5GMOBIX

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

D5.1

Evaluation methodology and plan

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Control sheet

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ABBREVIATIONS

Abbreviation	Definition
AD	Automated Driving
AMF	Access and Mobility Management Function (AMF)
ARFCN	Absolute radio-frequency channel number
BI	Behavioural Intention
CAM	Cooperative Awareness Message
CAV	Connected and Automated Vehicles
CBA	Cost-Benefit Analysis
CBC	Cross Border Corridor
CEA	Cost-Effectiveness Analysis
CCAM	Cooperative, Connected and Automated Mobility
CEPT	European Conference of Postal and Telecommunications Administrations

C-ITS	Cooperative - Intelligent Transport Systems
CP	Control Plane
CPM	Cooperative Perception Message
CQI	Channel Quality Indicator
C-V2X	Cooperative-Vehicle-to-Everything
DENM	Decentralized Environmental Notification Message
DL	Downlink
E2E	End-to-end
EC	European Commission
EPC	Evolved Packet Core
ETL	Extract Transform and Load
ETSI	European Telecommunications Standards Institute
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High Definition
IP	Internet Protocol
ITS	Intelligent Transportation Systems
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LTE	Long Term Evolution
MAMCA	Multi-Actor Multi-Criteria Analysis

MCC	Mobile Country Code
MCM	Manoeuvre Cooperation Message
MEC	Multi-access/Mobile Edge computing
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MNC	Mobile Network Code
MSC	Message Sequence Chart
MTTR	Mean Time To Repair
MTU	Maximum Transmission Unit
NG-RAN	Next Generation – Radio Access Network
NSA	Non-Stand-Alone
OBU	On-Board Unit
PCell	Primary Cell
PCI	Physical Cell Identity
PCO	Points of Control and Observation
PDR	Packet Delivery Ratio
PEOU	Perceived Ease of Use
PGW	Packet Data Network Gateway
PLMN	Public Land Mobile Network
PTP	Precision Time Protocol
PU	Perceived Usefulness
QoL	Quality of Life

QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RRC	Radio Resource Control
RSI	Road-Side Infrastructure
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RSU	Road Side Unit
RTT	Round Trip Time
SAE	Society of Automotive Engineers
SCell	Secondary Cell
SDU	Service Data Unit
SGW	Serving Gateway
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol
SNR	Signal Noise Ratio
TA	Timing Advance
TAC	Tracking Area Code
TCP	Transmission Control Protocol
TS	Trial Site
UCC	Use Case Category

UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UP	User Plane
UPF	User Plane Function
US	User Story
V2I	Vehicle-to-infrastructure
V2N	Vehicle-to-network
V2V	Vehicle-to-vehicle

EXECUTIVE SUMMARY

This is deliverable D5.1 "*Evaluation methodology and plan*" of the 5G-MOBIX project. The main objective of the deliverable is to provide a detailed and rigorous description of the evaluation methodology that will be employed for the quantitative and qualitative evaluation of 5G-MOBIX solutions for cross-border mobility in the context of advanced automated driving (AD) applications. The deliverable identifies the key objectives of the evaluation methodology, across all fronts, namely, Technical Evaluation (T5.2, in Section 2.1), Impact Assessment (T5.3, in Section 2.2), and User Acceptance (T5.4, in Section 2.3). The document provides a detailed description of the overall evaluation methodology, with a particular focus on the Technical Evaluation front (Section 3). To this end, D5.1 initially overviews the evaluation methodology (Section 3.1), identifying the main stages including data collection, aggregation, post-processing, etc. The data collection framework is described in detail (Section 3.2) including the identification of logging information required for the evaluation of the selected key performance indicators (KPIs) and technical approach in collecting this data from the various locations in the network. At the same time, D5.1 delves into the details of the network events, states and transitions identified in the presence mobility (Section 3.3). This serves the purpose of defining the framework for the corresponding statistical manipulation of the measurement data, but further also allows the specification additional KPIs, explicitly capturing roaming latencies (Section 3.3.2). In this overall context, the deliverable next identifies the exact measurement data required for the evaluation of the selected KPIs. This includes measurement data both for the evaluation of network capabilities (Section 3.4) i.e., application agnostic performance evaluation of the established infrastructure, and for the evaluation of performance as perceived within the context of the selected user case categories / user scenarios (UCC/US) in 5G-MOBIX (Section 3.5 and Appendix C). This information associates the exact measurement data with KPIs and X-border issues completing the big picture of technical performance evaluation. Finally, D5.1 focuses on activities on the generalization front (Section 3.7), identifying and elaborating on simulation-based activities and their complementarity to the trials themselves. This includes aspects related to the use of traffic traces for the evaluation of network/system scalability aspects, as well as the investigation of radio propagation and interference issues aimed to support network deployment decisions. In Section 4 the document presents the methodology for the assessment of the impact of 5G-MOBIX solutions, with respect to both societal and business aspects, taking both a qualitative and a quantitative evaluation approach. Section 5 presents the methodology developed for the assessment of the user acceptance, in what concerns the overall technological proposition of 5G-MOBIX and related services.

The rest of the document is organized as follows. Section 1, describes the purpose of the document and its intended audience. Section 2, presents the objectives of the evaluation process on 5G-MOBIX. Sections 3, 4 and 5 subsequently present the methodologies for the Technical Evaluation, Impact Assessment and User Acceptance evaluation processes correspondingly. Finally, Section 6, presents the conclusions.

1. INTRODUCTION

1.1. 5G-MOBIX concept and approach

5G-MOBIX aims to showcase the added value of 5G technology for advanced Cooperative, Connected and Automated Mobility (CCAM) use cases and validate the viability of the technology to bring AD to a high level of vehicle automation (SAE[1] L4 and above). To do this, 5G-MOBIX will demonstrate the potential of various 5G features on real European roads and highways and create and use sustainable business models to develop 5G corridors, with particular emphasis on seamless service provisioning across borders. In this effort, 5G-MOBIX will utilize and upgrade existing key assets (infrastructure, vehicles, components) and further ensure the smooth operation and co-existence of 5G within a heterogeneous environment comprised of multiple incumbent technologies such as ITS-G5 and C-V2X.

5G-MOBIX will execute CCAM trials along cross-border and inland corridors using 5G core technological innovations to qualify the 5G infrastructure and evaluate its benefits in the context of CCAM services across borders. To this end, the Project first defines critical scenarios needing advanced connectivity provided by 5G, and the required features to enable some advanced CCAM use cases. The matching of these advanced CCAM use cases and the expected benefits of 5G will be tested during trials on 5G corridors in different EU countries as well as in Turkey, China and Korea.

The trials will also allow 5G-MOBIX to conduct evaluations and impact assessments and to define business impacts and cost/benefit analysis. As a result of these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX will identify new business opportunities for the 5G enabled CCAM and propose recommendations and options for its deployment. Through its findings on technical requirements, operational conditions and pilots, 5G-MOBIX is expected to actively contribute to standardization and spectrum allocation activities.

1.2. Purpose of the deliverable

The purpose of this deliverable is to provide a detailed and rigorous description of the evaluation methodology that will be employed for the quantitative and qualitative evaluation of 5G-MOBIX solutions for cross-border mobility in the context of advanced AD applications. To this end, the deliverable defines a clear set of evaluation objectives aimed to clarify the target of the evaluation methodology. Previously, D2.5 presented an initial set of KPIs and metrics, aimed to set up the scene for the evaluation framework across UCCs/USs, including also aspects related to Impact Assessment and User Acceptance. D5.1 takes the next step in pursuing a high degree of detail regarding the KPIs and metrics, taking into account the specificities of the Trial Sites (TSs) e.g., deployed features/solutions, and the selected UCCs and USs, for each TS. At the same time, D5.1 highlights the relation of the selected KPIs and evaluation methodology with the identified

[1] Society of Automotive Engineers

x-border issues (D2.1). This aims to pave the way towards the evaluation of the 5G-MOBIX solutions, eventually leading to the sought-after conclusions. On the technical evaluation front, D5.1 aims to establish the evaluation methodology of the project, including a wide set of aspects related to measurement activities i.e., required logging information, technical approach on retrieving this information, as well as post-processing of the retrieved information for the purpose of KPI evaluation. This constitutes a first step in identifying the requirements for the subsequent delivery of the corresponding data collection and management software infrastructure in T3.5. Taking a step further, the deliverable builds on the established methodology to further assess the selected KPIs and identify the overall data measurement objectives/requirements, providing the initial guidelines for exact configuration of the measurement tools provided by WP3 and utilized in the trials, managed in WP4. D5.1 further delivers a precise description of the states of the network components, along with events taking place due to mobility (on both the user and control planes) and the transitions in between. This description sets the ground for the detailed evaluation of handover events and provides a framework for the evaluation of the recorded measurement data, as highlighted in D2.5. In this context, D5.1 describes the details of statistical manipulation of the measurement data, with respect to the identified events/transitions. Furthermore, the deliverable provides an evaluation methodology that will be used for the generalization of the experimental results from the trial sites, to broader scenarios. Though the deliverable puts particular weight on the technical performance evaluation methodology, it also establishes the evaluation methodology for the Impact Assessment and User Acceptances activities in 5G-MOBIX. The Multi-Actor Multi-Criteria Analysis (MAMCA) methodology is presented along with the methodology for the Cost-Benefit Analysis (CBA) that will be employed for Impact Assessment. Additionally, D5.1 describes the methodology employed for the User Acceptance investigation, including a framework for modelling User Acceptance, along with the user survey and validation methodology.

By establishing the methodology to be followed in Tasks 5.2 to 5.4, D5.1 sets the ground for the subsequent work in WP5, which will be reported in Deliverables 5.2 to 5.4.

1.3. Intended audience

The dissemination level of D5.1 is public (PU) and is meant primarily for (a) all members of the 5G-MOBIX project consortium, and (b) the European Commission (EC) services.

This document is intended to serve not just as an internal guideline and reference for all 5G-MOBIX beneficiaries, especially the TS and the UCC/US leaders, but also for the larger communities of 5G and CCAM development and testing.

2. EVALUATION OBJECTIVES

2.1. Technical evaluation objectives

Task 2.5 provided a list of technically related KPIs grouped into two main areas: general KPIs, devoted to qualify 5G as the core connectivity infrastructure for CCAM, and handover KPIs, more explicitly focused on the cross-border mobility performance. At the same time, D2.5 further identified target KPI values capturing the performance requirements of the applications considered in 5G-MOBIX. The evaluation methodology will contribute to the obtainment of the result KPI values from the trials phase, further subsequently enabling a comparison with the predefined target values (where available). On a high level, this will serve the purpose of evaluating the performance of the 5G-MOBIX architecture as perceived by users on the CCAM application level. The main focus of this performance evaluation process is to assess the impact of cross-border mobility on the CCAM services. To this end, the comparison against the predefined target KPI values aims to capture service deterioration / disruption in the presence of cross-border mobility and the associated handover/roaming events, in the form of the observed deviation from the target values.

