructure maintenance entities with map providers so that whenever the first do changes the second can update its database. Add a certificate to the map information so that when it is updated in the car the source can be trusted.

4.5.4. Overview of stakeholder cooperation challenges

Based on the input from trial site interviews, stakeholder inputs as well as previous analysis performed in WP6.4, we summaries the key cooperation issues that arise in the context of 5G-CAM. The table below provides a high-level overview of the issues identified, as well as the stakeholders that have a vested interest.

Table 1: Overview of stakeholder cooperation issues

Challenges	Description	Stakeholder cooperation involved	Source
Roaming	International cooperation among telco providers is necessary to solve technical and organisational issues. Legislative measures might be required in order to clarify billing/taxing of M2M roaming.	EU and International Cooperation (esp in cases of hard borders) BEREC and National Authorities can be key stakeholders in the definition of harmonised rules.	BEREC recommendations
National Roaming	In order to combat outages that could leave customers without service, national roaming should be enabled	National Regulators, Telco operators.	Stakeholder inputs

	and particularly for M2M communications. This can greatly improve 5G coverage for CAM, particularly in rural areas and secondary roads.		
Incentives for infrastructure sharing	Infrastructure sharing can also serve to improve coverage, especially in rural areas, as well as in tough propagation environments such as tunnels, etc. There should be incentives in place in order to roll-out experimental or commercial infrastructure sharing.	National Regulators, Telco Operators, National Governments, EU policy makers	Interviews
Data Governance	Take into account the new EU proposal for Data Governance. Maintain compliance with EU legislation across hard borders.	Infrastructure providers, data producers/consumers, data intermediaries.	Stakeholder inputs
Spectrum	Spectrum harmonisation across borders. Flexibility in spectrum licensing.	National Regulators, Body of European Regulators for Electronic Communications (BEREC)	Interviews, Results of Public Consultations
Standardisation	Standardisation of interfaces, deployment templates/descriptors, map formats, data formats etc. Introduction of certification mechanisms.	ETSI, and other international SDOs	Stakeholder input
Policies in support of CAPEX/OPEX reduction	Perception and localization related capital expenditures (CAPEX) are standing as an obstacle for autonomous vehicles to be readily available on the market.	EU legislators, Automotive OEMs, Road Operators National regulators of electronic	Interviews

	Policies in support of passive/active network sharing	communications & Telco providers	
Establishment of rules for minimum CAM services provided	There should be a way to ensure that a necessary subset of critical services is mandatory in all vehicles, e.g., for vulnerable road user protection.	EU legislators, Telco providers, Automotive OEMs	Stakeholder inputs
Cybersecurity	Cross-border threat information sharing.	Infrastructure providers, Application developers.	Stakeholder inputs, Results of public consultations
Security and Reliability of the Supply Chain	Ensure uninterrupted supply chain and EU resilience in case of disruptions. Ensure security of supply chain and trust to chip suppliers	EU policy makers, national regulators.	Interviews, Stakeholder inputs, Results of public consultations

5. RECOMMENDATIONS

Autonomous driving is a very critical functionality as it affects the safety of the passengers of the vehicles. Accordingly, the correct behaviour of the functionality must be assured under all circumstances. Policy makers and regulatory entities should take all required measures to secure this.

The extensive number of tests performed in 5G-MOBIX produced a long list of recommendations for policy makers and regulatory entities, which are depicted in this section. The recommendations focus on ensuring the safety of passengers and other road entities and can be summarized in the following ones:

- Ensure network coverage along the places where autonomous driving (V2X communication) will take place.
- Ensure the communication quality of the entities participating in the autonomous driving functionalities by certification of vehicles, road elements and also cellular networks.
- Foster cooperation between MNOs to cover cross-border areas, and also to share infrastructure in those cross-border areas where there is no commercial interest to develop several infrastructures.
- Increase support to improve technical and cooperation issues related to V2X communications, especially in cross-border areas. Take special attention to existing gaps, especially in cybersecurity, scalability and Interoperability.
- Promote coordinated development of non-existing infrastructures along Europe.