However, in order to comprehend the performance of the network and identify the exact sources of any (quantified) service deterioration, the project will further engage in a finer grained look on performance. First, this translates to the assessment of the network capabilities in an application-agnostic manner e.g., identifying the maximum achievable throughput in a particular cell, assessing the latency in particular segments of the network. Such measurements will serve the purpose of evaluating the later on observed end-to-end, user perceived and application-specific performance in the context of the underlying network capabilities. Second, paying particular attention to the impact of cross-border mobility, the evaluation methodology will further include the identification of mobility related events, states and transitions e.g., identifying the handover/roaming events, with the purpose of both quantifying the effect of the corresponding control plane procedures triggered by user equipment (UE) mobility events, and further enabling the appropriate statistic processing of the raw measurement data (as also discussed in D2.5).

Summarizing, the technical evaluation methodology will serve the following high-level objectives:

- Assess network capabilities in an UCC/US-agnostic manner, contributing to the understanding of the baseline performance of the network, orthogonal to application specificities and performance requirements. The evaluation methodology aims at both data and control plane performance:
  - *Data plane*: network capabilities will be assessed on both an end-to-end and a per network segment basis (see Section 3.4).
  - *Control plane*: a detailed assessment of events/states and transitions will enable the finer-grained, explicit look at X-border issues e.g., roaming latency (see Section 3.3)
- Assess user perceived performance on an end-to-end basis, in a UCC/US-specific manner. This will allow the assessment of the impact of cross-border mobility on CCAM application-level (see Section 3.5)

2.1.1. Technical assessment of X-border issues

As mentioned in D2.1 and D2.2, the great challenge in the deployment of the UCC/US[2] in cross-border locations is to deal with the effects of roaming/ handover processes to get a timely, continuous and seamless operation of the corresponding CCAM applications. In this sense, it is the design of the architecture of the UCC/US which is conditioning the appearance of the particular cross-border issues. The goal of the Technical Evaluation is to analyse the different implementations of these cross-border mobility solutions provided by the trial sites involved in the Project and validate them for automated driving.

5G-MOBIX employs two types of trial sites in order to cover a wide range of scenarios and implementations of the UCC/USs, namely, the cross-border corridor (CBC) trial sites and the local trial sites. The CBCs are the real testing grounds to understand the implications of roaming/handover processes in the execution of the CCAM applications. The local trial sites, both in the inland corridors and also the ones in the two sides of the CBCs, are thought as a kind of early deployments in the trials phase in order to get the first insights into the 5G core technological innovations in CCAM functions. In addition, the inputs from inland corridors allow both CBCs to test additional features and mainly will help to align views in 5G among the trial sites; this is particularly significant in the case of the international cooperation with CN and KR trial sites. The roadmap of the Project is designed in such a way the goal of the inland corridors is to deliver an added value (D2.2 section 4.6 and 5.6, appendix to D2.3, and annexes A, B and C to D2,3) to the cross-border sites.

In the framework of 5G-MOBIX, four different categories of cross-border issues were identified (D2.1 and D2.2): telecommunication, application, security & data privacy, and regulation. Telecommunication and application issues can be directly linked to the behaviour of the Technical KPIs, but this is not the case of security & data privacy and regulation issues that consequently are out of the scope of this Evaluation.

The collaborations between ES-PT and GR-TR and the local sites are defined by WP2. The next subsections explain the complementarity between the CBC and local trial sites, with respect to evaluation objectives, and define the way to evaluate the technical inputs in the CBCs.

2.1.2. Technical evaluation of ES-PT contributions from local trial sites

The ES-PT corridor deploys four out of the five UCCs. The contribution of the local trial sites to the ES-PT cross border affects/relates to Advanced Driving and Extended Sensor UCCs.

In the case of Advanced Driving UCC, the designs of ES-PT UCC/USs are expected to have issues with the roaming latency between Telefónica and NOS networks (TR1) and with the change of IP between the applications hosted in ES and PT MECs for the message transmission (TC1). At application layer, ES-PT approach implies an in-vehicle processing of the CCAM applications dealing with issues of interoperability (AI1) and unsteady communications (AC1). A combined contribution between FR and FI and the solution by DE will feed ES-PT CBC supplying alternatives of design and implementation. ES-PT vehicles use one single

[2] An overview of the project UCC/US is provided in Appendix A.

SIM so that it is expected and thus longer latencies are expected in the cases of ITS messages, when switching between the NSA networks of Telefónica and NOS (TR1),) and also and of the IP change in of the applications hosted in the Spanish and Portuguese MECs for the message transmission (TC1). At application layer, ES-PT approach implies an in-vehicle processing of the CCAM applications dealing with issues in of interoperability (AI1) and causing unsteady communications (AC1).

Table 1: FR+FI contribution in Advanced Driving UCC

UCC	**Advanced Driving**
US	Complex manoeuvres in cross border settings (lane merge + overtaking)
Trial Sites involved	FR, FI
Description of the contribution	Provide multi-SIM OBUs for testing different approaches in multi-PLMN roaming and handover scenarios
Extended evaluation	Comparison between the change of network managed by the operators when one single SIM and the management in the OBU when two SIMs are available
Cross border issues addressed	*TR1: NSA Roaming Latency* *TC1: Continuity Protocol*

The extended evaluation with FR and FI (Table 1) is focused on the telecommunications issues addressed in ES-PT designs (TR1 and TC1). To handle them, the FR and FI solution is based on an OBU that allows two SIMs working simultaneously, while the ES-PT approach uses one single SIM. This means to manage in an appropriate way the switching between the Telefónica and NOS networks. Based on this, the key KPIs to measure the degree of impact on the cross-border situations are those related to latency (KPI 1.3-End to End Latency and KPI1.5-User Plane Latency), KPI1.2-Throughput and the ones specific for the handover process (KPI2.1-NG-RAN Handover Success Rate, KPI2.2-Application Level Handover Success Rate and KPI2.3-Mobility Interruption Time[3]).

Table 2: NL contribution in Advanced Driving UCC

UCC	**Advanced Driving**
US	Complex manoeuvres in cross-border settings (lane merge)
Trial Sites involved	NL
Description of the contribution	Compare the vehicle and infrastructure decision-making approaches. NL brings OBU (device and software) and MEC (software) to the CBC. During the manoeuvres, both ES-PT OBU and NL OBU log the performance in order to compare it later.

[3] Including also the additional KPIs defined in D5.1, see Section 3.3.2. This applies to subsequent references to handover/roaming KPIs.

Extended evaluation	Comparison between in-vehicle or infrastructure decision-making approaches for Advanced Driving user stories.
Cross border issues addressed	AC1: V2X continuity AI1: Data Interoperability

NL provides also an alternative design for Advanced Driving UCC (Table 2), but in this case, providing alternatives for the application border issues (AC1 and AI1) by processing the data needed to run the test in the MEC, instead of the vehicle as ES-PT design. Again, the Technical Evaluation should be focused on the handover KPIs (KPI2.1-NG-RAN Handover Success Rate, KPI2.2-Application Level Handover Success Rate and KPI2.3-Mobility Interruption Time), but also on quantifying the degree of the delays (KPI 1.3-End to End Latency and KPI1.5-User Plane Latency).

For the Extended Sensors UCC, the more critical cross-border issues are again the roaming between the ES and PT NSA networks when uploading the large files with the in-vehicle sensors data or downloading the updated HD-Maps (TR1) and the IP change in applications running in both ITS Centers (TC1) at telecom layer. At application layer, it can suffer unsteady communications between vehicles and ES and PT ITS Centers (AC1), interoperability issues (AI1) and lack of computing when processing the data from the in-vehicle sensors (AP2).

Table 3: DE contribution in Extended Sensors UCC

UCC	**Extended Sensors**
US	Complex manoeuvres in cross-border settings (US1) and Public transport with HD media services and video surveillance (US2)
Trial Sites involved	DE
Description of the contribution	Provide vehicles, MECs and RSUs in order to deploy their own user story "*EDM-enabled extended sensors with surround view generation*" within the "*HD maps*" scenario conditions.
Extended evaluation	Deployment of the DE user story in new scenarios. Exploration of the interoperability between systems and networks in different countries. Compare results of ES-PT and DE deployments.
Cross border issues addressed	TR1. NSA Roaming Latency TC1. Continuity Protocol AC1. V2X Continuity AI1. Data Interoperability AP2. On demand Processing

DE supports the Extended Sensors UCC by testing its own developments in ES-PT infrastructure (Table 3). This comparison touches on telecommunications and application border issues. In this case, there is no a 1-1 link between the data flows in both implementations so that the KPIs have to be calculated for the global solution. As it is supposed a great amount of data to be transferred, the key KPIs are those related to the bandwidth (KPI1.1-User Experienced Data Rate, KPI1.2-Throughput, KPI1.6-Reliability, KPI1.8- Network Capacity) and also the ones involved in the roaming process (KPI2.1-NG-RAN Handover Success Rate, KPI2.2-Application Level Handover Success Rate and KPI2.3-Mobility Interruption Time).

2.1.3. Technical evaluation of GR-TR contributions from local sites

The GR-TR corridor deploys two out of the five UCC. The contribution of the inland corridors to the GR-TR cross border is in Platooning UCC that is affected by the switching between the NSA networks in GR and TR (TR1), the communication between both MECs (TN4), the potentially unsteady communications between the infrastructure and the vehicles (AC1) and geo-positioning (AG1).

Table 4: FI contribution in Platooning UCC

UCC	**Platooning**
US	Platooning with "see what I see" functionality
Trial Sites involved	FI
Description of the contribution	The LEVIS (Live strEaming VehIcle System) platform from AALTO is used to obtain HD video streams (with location tags) from vehicle(s) and relaying it to authorized subscribers of the stream
Extended evaluation	Explore continuity related issues of CCAM services when vehicle platoon travels cross-border and roams between networks
Cross border issues addressed	Streaming continuity during inter-PLMN HO TR1 NSA Roaming Latency AC1 V2X Continuity

FI is contributing GR-TR corridor in Platooning UCC by a streaming service (Table 4). This feature is addressed to evaluate the impact of the roaming latency (TR1) and the communication between the vehicles and the cloud (AC1). The KPIs that will give the most meaningful results are the ones linked to the bandwidth (KPI1.1-User Experienced Data Rate, KPI1.2-Throughput, KPI1.6-Reliability, KPI1.8- Network Capacity) and also the ones involved in the roaming process (KPI2.1-NG-RAN Handover Success Rate, KPI2.2-Application Level Handover Success Rate and KPI2.3-Mobility Interruption Time).

2.2. Impact assessment objectives

The 5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe[4] states that the European Commission has fully recognized the importance of 5G for future mobility solutions

[4] 5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe - Initial proposal 31 October 2019.
https://5g-ppp.eu/wp-content/uploads/2019/10/20191031-Initial-Proposal-5G-SDA-for-CAM-in-Europe.pdf

and embraced the deployment of 5G technologies including both network and direct communication in transport as a European public policy priority. It is also believed that transport and specifically Connected and Automated Mobility is the area where 5G technologies can yield tangible benefits more rapidly, acting as a catalyst to accelerate the way towards other sustainable 5G ecosystems. In the white paper "*Business Feasibility Study for 5G V2X Deployment*" by 5G-PPP[5] it has already been estimated, that positive business cases can be expected for 5G CAM cases. However, investments on 5G networks to cover highways and roads are required and business feasibility of that is yet to be verified.

The 5G-MOBIX project is positioned to showcase the added value of 5G technology for advanced CCAM use cases and validate the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). 5G-MOBIX spans cooperation between automotive and telecommunication industries, dynamically adapting 5G technologies to automated transport in response to the increasing importance of cooperative technologies in their sector. Therefore, multiple stakeholders are involved in 5G-MOBIX development, future implementation and use. This broad stakeholder community shall be consulted in the project and an analysis of the potential existing and emerging partnerships and conditions and capabilities among the stakeholders for developing innovations and business will be assessed.

In this context, the purpose of 5G-MOBIX Impact Assessment is to assess the impacts of seamless service provisioning across borders from a socio-economic perspective. The objective is to explore systematically the benefits, costs and business opportunities of the developed solutions and the services that they will enable, in order to identify the most promising opportunities and the main barriers for deployment, and to identify the key stakeholders for advancing in development of sustainable business supported by the 5G-MOBIX technologies.

To this end, a specific set of metrics is targeted for quality of life and business impacts. The **societal impacts** and **potential business impacts** of the systems and applications, that will be demonstrated in the CBC trial sites (supported by the local trial sites) in the context of 5G-MOBIX project, and future CCAM solutions and services that will be enabled by the solutions, will be explored. The aim is to perform an assessment of the proposed business models and value propositions (inputs from WP6) to assess the costs and the benefits for the different stakeholders and to identify the key stakeholders for advancing towards deployment of the solutions. Assessment of wider societal impacts will support public authorities and other organizations to identify the role of the 5G enabled cross-border CCAM services in solving challenges related to mobility and to recognize also the potential indirect impacts of those solutions in a region or country.

The main objectives of the impact assessment task are:

[5] 5G PPP Automotive Working Group (2019). Business Feasibility Study for 5G V2X Deployment, 5G Automotive White Paper. https://bscw.5g-ppp.eu/pub/bscw.cgi/d293672/5G%20PPP%20Automotive%20WG_White%20Paper_Feb2019.pdf

- Explore how 5G-MOBIX systems can affect quality of life, in terms of personal mobility, traffic efficiency, traffic safety and the environment
- Evaluate how the cooperation between the stakeholders and trial sites in the project has contributed to the development of new innovations and business models and (future) deployment of solutions
- Assess the costs and benefits of 5G-MOBIX solutions from the perspectives of the society, innovation ecosystems and individual businesses.

2.3. User acceptance objectives

A key success factor in the deployment of a new technology is a previous understanding of how end-users will react, experience and interact with it[6]. Measurements of acceptability, social acceptance, and public support appear to be positively correlated with the ease and success of implementation of a new technology [12][52]. Knowing in advance that a group of stakeholders produces positive assessments of a given system or technology, might predict willingness to accept and even support it actively in the future [25]. In this context, the main goal of the User Acceptance task in the 5G-MOBIX project is to obtain knowledge and comprehension about the acceptance rates of different stakeholders that will be effective end-users of 5G technology in CCAM scenarios.

Fagnant and Koleman [17] have identified main barriers to implementation and mass-market penetration of Connected and Automated Vehicles (CAVs). Those include the vehicles' initial cost; a lack of agreement on licensing and test standards; the definition of liability details; security and privacy concerns; and, finally, a lack of clear assessment of the impact on interaction with other components of the transportation system. Addressing the last of these barriers is an important focus for the 5G-MOBIX project. While one of the main project goals is to propose solutions for technical and logistical challenges inherent to border crossing, there is a concern for ensuring that public perception and user needs are taken into account, to guarantee higher levels of user acceptance. The negativity-bias in user experience happens when users tend to pay more attention, or give more weight to negative experiences over neutral or positive ones [46]. Particularly, recent incidents with CAVs have demonstrated that this technology may be particularly prone to be affected by this phenomenon [2][7][26].

In this context, one of the 5G-MOBIX project objectives is to understand the public reaction to the proposed 5G-Based cross-border solutions and to predict the effect of their implementation. While the potential users may not even know what communications technology is deployed in the system they are using, their overall experience with the mobility service may be affected by technological variables that are outside their awareness or comprehension. Many of the proposed CCAM use-cases are heavily dependent on vehicle-to-network (V2N), vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication and it is unclear how breaks in service continuity may affect the overall user experience. In this regard, country borders pose

[6] For instance, early experiments for assessing user annoyance caused by long conversational delays, conducted at the Bell Labs, guided the definition of orbit height for the first civil communications satellite. See Gertner, J. (2012) The idea factory: Bell Labs and the great age of American innovation. Penguin.

particular connectivity challenges. On the one hand, roaming and handover processes may cause increased latencies in the exchange of ITS messages, raw sensor data or video stream, which may affect operation of CCAM user-stories that depend on a timely and constant flow of data. On the other hand, differences at the application level between the networks of two countries may cause interoperability issues and unstable communications. It can also happen that lack of computing power at either vehicle or network processing units may result in sudden processing delays when switching networks.

Moreover, to ensure the safety of the vehicles and occupants, it may be necessary to compromise the performance of the use-case, for instance, by setting safety distances between vehicles that would seem excessive in a context of regular manual driving. This can also negatively affect the perception of users who may not understand the need for particular constraints and/or regard it as inefficient.

In the context of ITS, User Acceptance has been defined as a multi-dimensional concept that constitutes the end-result of a group of smaller factors such as: perceived safety, perceived usefulness and ease-of-use, perceived trust, perceived enjoyment, and objective usability. In Section 5 of this deliverable, we describe the development of user-inquiring methodologies to assess user acceptance through the metrics proposed on deliverable D2.5. This includes (1) analytic methods, such as questionnaires and structured interviews, and (2) observational ones, such as usability assessment using interaction data). Section 5 describes the rationale that guided the development of a User Acceptance Model (Section 5.1) adapted to capture user acceptance rates in all the dimensions relevant for the technology being developed in the 5G-MOBIX project; and will describe the planned analytical and observational methodologies for data collection (Section 5.2).

Summarizing, the objectives of the evaluation process, with respect to User Acceptance aspects are as follows:

- Evaluate acceptance and acceptability for the CBC user-stories, for the participants taking part in the trials
  - Evaluate perceived acceptance metrics (self-assessed KPIs)
  - Evaluate usability metrics regarding the performance experienced by the users (e.g. number of forced retakes), when engaged in the trials
  - When applicable, evaluate the user-system interaction metrics (e.g. errors made by the remote operator in the remote driving US)
- Evaluate acceptance of general public to the CBCs user-stories.

3. TECHNICAL EVALUATION METHODOLOGY

This section describes the technical performance evaluation methodology[7] to be followed during and after the trials to enable evaluation of the KPIs as defined in D2.5. As explained in the previous section, this includes not only the assessment of CBC mobility on CCAM application level, but also the baseline network performance / capabilities in an application-agnostic manner. In the following, we present an overview of the overall evaluation methodology, which applies to both types of evaluation activities (Section 3.1). Then, we delve into the details of the methodology, elaborating on the identity of the measurement data (Section 3.2.1), as well as the measurement methodology (Section 3.2.2). We present our approach in identifying key events/states and transitions occurring in the network during CBC mobility events (Section 3.3), that, on the one hand, drive the specification of additional roaming/handover specific KPIs to complement the ones defined in D2.5, while, on the other provide a firm mobility-related timing framework for the evaluation of the perceived KPI values. Having defined the overall measurement framework, we subsequently describe how it is going to be applied across trial site infrastructure and UCC/US so as to eventually derive the necessary data for the KPI evaluation; in this, we further link the measurement methodology with the selected KPIs and the related X-border issues (Sections 3.4 and 3.5). Finally, we elaborate on the post-processing of measurement data for the evaluation of the final KPI values (Section 3.6), and we further present our approach on the generalization of results (Section 3.7).

3.1. Evaluation methodology overview

The objective of the technical evaluation is to produce the relevant KPIs values. During the execution of the relevant UCC/US in the trials, numerous measurements will be performed. Once the measurements are made, the KPIs can be calculated. Based on standard and established conformance and interoperability testing methodology [29], one of the first steps is to identify the potential location of *Points of Control and Observation* (PCOs) in the system under test where measurements will be taken. A PCO, in the context of

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[7] The FESTA methodology [19] has been taken into serious consideration in the definition of the Technical Evaluation methodology. However, the methodology aims "…*to identify real-world effects and benefits…* " and "…*to investigate the impacts of mature ICT technologies in real use. The core research questions should therefore focus on impacts*…"[19]. As such the FESTA methodology has been considered most suitable for contributing in the shaping of the Impact Assessment and User Acceptance methodologies (Sections 4 and 5 correspondingly). Nevertheless, we note the following (high-level) alignment of the Technical Evaluation Methodology with the FESTA methodology steps: (1) *Function selection*: corresponds to the functionality supported both on the network domain, as described in D2.2, and the application level functionality, as described in D2.1; (2) *Use case definition*: corresponds to the set of UCC/US defined in D2.1; (3) *Identification of research questions:* on high level, the main research question relates to the support of service continuity in CBC environments, however, on a closer look, a series of research questions are defined in a direct correspondence to the X-border issues (and related challenges) defined in WP2; (4) *Hypotheses formulation:* in terms of technical evaluation purposes, and on a rather high level, the main hypothesis to be tested relates to the existence of service deterioration due to mobility in CBC environments; taking a closer look, a series of test hypotheses is directly derived when assessing the "Consequences & impact" of the identified X-border issues (with a focus on Telecommunication issues), (5) *Definition of KPIs:* preliminary KPIs were identified in D2.5, but a refinement has taken place in D5.1, linking the KPIs with particular X-border issues (see Sections 3.4and 3.5, as well as Tables in Appendix C).

the project evaluation methodology, is a specific point within the system under test, at which either an observation (measurement) is recorded, or traffic is injected (see also Sections 3.7.1.2 and 3.7.1.1). In general, most of the measurements will be passive and based on recording real UCC/US traffic; however, in order to characterise the network, prior to the UCC/US trials, and even to support the obtainment of certain KPIs, specific traffic may need to be injected (active measurements). The concept of system under test refers to the complete implementation of the solution for each UCC/US, which includes the vehicle with its communication modems and other elements and all the components of the networks.