This section includes recommendations for policy makers and regulatory entities. These recommendations are sometimes also applicable to other parties, especially for MNOs which should have closer cooperation with them. Recommendations for the ICT sector, road operators, car industry and automotive OEMs have already been developed in section 4.3. Recommendations for standardization are part of task WP6.3 and they are not listed in this section.

5.1. Recommendations for policy makers

Policy makers take a highly relevant role in the development of autonomous driving functionality. They must foster its development by assuring the required conditions and easing the steps to remove the existing gaps. They must develop the legal aspects to ensure a safe service and cooperation between parties to ensure this as well as a commercially viable business model.

The most relevant recommendations for policy makers are depicted in the table below.

Table 2: Recommendations for policy makers

No.	Recommendation	Target body
1	For CAM services, policy makers have to ensure that MNOs provide consisted coverage along relevant routes. Target area: 5G Timeline: Medium term	Authorities, MNOs
2	There is a need to increase 5G coverage in the motorways and other roads where there is no coverage. Policy makers need to play a relevant role to improve the situation. In any case, the networks deployed need also to be commercially viable. Target area: 5G Timeline: Medium term	Authorities, MNOs
3	There is a big coverage challenge in rural areas, where 5G coverage is limited and it might be difficult to provide backhaul transport services. It makes no sense to have many operators' infrastructure covering these areas, therefore sharing infrastructure between operators or a "neutral host" to have the infrastructure could be an obvious solution. Authorities should encourage MNOs to share infrastructure especially in areas with low population. Target area: 5G Timeline: Medium term	Authorities, MNOs
4	MNOs coordination within a country in case there is a loss of coverage from one operator to have a backup operator providing the services. MNOs are expected to compete and create a healthy market but because of the criticality of CAM applications, operators should support other operators even if there is an expense. Target area: 5G Timeline: Long term	Authorities, MNOs
5	MNOs coordination between MNOs in different countries. Each MNOs has to provide target eNB information (for NSA) so that an inter-PLMN handover	MNOs

	can be completed in a short time. The exchange of information among MNOs should follow an automated procedure. Target area: 5G Timeline: Medium term	
6	Further research is needed. Relevant areas are at least: 1. Selection of PLMNs before handover based on signal strength, capabilities and roaming agreements (not tested and probably not yet possible) 2. Making sure the technology also works when moving from a visited network to a new visited network (not tested in our project). 3. Making sure the technology works cross vendors. 4. Define the optimal handover parameters based on the status of the technology (e.g., receiver sensitivity) and produce guidelines for deployment. Target area: 5G Timeline: Long term	MNOs
7	Today there is no network certification for performance. The authorities can state requirements when auctioning the spectrum. After that they can test for compliancy. However, in most countries MNOs are responsible to provide relevant information (statistical results) about performance (coverage, throughput, availability, etc.). Considering the criticality of the performance of the network to support services some kind of certification or approval mechanism should be developed. Target area: 5G Timeline: Medium term	Authorities
8	MNOs network deployment includes a large number of base stations (RAN elements such as eNB and gNB) plus other network elements (MME, etc.). As software is the key component of any of those elements, it is obviously subject to permanent updates. MNOs typically program tasks to automatically perform those software updates as these cannot be done	MNOs

	manually due to the huge number of elements to upgrade. However, RAN elements at cross borders may need to be configured and parametrized differently than RAN elements in other geographical areas, thus the upgrade has to be carefully controlled. There is also a time constraint, as the upgrade of the network does not take place instantaneously in all elements but in batches or sequentially by groups. Thus, having elements upgraded and elements not upgraded closely may produce unexpected behaviours. MNOs should develop procedures to ensure that those updates do not negatively affect CAM applications. Target area: CAM Timeline: Long term	
9	Controlling where the handover takes place at a cross-border is challenging as the receiver characteristics of each vehicle can be different, terrain and signal propagation is different, etc. Typically, any base station supports various frequency bands making the handover process much more complicated to control. To simplify operations the recommendation is to favour handover at the cross border in unique frequency bands, not for the whole bands supported by the base stations. Target area: 5G Timeline: Long term	MNOs
10	Characterization of performance behaviour and minimum target values of either the network or the vehicle terminal is complex. There are no standardized measurement methods. The recommendation is to agree on a common methodology that will allow auditing the conditions of the deployment and the vehicle radio signal behaviour. International coordination, not just in Europe, and making use of the experience of established organizations such as GCF should be sought. Target area: 5G Timeline: Medium term	MNOs, OEMs, authorities
11	In vehicle monitoring, sensors should be standardized (interfaces, data format, etc.) to increase market volume and to facilitate incident analysis. Target area: CAM	OEMs