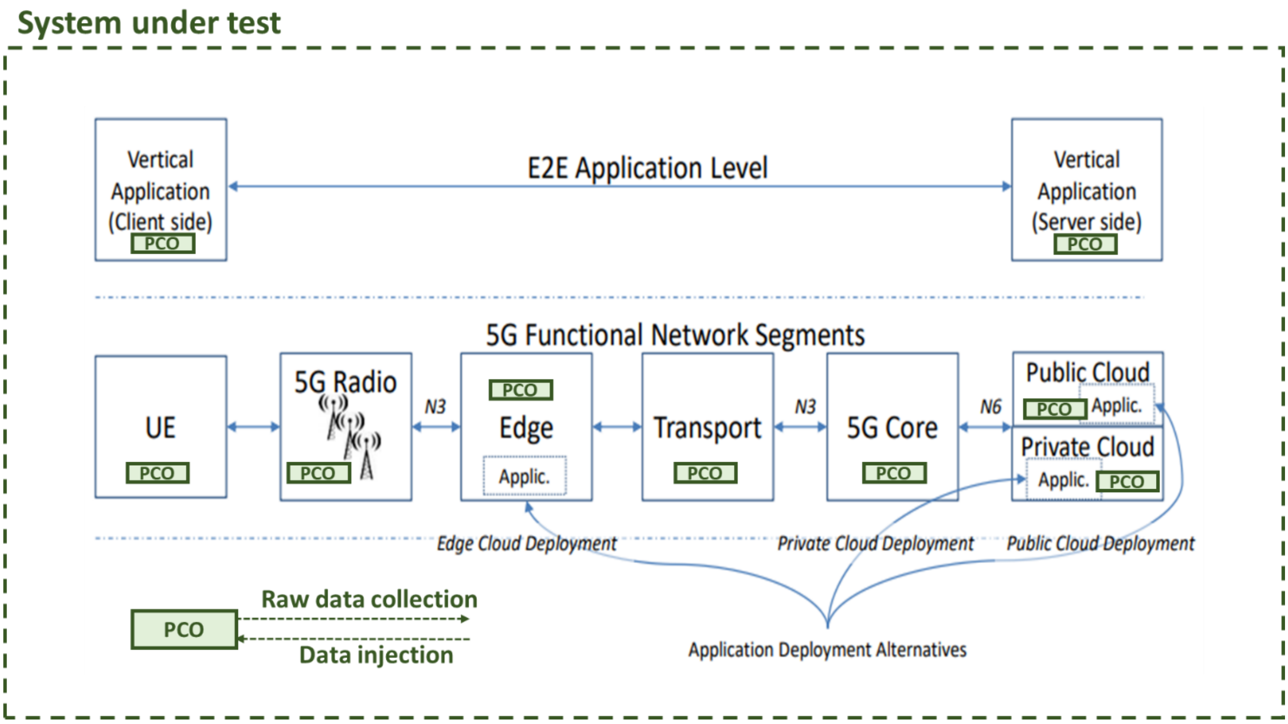

Figure 1: System under test and Points of Control and Observation (PCOs) measurement approach

The "raw data injection and collection" approach combines all the solutions needed to gather the raw data (measurements) that have to be collected to later process and calculate the KPIs. This approach also includes the capability of injecting traffic packets in the system under test to be able to set the adequate test scenario so that the relevant KPI can be computed, out of the measurements taken.

The complete measurement system to perform the validation, includes not only the 'raw data injection & collection' module(s) but also an ETL-like (Extract, Transform and Load) module to convert the raw data (measurements) into a suitable data format. The formatted data will be processed in a 'processing module' and the output will be the calculated KPIs. Figure 2 provides an overview of the process to perform validation in any UCC/US.

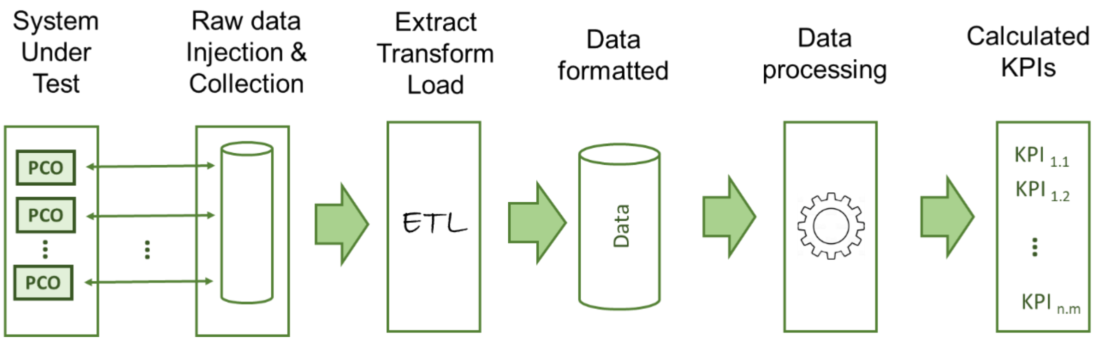

Figure 2: Complete measurement methodology from capturing data to obtaining KPIs.

The data processing step, further detailed in Section 0, consists of taking the formatted data and applying a set of filtering and processing calculations to finally obtain the targeted KPIs. This will be done using data processing tools and scripting languages, and specific attention will be paid on the events, states and transitions of the system due to mobility, in the targeted handover scenarios. As described in Section 3.7, an alternative measurement methodology will be considered through simulation to obtain estimations about the behaviour of the 5G network under high traffic load and considering different mobility and data transfer scenarios.

3.2. Data collection methodology

The system under test, where the evaluation has to take place, has three basic elements: ITS station, network and ITS control centre.

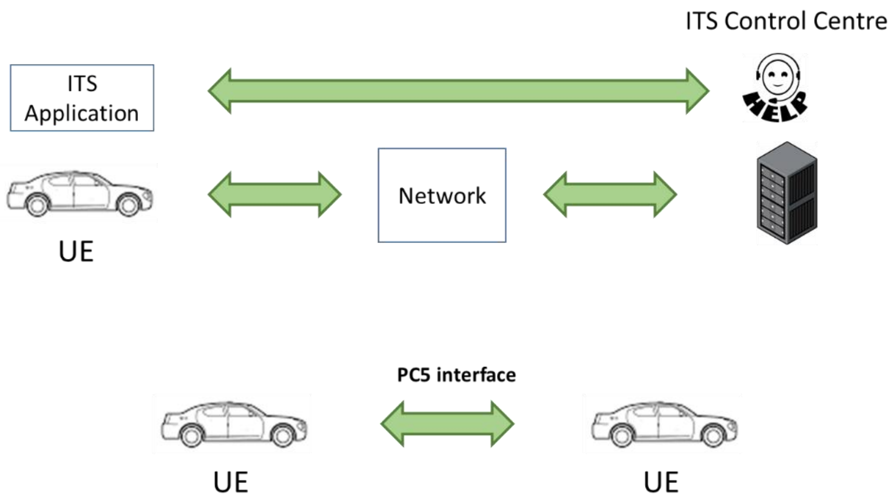

Figure 3: Main elements in the System Under Test.

The PCOs will be located at relevant communication interfaces. In terms of communications, there are various relevant communication channels where interfaces to be "controlled and observed" can be located.

- ITS station to ITS control centre communication channel.

- ITS station to cellular network communication channel.
- ITS control centre to network communication channel.
- ITS station to ITS station (for some UCC/US use case categories-user stories) communication channel.

PCOs shall be organized in levels. The levels are associated to the architecture layer where data collection has to be performed, in an approach similar to "*Information technology – Open Systems Interconnection – Conformance testing methodology and framework*" [29]. Three levels are proposed, as described below.

- **Level 0, Access:** Above the Access layer (LTE, 5G, etc.) defined in ETSI EN 302 665 [16]. This PCO is required to obtain relevant information about the radio access network parameters (signal strength, cell identification, etc.).
- **Level 1, Transport:** Above the transport level, specifically at the IP network/transport layer. This PCO is required to obtain relevant information about the capacity of the network (throughput, delay, etc.).
- **Level 2, ITS application:** At the level where ITS messages or other application data, such as video streams, are exchanged between the ITS stations or between an ITS station and the ITS control centre. This PCO is required to obtain relevant measurement data at application level such as end-to-end latency, user experienced data rate, reliability, etc. which can be employed for the evaluation of the corresponding KPIs e.g., TE-KPI1.1-User experienced data rate, TE-KPI1.3-End to End Latency, TE-KPI1.6- Reliability, etc., as defined in D2.5.

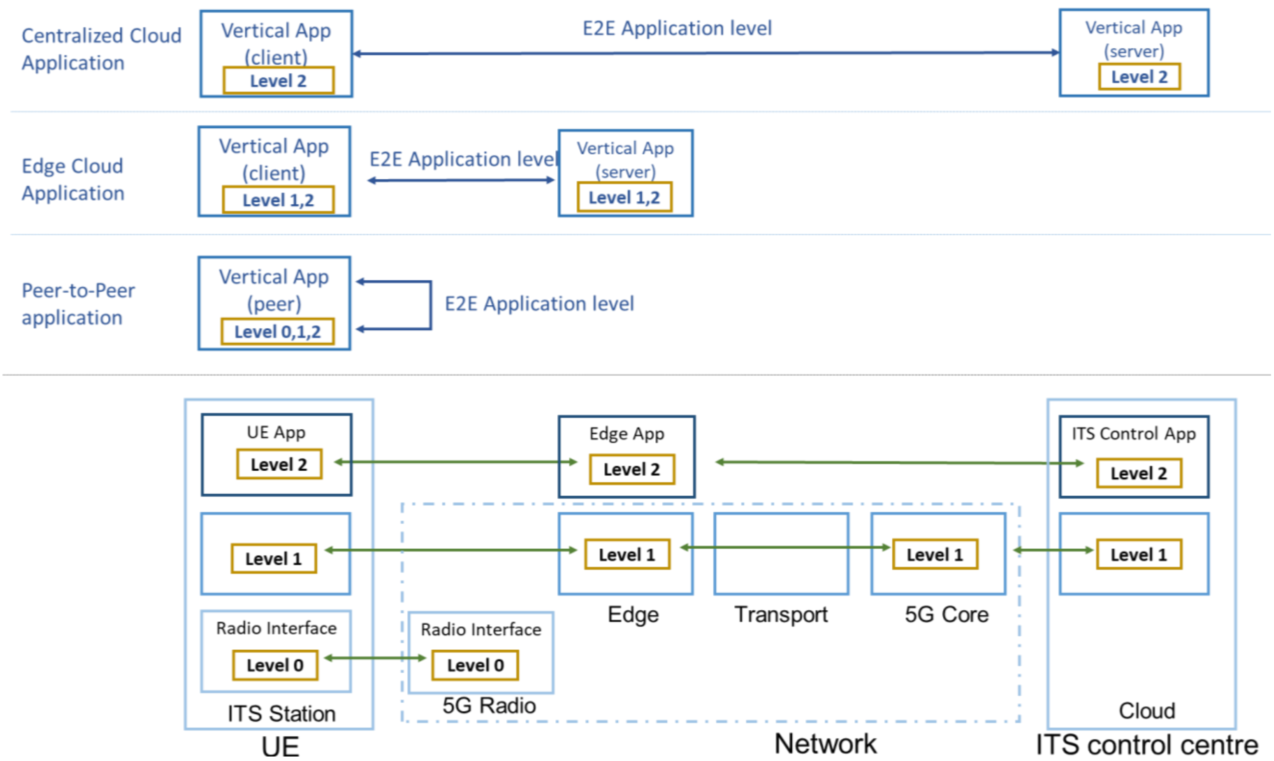

Figure 4: PCO levels in the system under test.

<u>At the ITS station</u>, the three PCOs (level 0, 1, and 2) are located as shown in the next figure.

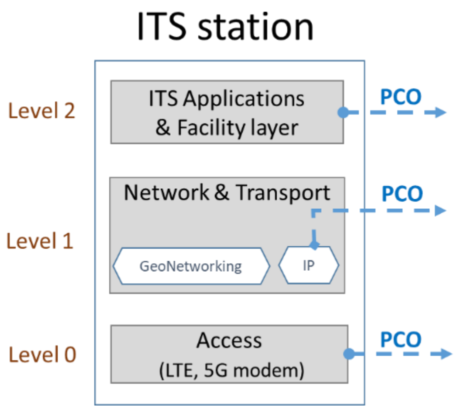

Figure 5: ITS Station PCO levels in the system under test.

Level 0, Access: Above the Access layer (LTE, 5G, etc.). These measurements shall be performed at chipset level, and specific tools of the chipset vendor of the communication chipset incorporated into the ITS station (OBU, RSU, etc.) are required to observe this point (i.e., take measurements)[8]. This PCO will allow taking measurements of relevant cellular network information, signal strength and quality, plus the protocol message exchange. It will allow to identify when a handover is taking place.

Level 1, Transport: Above the transport level, specifically at IP network/transport layer, using IP connectivity. This level allows evaluating QoS indicators (such as TCP/IP or UDP/IP throughput, UL and DL, one-way delay, packet loss, etc.) and monitoring the traffic received. This level can also be used to run tests using synthetic traffic that emulates the characteristics of real traffic (see also Sections 3.7.1.2 and 3.7.1.1).

Level 2, ITS application: ITS messages, or other traffic, exchanged between the ITS station and the ITS control centre (or between ITS stations) at application level shall be logged, together with the timestamp when these messages are transmitted and received by other ITS stations. This evaluation point is required to obtain relevant parameters at application level such as latency, inter-packet gap, reliability, etc.

The vehicle where the ITS station is installed shall provide positioning information using and external position estimation device (e.g., external GPS). In the particular case of the NL trial site, 5G-enabled positioning information (e.g., using mmWave) will also be available and subject to assessment.

At the network, the PCO levels are located as shown in the figure below, in the cases of both NSA and SA deployment options.

[8] The related chipset capabilities are under investigation with the vendors.

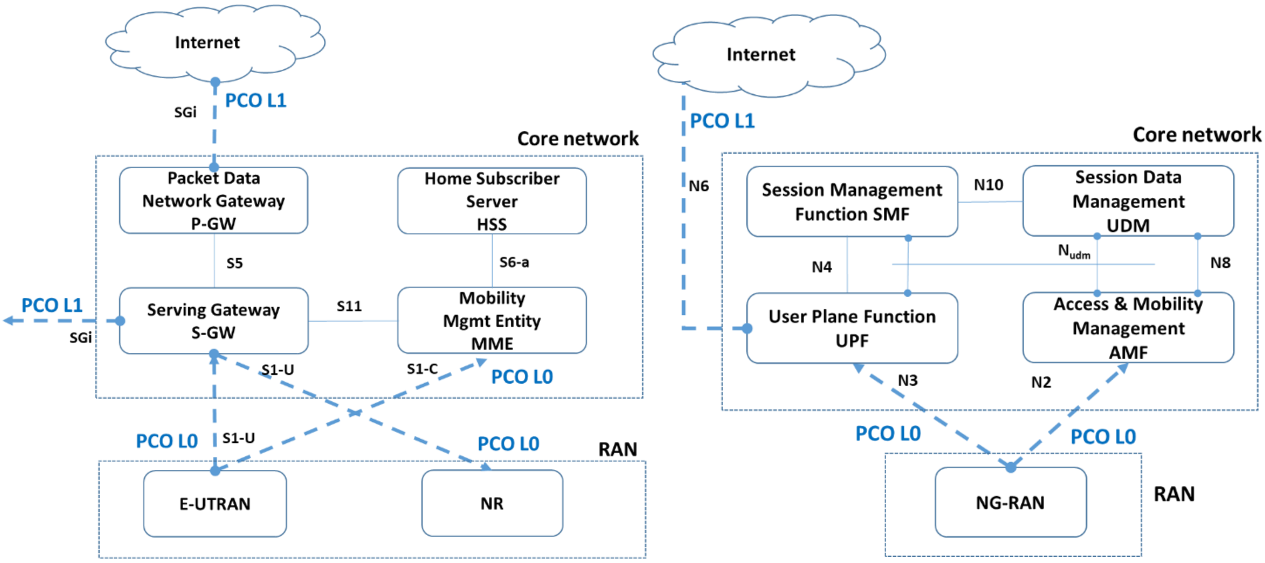

Figure 6: Network PCO levels in a 5G NSA network - option 3 (left) and 5G SA network - option 2 (right).

Level 0, Access: Above the Access layer (LTE, 5G, etc.). This PCO shall be provided by the base station (nodeB or gNodeB) and the Mobility Management Entity (MME) logging software capabilities. It will provide information equivalent to the access level at the ITS station side. These measurements provide information about specific ITS station connections, but they can also provide data referred to the total number of ITS stations or devices connected to the network, to provide statistically meaningful information.

Level 1, Transport: Collect network and transport related information at network side. Capability to monitor traffic at the SGi interface. After the Serving Gateway (SGW) or after the Packet Data Network Gateway (PGW). Endpoints between the ITS station (level 1) and after the core network (level 1) shall be available to test the communication link.

Level 2, ITS Application: This PCO level is not part of the network. In the case of a MEC located at the network edge, it is considered as part of the ITS control centre executed at the network edge. Although the MEC is hosted inside the network, the software is managed by the provider of the ITS solution and thus it has been considered as being logically outside the network.

At the ITS control centre, the PCO levels are located as shown in the next figure. The logical ITS control centre has two components: the MEC server (with the ITS software) and the remote ITS centre, connected to the core network via internet. The MEC server shall be located at the edge site, and will be connected to the core network SGW or PGW through an SG_i interface.

Level 1, Transport PCO shall be located inside the MEC to allow injection and monitoring of IP traffic.

Level 2, ITS Application **PCO** is provided by the logging capabilities of the MEC server ITS application software.

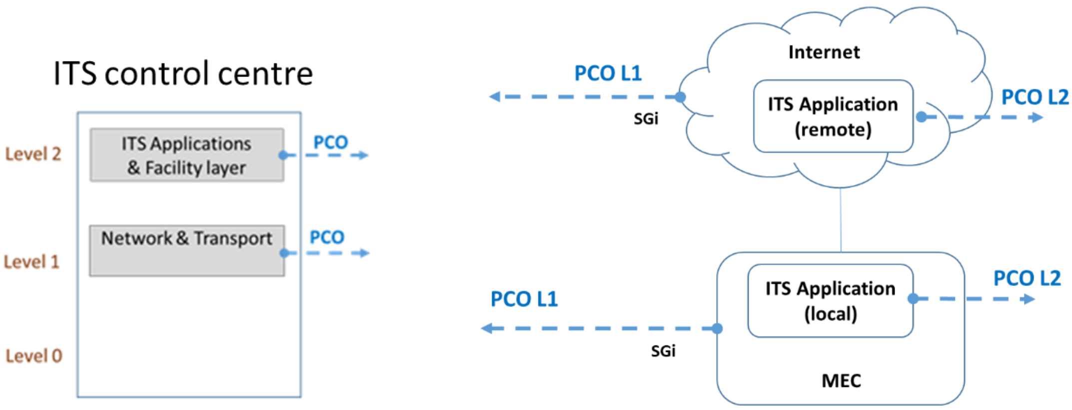

Figure 7: ITS control centre PCO levels in the system under test.

The remote ITS centre is connected to the core network via internet using the SG_i interface.

Level 1, Transport PCO shall be located inside the server supporting the ITS application in the remote server, to allow injection and monitoring of IP traffic.

Level 2, ITS Application PCO is provided by the logging capabilities of the remote server ITS application software. The ITS application supports the logic for the messages exchanged between the ITS control centre and the ITS station. The logging capabilities should allow to record the ITS messages or other application traffic (meta)data (see Section 3.2.1) sent by the ITS control centre and ITS (or other) messages received the ITS control centre, together with its related timestamp.

To facilitate the evaluation of the contribution to the message packets delay of the different elements involved, the ITS messages exchanged may be modified by adding local timestamps.

Some UCC/US to be trialled in some local sites include direct ITS station to ITS station communication (PC5 interface). The testing scenario requires testing the communication among ITS stations (as shown in the bottom part of Figure 3).

3.2.1. Logging information

5G-MOBIX will collect several pieces of information from the PCO levels defined above (level 2, level 1 and level 0). This information will be logged together with the related time and position information as appropriate. Accordingly, each measurement will be stored including:

- **Timestamp:** It shall be set to precise absolute time obtained by the *Global Navigation Satellite System* (GNSS) component of ITS station or the network. If the precise absolute time is not available, a method to compensate the drift shall be investigated.
- **Precise location**: Provided by reference navigation system, ITS messages (from messages that contain location information). For other data transmission that does not incorporate location, the location information could be extracted from level 1.

- **Identity** of the ITS station or network / infrastructure element.
- **Identity** of the PCO (and related level).
- Level (2, 1 or 0) specific information.

Level 2 specific information

Level 2 information will contain the specific application information to be logged.

- In the case of applications using ITS messages, every CAM[9], DENM[10], CPM[11], MCM[12] or other type of ITS or other message sent or received via V2V, V2I or V2N, shall be logged by the raw data injection and collection module (measurement subsystem).
- In other types of applications, each specific UCC/US will specify the application information to be logged e.g., MPEG-DASH for video transmission (see Section 3.5 and Appendix C).
- Measurement information: Measurement information, as specified by each UCC/US (according to the related KPIs), will be logged. It will include, at least, one or more of the following elements (measured at least every second):
  - Data rate: Measurement of the *instantaneous* data rate per second for each data flow. It will be stored preferably in kbps.
  - Error code: Code of error during the measurement, in case there is an error preventing from performing a measurement e.g., throughput measurement cannot be performed because the connection has been lost.
  - Error: Text describing the error during the measurement (linked to the error code).

Level 1 specific information

Level 1 information is mainly composed by information related to the network and the communication channel, and information related to level 1 measurements performed on the communication channel (if any).

- Network and communication information: Basic information available at level 1 (Complete network information is available at Level 0). It may include parameters such as Mobile Network Code (MNC), Mobile Country Code (MCC), RAT (LTE, NR, etc.), cellular ARFCN[13], Physical Cell Identity (PCI), Cell ID, eNB ID, gNB Id, LTE Tracking Area Code (TAC), Received Signal Strength Indicator (RSSI), Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal Noise Ratio (SNR), Channel Quality Indicator (CQI) or Timing Advance (TA).