	Timeline: Medium term	
12	More support from policy makers (such as the European Union through research funding) to improve technical and cooperation issues, including promotion of studies and projects could help to improve and get better results faster in the future. Target area: 5G Timeline: Long term	Policy makers
13	Policy makers could provide resources to grant external technical supervision. Also, promote the R&D projects by establishing friendly procedures to get the approval for testing. Putting in place more aggressive penalties in case the results are not the expected ones. Target area: 5G, CAM Timeline: Medium term	Policy makers
14	It is required to accelerate the reduction of existing gaps, especially in cybersecurity, scalability and Interoperability. Probably specific regulation such as the cybersecurity act (CSA) targeting the specific automotive sector is needed Target area: CAM Timeline: Short term	Policy makers
15	On the long term, it would be very helpful the definition of a common roadmap with common investment plans, including infrastructure as well as business plans for the development of the CAM industry). Target area: 5G Timeline: Medium term	MNOs, Authorities
16	Prioritization towards the most relevant use cases, including the definition of the corresponding architectures and validation methods. Target area: CAM	MNOs, Authorities

	Timeline: Short term	
17	Currently, there are no European suppliers (integrators of chips but not suppliers) involved in this business. In order to mitigate the current issue and possible future challenges, it would be a good idea to invest in this matter. Target area: 5G Timeline: Long term	Authorities

5.2. Recommendations for regulatory entities

Regulatory entities, both at the national and European level, are required to ensure the necessary quality in all the elements participating in the V2X communication that enables autonomous driving.

The most obvious way to perform this task is by means of certification or audit of those elements, including cellular networks, roads, vehicles and road elements.

The list of recommendations that have been collected for regulatory entities is shown in the table below:

Table 3: Recommendations for regulatory entities

No.	Recommendation	Target body
1	Vehicle certification/Type approval. Vehicles that rely on V2N and V2V communications should be subject to some level of certification for the whole vehicle, not just the modem component or the OBU. The vehicle chassis, the location of the antenna, and the losses in the cables, all have a relevant impact on the performance of the communication. Target area: CAM Timeline: Long term	Regulators
2	Coverage cannot be guaranteed 100%, thus mechanisms should be designed so that autonomous vehicles (different levels of autonomy	Regulators

	may have different requirements) are capable of safely coping with coverage loss or signal degradation. Target area: 5G Timeline: Long term	
3	5G is still in its early phases but LTE is mature. The recommendation is to foster the deployment of 5G networks. Target area: 5G Timeline: Short term	Regulators
4	NSA versus SA. This is a tough decision as each one has advantages and limitations. A discussion should take place at the relevant levels and regulatory bodies. Target area: 5G Timeline: Medium term	Regulators
5	There are no standards for (functional) security in the form of trusted perception from off-vehicle sources (GNSS, HDmaps, etc.). This needs further study. Target area: 5G Timeline: Medium term	Regulators
6	Autonomous vehicles, especially when sharing roads with non-autonomous vehicles (or vehicles with lower levels of autonomy) will not be free from getting involved in accidents. Protocols and standards (access to information in defined formats) should be developed for incident investigation. Cooperation with UNECE in this area is very relevant. Target area: CAM Timeline: Medium term	Regulators
7	Road infrastructure. Road infrastructure and maintenance are costly to deploy. As for the network infrastructure, there should be a	Regulators, road infrastructure operators

	subject to certification or audit procedures. A Quality Criteria should be developed. Target area: CAM Timeline: Long term	
8	Road infrastructure cannot be deployed instantly. A roadmap for road infrastructure deployment should be developed in a coordinated way within Europe and some kind of geolocation method should be standardized and developed so that vehicles are aware of the locations where road infrastructure for vehicles to infrastructure communication exists. Target area: CAM Timeline: Medium term	Regulators
9	Standards for teleoperation are missing. This is an important functionality that needs to be developed to handle stranded autonomous vehicles or foster new mobility services (e.g., robotaxi). Target area: CAM Timeline: Medium term	Regulators and standardization organizations
10	Cybersecurity is a critical issue. Research and standardization plus methods of testing and certification should be developed. 2 UNECE recommendations and RED directive are the starting points for defining the tests and the certification methodology. Target area: CAM Timeline: Short term	Regulators and standardization organizations
11	Road signs are not homogeneous across countries. Also, traffic rules are not homogeneous and autonomous countries need to abide to traffic rules in each country. Regulators should get together to homogenise rules and road signs. Target area: CAM Timeline: Medium term	Regulators