[9] Cooperative Awareness Message
[10] Decentralized Environmental Notification Message
[11] Cooperative Perception Message
[12] Manoeuvre Cooperation Message
[13] Absolute radio-frequency channel number

- Level 1 measurement information: It will include one or more of the following instantaneous measurements, which are acquired at a per second rate, and depend on the specific network conditions at that moment due to UE position, traffic load, etc.; and will later be processed to produce the UCC/US KPIs.
  - Instantaneous Throughput: Stored preferably in kbps.
  - Instantaneous One-way delay: Time required a packet to be transmitter from the source to the destination.
  - Instantaneous Jitter: Deviation from expected reception time (periodic signals).
  - Instantaneous Packet loss rate: Percentage of loss packed to the total number of packets.
  - Round Trip Time (RTT): Time passed from the moment a packet is sent to the moment it is received the acknowledgement that the packet has been received.
  - Error code: Code of error during the measurement
  - Error: Text describing the error during the measurement (linked to the error code).

Level 0 specific information

Level 0 information is normally linked to the specific provider of the chipset (in the UE case). The format of the logging is usually proprietary, and manufacturer tools may be required to access the information.

The logging of level 0 information shall include the following elements

- Signalling traces: At least signalling logging required for KPI computation will be logged, such as attach procedures, RRC connection establishment and release, etc.
- Network and communication information: Level 0 information provides a deeper access to network information compared to Level 1 information, as it details the information the UE handles to communicate with the network.

3.2.2. Measurement methodology

The data collection methodology builds on a variety of measurements realized in different PCOs throughout the infrastructure i.e., across UEs / OBUs, Road-Side Infrastructure (RSI) or Network devices. The approach is to set/deploy lightweight software agents in the respective Level of each PCO of interest (depending on the KPIs). The agents are responsible for collecting the measurements i.e., the Logging Information (Section 3.2.1), and are typically deployed in pairs, corresponding to the network paths/segments measured. The measurement procedure between two PCOs (source and destination) is performed as defined below:

1. The measurement is configured. The Source and Destination Agents are started and synchronized with each other, that is, they have clocks that are very closely synchronized with each other and each fairly close to the actual time. This is typically accomplished through means of protocols such as the Precision Time Protocol (PTP) [27]. Source and Destination IP addresses are selected.
2. The Destination-Agent is configured to receive the packets.

3. At the Source Agent host, the traffic flows under observation are either created by the application at hand or synthetically created according to the selected protocol (such as TCP/IP). The content of the test packets, in the latter case, is random. The size of the packets (service data units, SDU) and other parameters such as packet departure time is configured according to the specific measurement to be performed (see also Sections 3.7.1.2 and 3.7.1.1).
4. At the Destination Agent host, the packets are received and the corresponding measurement data is logged. The measurements are typically performed on a 'per second' basis and for each measurement frame.

   The derived measurements are aggregated at a trial site level (subsequently aiming the aggregation at cross-site level[14]). The measurements obtained by this procedure will be processed to produce the network performance evaluation (see Section 0). The overall process is managed by a corresponding controller entity. In several realizations of this methodology, the controller entity also allows the post-processing and graphical representation of the corresponding KPIs. Figure 8 below illustrates the measuring procedure.

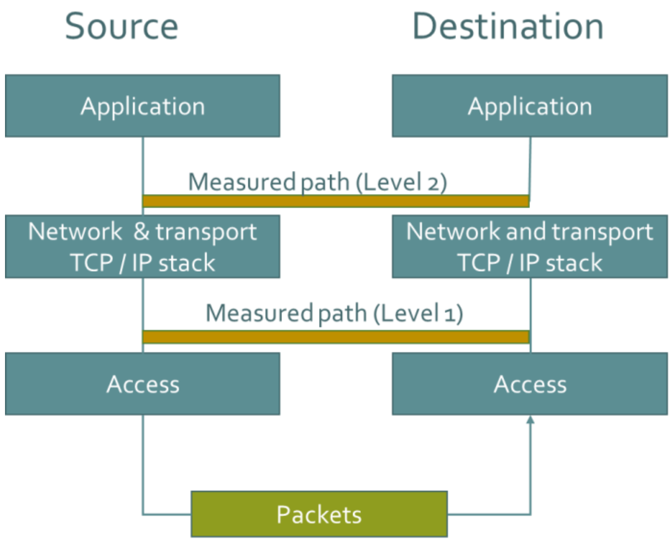

Figure 8: Measurements methodology overview

Conforming to this generalized measurement methodology, two realization approaches are foreseen, according to the type of the involved agents. Namely:

Existing Agents: There are dedicated agents for widely used software projects that are readily available to be deployed, enabling the collection and subsequent export of measurements to the monitoring system without customizing any source code. These agents are called *Exporters*.

[14] Subject to the Data Management processes and tools handled by T3.5.

Figure 9 below illustrates an example setup for measurements taken at L1, by the Prometheus tool agents[15]. The goal is to monitor two RSUs. To achieve this, a Simple Network Management Protocol (SNMP) instance is installed in each of the RSUs, providing network measurements which need to be sent to the monitoring system i.e., get centrally collected/aggregated. In this case, there is a SNMP exporter available, which gets installed and automatically exports all measurements of interest that are provided by SNMP to the monitoring system, in the right format.

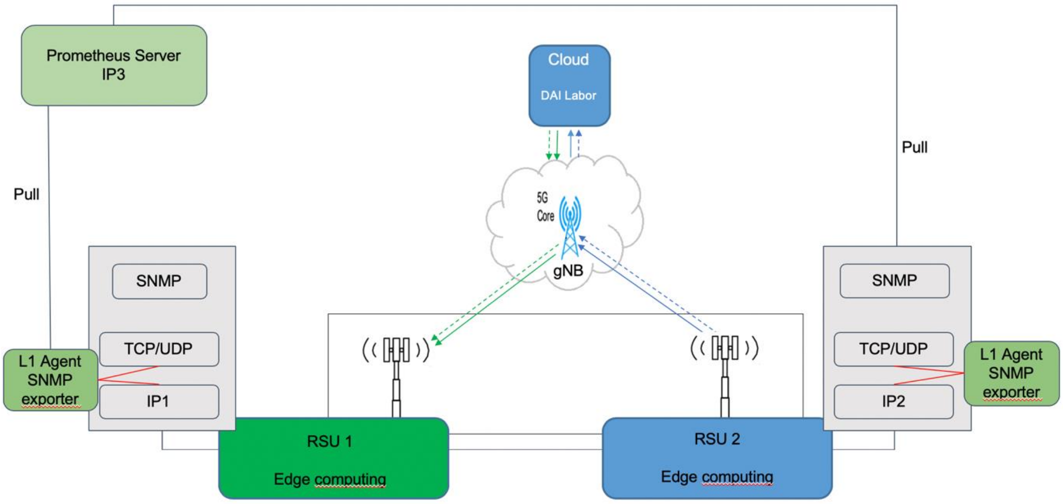

Figure 9: Network Monitoring Architecture (L1)

The same concept can be applied in different contexts. If there is a tool which provides interesting metrics and its exporter is available, it just has to be installed in the RSU and the metrics will be exported to the monitoring tool. A selection of interesting tools, which already include exporters to the monitoring system, are shown in Table 63 in Appendix D.

[15] See also Table 63 in Appendix C.

Tailored Agents: In other cases, where there is no Exporter readily available for the utilized Software or PCO level of interest, the agent has to be amended as a part of code and will "manually" expose the measurements to the monitoring system. Those agents are referred to as client libraries that are added by instrumenting application code. Such client libraries are already available for the most widespread programming languages (Java, Go, Python, Ruby), and a wide range of unofficial third-party clients exists for other languages like C/C++, Node.js, Bash, just to name a few. The client libraries have to be included in the application that is going to be monitored as part of the code.

An example of this type of measurement approach is illustrated in Figure 10. The example focuses on the measurement of TE-KPI1.1-User experienced data rate KPI for a WebRTC-based video streaming application. As described in D2.5, this KPI aims to measure the perceived data rate at the application layer (Level 2) from UEs and OBUs. That means the amount of application data (bits) correctly received within a certain time window in an OBU. In this case, the addition of a small number of code lines allows the calculation of the instantaneous data rate for the received video in that OBU. Once this value is calculated, it has to be visible for the monitoring system i.e., get centrally collected. To accomplish this step, it is needed to add an agent in the application by inserting it directly in the code. This agent exposes the measurements to the monitoring tool in a specific IP address and port. The monitoring tool needs to know beforehand in which address the metrics will be exposed, which is typically done through a configuration file.

Once the measurements arrive in the monitoring system, they can be represented in graphics, stored in data bases or queried with simple commands, among other possible tasks. As an example, it is possible to query the mean value of all instant data rate values measured in a specific interval of time. The result would be the average data rate which could be an adequate value to compare with the KPI goal value in question.

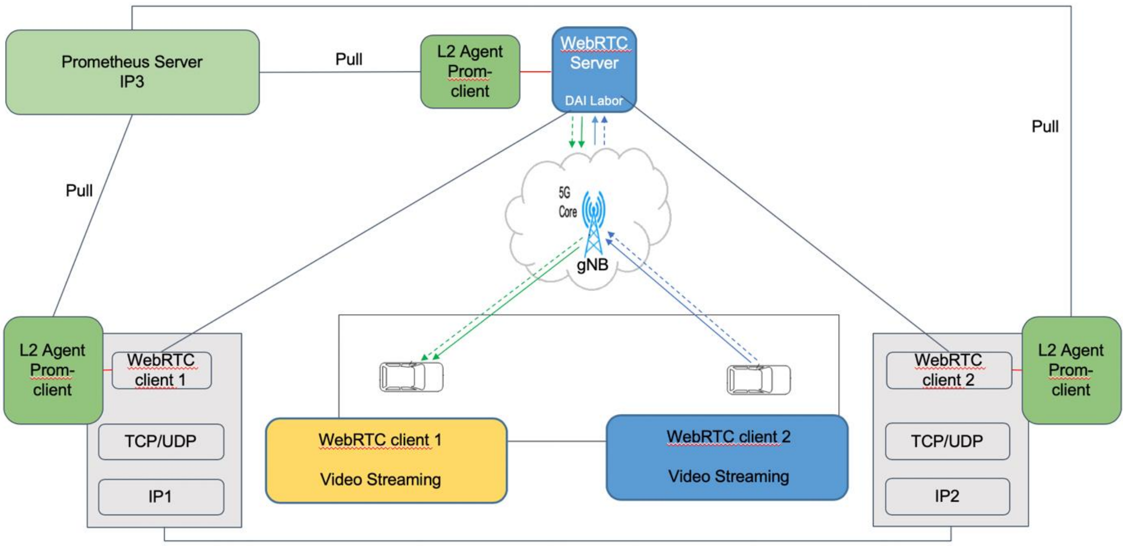

Figure 10: WebRTC Monitoring Architecture (L2)

3.3. Specification of events, states and transition

The 5G-MOBIX project focuses on assuring the QoS of automotive services in mobile networks, especially in cross-border conditions. As specified in D2.5, Section 2.1.1, the identification of the network component states defined by mobility, the transition between these states and the events that trigger these transitions are required to properly obtain the defined KPIs in cross border conditions, but to also further specify additional KPIs directly targeted at capturing the effects of cross boarder mobility (see Section 3.3.2) . From the cellular network point of view, four states are considered to analyse UEs mobility:

- **UE OFF:** The UE is not powered.
- **Idle (or Registered):** The UE is attached to a network. i.e., in the case of LTE, the UE is in RRC Idle mode. The UE is not able to perform any data transmission or reception, and the terminal sleeps most of the time for battery saving purposes. The UE has been assigned an IP address and is known by the network EPC. The UE can perform cell selection and cell reselection procedures to camp in the most suitable cell.
- **Active (or Connected):** This state is intended for data transfer between the UE and the network. In the case of LTE, the UE is in RRC connected mode. There is an RRC context established, meaning that both the UE and the radio access network know the parameters necessary for their communication. The location of the UE is known at cell level. The mobility of the UE is controlled by the network and assisted by the UE with the provisioning of contextual information.
- **Inactive**: This state is applicable only to 5G, as a solution to cope with URLLC, eMMB and massive IoT requirements in terms of latency, power saving etc. (e.g. in the case of IoT devices that transmit only during short periods of time). This state uses a RAN-based Notification Area (RNA) update.

According to these four main states, the following transitions between states, shown in the table below, are identified.

Table 5: UE Transitions between states

Initial state	Event	Procedure	Final state
UE OFF	Power on UE	Registration	Idle (Registered)
Idle (Registered)	TX/RX data	RRC Connection Establishment	Active (Connected)
Active (Connected)	End of TX/RX	RRC Connection Release	Idle (Registered)
Idle (Registered)	Cell Reselection algorithm	Cell Reselection	Idle (Registered)
Active	A3, A5, A6 (see Figure 11)	Handover - Intra frequency - Inter frequency - Inter RAT	Active

Active	-Loss of home PLMN coverage -Availability of home PLMN coverage -Loss of current PLMN coverage	Roaming	Active
Active	- No activity for a certain period of time	RRC suspend	Inactive
Inactive	TX/RX data	RRC resume	Active
Active	Connection failure	Cell Reselection	Idle
Inactive	Connection failure	Cell Reselection	Idle

The figure below shows in a graphical way the four states and the possible transitions between them.

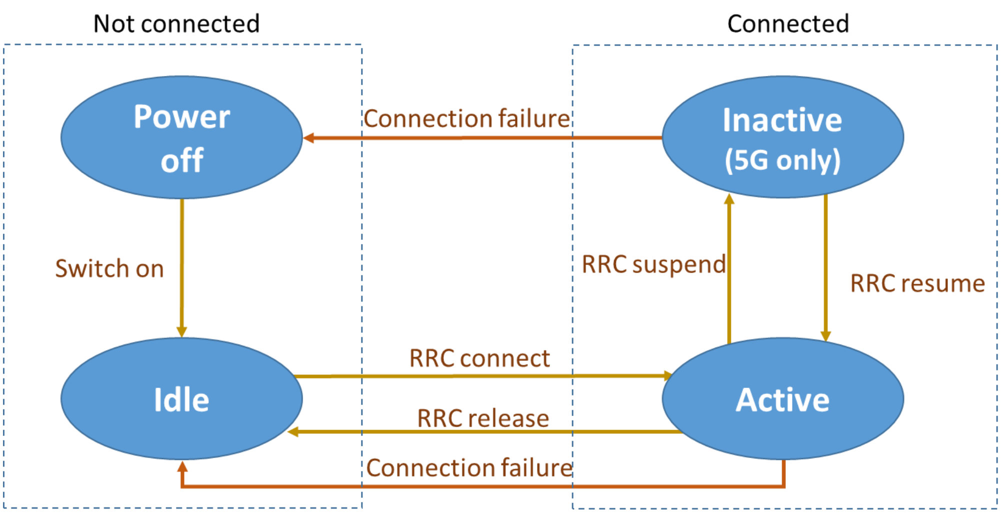

Figure 11: State transitions

5G-MOBIX will mainly focus on the transitions in cross border conditions affecting QoS, i.e., handovers and roaming. Each UCC/US will analyse specific scenarios with the UE camped on cross border networks and different states, and with the above events originating transitions between UE states.

Figure 12 below illustrates an example of a transition from 'UE off' state to 'Idle' state activated by a 'Power on UE' event. The procedure required to perform this transition (registration) is decomposed in the figure in several steps, from system acquisition to the completion of the attach procedure and Packet Data Network (PDN) connection. The UE communication with the network will be logged during the trials, with the corresponding timestamp for all the signalling messages transferred, so as to be able to determine when transitions start and end) and the selected KPIs can be computed and analysed across the various steps of the transition. The logging of the required information will take place within the network infrastructure PCOs, as well as the UE, subject to 5G chipset debug mode information availability (see also Section 3.2, Figure 6).

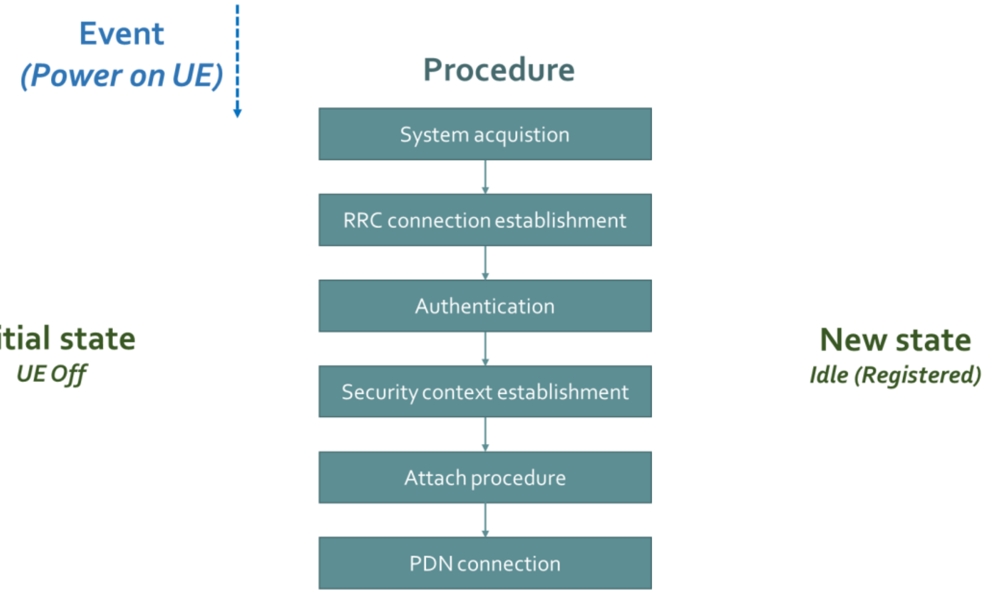

Figure 12: Example of UE transition from 'UE Off' state to 'Idle' state.

Figure 13 shows an example of a further step, depicting a detailed protocol flow between the UE and the network. The level of detail may even be increased by adding different entities inside the network (Access Network, MEC, core, etc.). For each UCC/US, the granularity level will be adjusted according to the needs of the US, such as the cause that triggers the event, the information to be logged, etc.

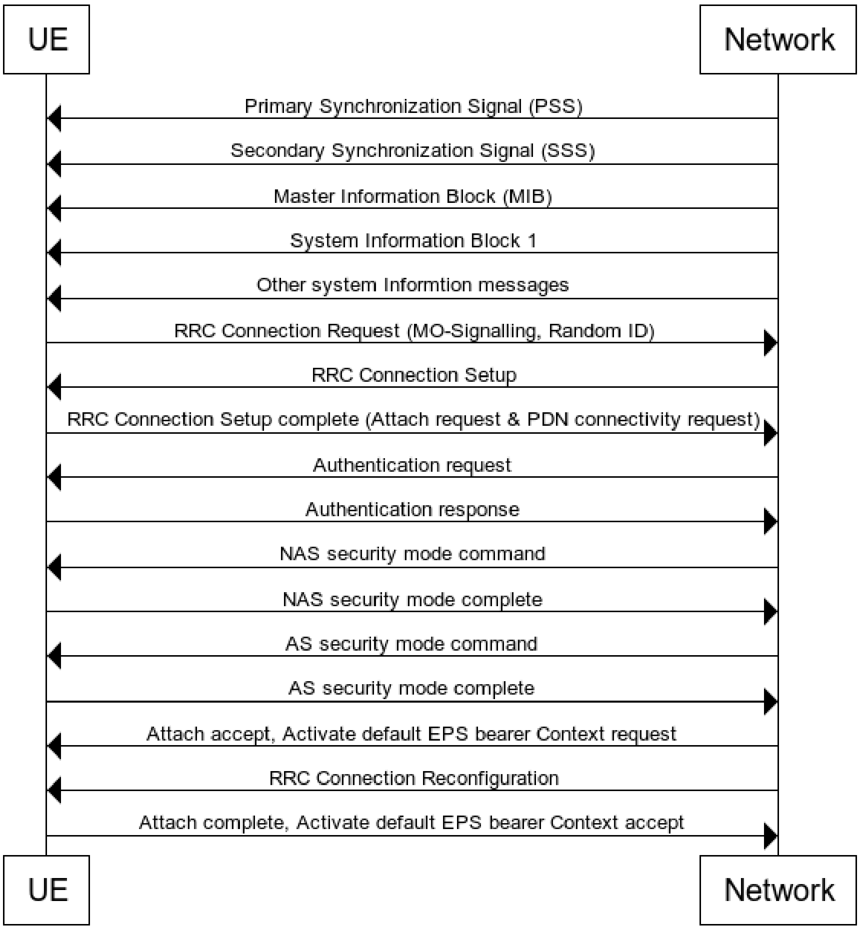

Figure 13: Message Sequence Chart (MSC) diagram showing signalling between the UE and the network.

In the context of 5G-MOBIX project, 5G handovers between 5G cells are possible based on event A3, event A5 or event A6 radio conditions measured in the RSRP/RSRQ domain. These events are triggered depending on specific network conditions as detailed in 3GPP TS 36.331 [1]. Specifically, event A3 is triggered when a neighbour cell becomes offset better than the primary cell (PCell/ PSCell); event A5 is triggered when the primary cell (PCell/ PSCell) becomes worse than a defined threshold1 and a neighbour cell becomes better than a defined threshold2; and event A6 is triggered when a neighbour cell becomes offset better than a secondary cell (SCell).

Apart from the cellular handovers and roaming procedures that will occur in the cross border environment and that may affect the QoS of the automotive services, in some UCC/US, *application level handovers/roaming events* are expected to happen, mostly referring to scenarios where edge computing (MEC) is supporting the application at hand i.e., a MEC node is serving the application in a PLMN, but due to mobility in cross border environment, the automotive applications would need to change the MEC serving them, and would start being served by a different MEC node. The states, events and transitions related to these application handovers also need to be defined and evaluated as they also affect the QoS of the offered services. As the project does not focus on designing a generic *application level handover/roaming* procedure, these events, states and transitions will be identified on a per UCC/US basis, and will be further illustrated within the evaluation scenarios to be reported in *D5.2 "Report on the Technical Evaluation*".