12	The quality of roads is disparate among countries and within a country (highways, rural roads, etc.). Minimum standards for roads suitable for autonomous vehicle transit. Target area: CAM Timeline: Long term	Regulators
13	Testbeds and test centres with proper facilities, staff and accreditations should be available. They should have reasonable access to (4G/5G) frequencies to be able to test. There should also be designated areas to be able to test real world conditions, not just simulated ones in test tracks. Target area: 5G Timeline: Medium term	Regulators
14	Extensive field validation tests and open data are a must to ensure all stakeholders have the right information about unexpected conditions (traffic, radio signal, interference, coexistence, etc.) so that they can be addressed in future designs. Target area: CAM Timeline: Long term	Regulators
15	GDPR implication on the handling, storing and treatment of data needs to be further analysed to have common guidelines to safeguard privacy but ensure data is available to guarantee safe behaviour of autonomous cars. Target area: CAM Timeline: Medium term	Regulators
16	The regulators should focus firstly on the identified priorities: interoperability, service continuity, precise positioning and cyber security. Moreover, how to handle non-compliance (e.g., lack of service continuity, safe response to cyber-attacks, etc.). Target area: CAM Timeline: Short term	Regulators

17	Analyse ways to facilitate, foster or even enforce a minimum coverage rate in the case of the cross-border areas. For example, in some EU countries, the administrative burden for getting an operational permit (i.e., for deploying a new base station) is considerably lightened when the new base station is located far away from permanent living places, which is typically the case in cross-border areas. Target area: 5G Timeline: Short term	Regulators
18	It is required that sufficient spectrum licenses for testing are supplied. Additionally, it would be positive to relax some constrains to allow experimentation (as there are limited to specific test sites). In any case, testing needs should not disrupt commercial networks, but there should be areas enabled for testing. Target area: 5G Timeline: Short term	Regulators
19	Analyse if complex positioning systems (such as differential GPS) should be mandatory in order to cope with the CAM applications. Target area: CAM Timeline: Long term	Regulators

6. CONCLUSIONS

The objective of D6.8 is to narrow down the recommendations presented in D6.4 and to close the gap between the regulatory authorities or lawmakers and the stakeholders in 5G mobility, towards the implementation of appropriate regulations and legislative background regarding the roaming, to resume the issues from the cross-border trials (X-border) and to provide brief directions for the authorities. The activities defined to address this objective were:

- Monitor the specification, deployment, trial and evaluation activities to identify issues related to deployment and x-border issues:
  - Transforming the expression of issues into topics of discussion with the related organizations.
  - Providing the corresponding recommendations to policy makers and regulators.
- Analyse the issues detected to transform them into topics of discussion to the relevant EU bodies and provide afterwards recommendations to those bodies.
- Interact with the relevant bodies to push the general matters for the CAM and 5G mobility technology researched in 5G-MOBIX, the issues encountered and the expertise and technically relevant recommendations based on the work of the project and the relevant stakeholders.

The methodology followed in WP6.4 and culminating in this deliverable follows up on the main instruments and findings reported in D6.4, that is, the questionnaire for partners and external stakeholders facilitating the collection of requirements on different relevant areas. Experts and professionals provided their feedback on the technology, infrastructure, regulatory framework and business potential of 5G technologies, setting the foundation for the WP6.4 cross-border and deployment issues. For the D6.8, the first assessment carried out on the responses of the WP6.4 questionnaire has been complemented with the findings of the Field Trials in WP5, providing an additional view on the cross-border issues reported on these trials, which together with a more detailed analysis of WP6.4 questionnaires has resulted in the more thorough outcomes described in this document.

The main results from the preliminary questionnaire analysis showed that the main concerns of 5G-CAM were considered to be interoperability, cybersecurity, and scalability of the architectures, technical maturity of the different applications, technical priority, and investments in CAM development. Apart from the initial questionnaire, 4 additional questions were introduced for getting an additional response from commercial partners and all cross-border trials participants. Additional 12 recommendations were included as a result of the additional questions, focusing on the areas of 5G coverage and access, spectrum allocation and signalling, road infrastructure maintenance, security and responsibilities.

Results from the field trials

Field trials have provided an additional hands-on perspective on cross-border issues, now arising from the deployments of the use cases at each of the test sites. The issues found revolve mainly around the following aspects:

Implications of the deployment of cross-border CAM services using network slicing technologies.

Network slicing is a mechanism that facilitates the management of services with strict QoS requirements, by providing isolated 'virtual' networks over physical network infrastructures. In cross-border scenarios, however, the question arises on how these 'virtual' networks or slices can be carried out when the underlying physical network does not necessarily match, or even worse, when slicing is not even supported in one side of the border.

The analysis of the issue under the framework of the field trials has provided a possible solution by identifying precisely the requirements for the services and proposing an architecture with a set of slices that should be the minimum for compliance, according to currently existing EU regulation on network provisions. Details on this set, focused around the implementation of the Internet Access Services (IAS), and a Specialized Service (SpS) slice, together with the corresponding requirements for each of them depending on the specific CAM application are given in Section 'Cross border issues found in the field trials'.

Special aspects of roaming for MNOs and policy makers

- **Cross-border requirement 1: Ensure continuity of NSA roaming**.
  MNOs need to prevent NSA Roaming interruption. Currently, when a UE crosses a border, new connection and new data session needs to be established, resulting in a connection loss unacceptable for the CAM applications. Several solutions were considered in the field trials and described in section 4.3.1 of this document.
- **Cross-border requirement 2: Ensure continuity of SA roaming**
  SA roaming interruption should also be considered as first concern for MNOs. Handovers are still not specified, which together with other limitations in current specifications, result in disconnecting times again unacceptable for CAM applications. Solutions considered are described in section **Error! Reference source not found.**.
- **Cross-border requirement 3: Improve inter-PLMN interconnection latency**
  MNOs need to fix interconnection latencies. The current use of GRX network, while guaranteeing high continuity and throughput, makes this at the expense of network latencies, making it inadequate for CAM applications. Several solutions considered in 5G-MOBIX are described in section 4.3.2.
- **Cross-border requirement 4: Remove low coverage areas**
  It is not uncommon to see low coverage areas in borders due to sparse populations precisely there. Additional issues related to this are the fact that operators use normally same frequencies at both sides

of the border, resulting in potential interference issues. Several solutions considered in 5G-MOBIX are described in section 4.3.3.

- **Cross-border requirement 5: Ensure session and service continuity**
  In this case, the issue is related to the fact that when a UE is directed by the MNO to another network, the IP address and other routing information will probably change, giving rise again to continuity and latency problems. More complex scenarios of CAM applications, relying on edge computing, are particularly sensitive to this issue. Different solutions are considered and presented in section 4.3.4.
- **Cross-border requirement 6: Improve data routing**
  Roaming usually implies that data traffic is sent to the 'home' network of the UE and then routed to the roaming network. This leads to higher latencies, with the alternative being -in edge-computing CAM applications- connection to a close edge, with the corresponding loss of communications. Solutions proposed in the project are described in section 4.3.5.
- **Cross-border requirement 7: Improve accuracy of GPS positioning**
  Today, the positioning provided by GNSS cannot meet the Cam requirements (i.e. 20-30cm accuracy) when a vehicle is moving indoors or dense urban environments. Without accurate positioning, CAM applications have issues with Local Dynamic Maps, critical for resolving many situations. There only solution considered is described in section 4.3.6.
- **Cross-border requirement 8: Refine dynamic QoS continuity**
  When vehicles move from one MNO to another one in a cross-border area, a sudden drop in the network connection quality may happen. This is somewhat related to the requirements on hand-overs and session and continuity of service above. Different options considered are described in section 4.3.7.
- **Cross-border requirement 9: Contextualize the geo-constrained information dissemination**
  In this case, the issue is about the appropriateness of traffic information to be received by a CAM vehicle travelling close to the border. In this case, information in the immediate surroundings might include not only that coming from the network from which it is connected, but also the information coming from the network node right across the border. However, what information is relevant or not depends on the application and the specific case. From the technical point of view, different solutions considered in 5G-MOBIX field trials are described in section 4.3.8.

Finally, as the feedback from the interviews with the field trial leaders has been collected, it has also been incorporated into the findings of the challenges and ways to address them via the identified mechanisms and frameworks developed within the task WP6.4 as guidance on discussion topics and roadmap for future regulation and policy for 5G-CAM.

Key recommendations

From the ICT sector

The analysis of the available information from the ICT sector carried out in D6.4 has been completed for this activity outcome in D6.8. The major technical aspects being highlighted by the ICT sector stakeholders touch on several technologies, performance items, service and applications requirements, and, consistently from what was already described in D6.4, cybersecurity, privacy and digital infrastructure aspects for CAM.

- More data-intensive services for CAM will require improved cooperation with regard to the standardisation of interfaces and data formats to ensure interoperability and portability.
- Massive data collection for highly-automated operations will make the GDPR and the ePrivacy Regulation more relevant. Related aspects of data quality, integrity, accuracy and reliability will also need to be an integral part of the design and implementation of the services and infrastructures.
- The use of ethical data proxies, particularly in cross-border scenarios, may prove to be essential to comply with the above privacy requirements and integrity of data. The newly EC proposed Data Intermediaries entities fulfil the expected roles for these proxies and should be considered in such deployments.
- Harmonisation and roaming pose technical challenges in cross-border scenarios, with the aspects of flexible spectrum management and Service Level Agreements with different service providers necessary to ensure service continuity and Quality of Service consistency across borders in CAM applications.

From the road operators

Selected recommendations from the road operators are of relevance in the sense that the introduction of automated vehicles in public road networks is a challenge for the operators in the relation between infrastructure and road users. Amongst others, the feedback focused on aspects such as better definition and specification of infrastructure (physical and digital) autonomous-readiness-level -involving also infrastructure based information and support for AV manoeuvres, support for traffic law compliance dynamic mapping and data exchanges for vehicles-, traffic management and safety concerns in different scenarios -platooning, remote driving, human failure, higher AV levels- security and privacy issues in an increasingly monitored environment, and support for backwards compatibility of higher level AV functions.

From the automotive OEMs

Of relevance in relation to the requirements of automated vehicles for Cross-Border operation. Amongst others, the feedback focused on aspects such as the cross-border issues from multiple angles, from harmonization of application messages and information exchanges to regulation and homologation processes, to traffic law compliance for cross-border applications, to support for monitoring goods to facilitate border security control. These topics, as well as in-vehicle data access, as well as other sensitive information exchanges, are long-standing discussion issues from the car industry.

Closing the cycle of the work performed in WP6.4, these recommendations have been analysed to produce a set of recommendations for the policy makers and regulatory entities.

- Policy makers take a highly relevant role in the development of autonomous driving functionality. They must foster its development by assuring the required conditions and easing the steps to remove the existing gaps. They must develop the legal aspects to ensure a safe service and cooperation between parties to ensure this as well as a commercially viable business model.

- Regulatory entities, both at the national and European level, are required to ensure the necessary quality in all the elements participating in the V2X communication that enables autonomous driving. The most obvious way to perform this task is by means of certification or audit of those elements, including cellular networks, roads, vehicles and road elements.

Deliverable D6.8 completes the cycle of requirements gathering, analysis, target group and framework identification that was reported in D6.4. The added value over the previous document comes from the 5G-MOBIX field trials and the more detailed feedback from relevant stakeholders on key questions posed on the topic. This has resulted in a comprehensive list of recommendations and guidelines which address the identified issues on cross-border issues on deployment of 5G-CAM applications, together with a formulation that squarely targets the bodies and entities that are better positioned to implement the solutions explored in the project. These results, in conjunction with the other outcomes from WP6.4, form an integral package that aims to speed up the adoption of 5G for CAM scenarios.

7. REFERENCES

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