Based on the identification of the aforementioned key event/states and transitions, the evaluation efforts are in the position to identify cross-border mobility conditions, subsequently allowing a close look at their impact on the perceived performance. In practice, this translates to the ability to: (i) assess the different conditions under which the various performance KPI values will be observed during the trials, and (ii) specify handover/roaming KPIs aimed at explicitly capturing the corresponding handover/roaming latencies incurred by mobility. We elaborate on both these aspects in the following subsections.

3.3.1. Transitions between networks

The KPI values obtained when performing certain tasks in the home network may differ from the KPI values obtained when roaming in a 'non-home' network, and when in cross-border conditions. Even more, intra-operator and inter-operator conditions, and networks architecture (e.g. MEC existence, location and connection) may also affect the results. Accordingly, the UCC-USs will be performed with all the applicable relevant conditions in terms of home/visitor network and inter/intra-operator conditions and the related KPIs will be calculated for all these cases. In case of transitions, the KPIs will be assessed before, during, and after the transition. This way, the results obtained in the different contexts will be compared.

As an example, let's consider the case of TE-KPI1.3- End to End Latency in a CBC UCC/UC where this KPI is relevant. The end-to-end latency needs to be evaluated at least in the next cases:

- UE in country A in home network operator (network A) approaching and crossing the x-border into country B (service provided by network B):
  - E2E latency while the UE keeps attached to the home network, and before the UE connects to network B.
  - E2E latency during the transition from network A in country A to network B in country B.
  - E2E latency after the transition. At this moment the UE is roaming in network B (country B).
- UE in roaming in country A in a visitor network operator (network A) approaching and crossing the x-border into country B (service provided by network B):
  - E2E latency while the UE keeps in roaming in the network A, and before the UE connects to network B.
  - E2E latency during the transition from network A in country A to network B in country B.
  - E2E latency after the transition. At this moment the UE is its home network, network B (country B).

3.3.2. Additional KPIs

D2.5 defined a set of technical KPIs, including a set of general KPIs plus a group of specific handover KPIs. The latter category included KPIs focusing on the success rate of the handover/roaming events, as well as the explicit measurement of the mobility interruption time. Taking a step further, and enabled by the aforementioned analysis of related events, states and transitions, we hereby extend the overall set of 5G-MOBIX technical evaluation KPIs, by specifying the following additional KPIs. We employ the KPI definition template introduced in D2.5.

Table 6: TE-KPI2.2-International Roaming Latency

Title	TE-KPI2.4-International Roaming Latency[16]
Description	Applies to scenarios of cross-border mobility, where mobile UEs cross the physical borders between the involved countries, eventually triggering a roaming event. The KPI describes the duration of the roaming procedure, from initiation till completion and eventual continuation of communication sessions.
Where to measure	UE/OBU and/or Mobility Management Entity (MME) / Access and Mobility Management Function (AMF) / Serving Gateway (S-GW) / User Plane Function (UPF)
How to measure	The KPI will be calculated as the time interval between the roaming triggering event e.g., A3, A5, A6 (see Table 5 above) and the completion of the attachment procedure, where the Active state is reached (see also Figure 12 above).
Comments	• This KPI relates to TE-KPI2.3-Mobility interruption time, as defined in D2.5, since UE communications are interrupted during the measured period. However, TE-KPI2.3 is a user-level/data-plane KPI capturing the effective disruption, while TE-KPI2.4 isolates the control plane latency, decoupling the results from user plane traffic. • In some evaluation scenarios and trial sites (see also Section 2.1), the project will investigate the applicability of dual SIM card solutions, which largely focuses on overlapping cell coverage scenarios. In these cases, TE-KPI2.4 will focus on the time interval defined by the event triggering the initial attachment and association process with the visiting network, till the completion of the process i.e., reaching ACTIVE state (see also Figure 13). • This KPI does not aim to capture latencies related to application level handover in the case of edge computing scenarios. As mentioned above, this is considered as a latency component directly connected to the particular configuration/solution applied within each corresponding UCC/US. As such, we will employ *TE-KPI2.3-Mobility interruption time* for this purpose, as it includes the overall latency, including application level delay

[16] Continuing TE.KPI number from D2.5. The overall, updated list of Technical Evaluation KPIs is provided in Annex.

	components e.g., service discovery and/or traffic redirection in local break out scenarios. • The KPI will cater for all possible NSA/SA to NSA/SA handover/roaming events, subject to the eventual setup of the trial site infrastructures.

Table 7: TE-KPI2.2-National Roaming Latency

Title	TE-KPI2.5-National Roaming Latency
Description	Applies to inter-PLMN handover scenarios, where the involved networks operate within the national boarders i.e., alternative operators. This KPI applies to the case of the NL trial site, where such a trial setup will be available. On a technical front, this KPI is equivalent to TE-KPI2.3.

3.4. Evaluation of network capabilities

As explained in Section 2.1, the Technical Evaluation Methodology in 5G-MOBIX will pay attention to performance aspects related to the network infrastructure capabilities, so as to establish a reference point regarding the assessment of the UCC/US-specific KPI results i.e., in addition to the target KPI values defined on a UCC/US-basis. Table 8 below describes the template used for the evaluation of the network capabilities Table 9 subsequently summarizes the KPIs selected for this purpose, indicating the specifics of the data collection approach, in agreement to the data collection methodology presented in Section 3.2.

Table 8: Definition of Network Capabilities KPI Evaluation Aspects (template)

TE-KPI	
Network Segment / PCOs	*As defined in Section 3.2*
PCO Level	*As defined in Section 3.2*
Synthetic Traffic	*Defines the type of synthetic traffic to be generated for the measurements.*
Protocol	*Protocol employed at the selected PCO Level e.g., IPv4/IPv6, TCP/UDP, MPEG-DASH, etc.*
Logging Frequency	*The frequency of data logging: will be per second in the case of measurements (such as throughput), unless otherwise stated. In the case of application data (level 2), such as ITS messages, log entries shall be created as data is produced/consumed.*
Logging Information	*As defined in Section 3.2.1*

Table 9: Network Capabilities KPIs

TE-KPI	Network Segment / PCOs	PCO Level	*Synthetic Traffic*	*Protocol*	*Logging Frequency*	*Logging Information*
TE-KPI1.1 User Experienced Data rate	UE – UE UE- MEC UE – Core network UE – ITS control Centre	Level 2	Video streaming HD Maps[17]	ITS-G5 Application specific	Each second (min, max, average)	Timestamp Location Data flow (UL/DL) App Data rate
TE-KPI 1.2 *Throughput*	UE – UE UE- MEC UE – Core network UE – ITS control Centre	Level 1	Yes	UDP / TCP	Each second (min, max, average)	Timestamp Location Data flow (UL/DL) Throughput
TE-KPI1.3 End-to-end latency	UE – UE UE- MEC UE – ITS control Centre	Level 2	Yes	UDP/TCP	Second	Timestamp Location Data flow(UL/DL)
TE-KPI1.4 *Control plane Latency*	UE	Level 0	Not applicable	Not applicable	Second	Timestamp Data flow(UL/DL)
TE-KPI1.5 *User plane Latency*	UE, "egress point of the network radio interface"	Level 0 Level 1	Yes		Second	Timestamp Data flow(UL/DL)

[17] For UCC/US agnostic measurements, the type of data transmitted will be data used in several UCC/US, such as video streaming or HD maps data.

TE-KPI1.6 *Reliability*	UE – UE UE- MEC UE – ITS control Centre	Level 2	Yes	UDP / TCP	Each second	Timestamp Location Data flow (UL/DL)
TE-KPI1.8 *Network Capacity*	Network: S-GW (S1-U interface) / UPF level (N3/N6 interface).	Level 0 Level 1	Video streaming HD Maps FTP,...	UDP / TCP	Each second	Timestamp Data flow (UL/DL)
TE-KPI1.9 *Mean Time To Repair*	Network (Operation Support Systems - OSS): In VNFs such as UPF and AFs.	Level 1	Yes	Not applicable	Per event	Timestamp
TE-KPI2.1 *NG-RAN Handover Success Rate*	Network Radio UE	Level 0	Optional	UDP / TCP	Per session	Timestamp Location
TE-KPI2.2 *Application Level Handover Success Rate*	UE – ITS Control Centre MEC	Level 2 Level 1	Optional	UDP / TCP	Per event	Timestamp
TE-KPI2.4-International Roaming Latency[18]	UE-S-GW/UPF/MME/AMF	Level 0	Not applicable	Not applicable	Per event	Timestamp, Location

[18] TE-KPI2.5-National Roaming Latency is technically equivalent and therefore omitted from this table.

3.5. Evaluation of user perceived performance

The project will employ the same Data collection methodology, defined in Section 3.2, for the evaluation of user perceived performance as well. The evaluation process in this case heavily depends on the characteristics of the applications primarily demonstrated by the different traffic flow types involved i.e., each application may compose of multiple traffic flow types with different requirements and characteristics. We shed light on these aspects by employing the following two template tables. Table 10 is used for the definition of the various traffic flow types identified in each of the UCC/Uses (fields self-explanatory). This allows us in a second step to identify the type of logging data required on a per traffic flow type and UCC/US basis, for each of the selected KPIs. Table 11 below provides an explanation of the selected data collection methodology aspects.

Table 10: UCC/US Traffic Flow Type - Template Table

Title[19]	*Description*	*UL/DL/Sidelink*

Table 11: User perceived performance KPIs - Per UCC/US and Traffic Flow Type – Template Table

TE-KPI	*Selected KPI, as defined in D2.5.*
Traffic Flow	*The traffic flow type at hand, as previously identified. Subject to application specificities, not all flow types may be subject to the corresponding KPI evaluation.*
CB Issues	*Reference to the associated X-border issues as identified and listed in D2.1. See also Section 2.1.*
PCO	*The selected Point of Control and Observation for this KPI and flow e.g., OBU, gNB, MEC Application Server.*
PCO Level	*As defined in Section 3.2*
Protocol	*Protocol employed at the selected PCO Level e.g., MPEG-DASH, etc.*
Logging Frequency	*The frequency of data logging: can follow the application message rate by logging all exchanged traffic, or indicate a lower sampling rate.*
Logging Information	*As defined in Section 3.2.1.*
Target KPI Value	*The Targeted KPI Value (possible refinements to values reported in D2.5)*

Collecting this information aims to provide specific guidelines on the evaluation of the user perceived performance, in what concerns the realization of the data collection methodology presented in Section 3.2. This includes detailed information regarding the exact selection, placement/instantiation and configuration of PCOs across the overall 5G-MOBIX architecture, taking into account application level components and

[19] *(*)TFTx.y.z*
TFT: Traffic Flow Type
x: UCC index, y: US: index, z: TFT index

further pinpointing the targeted traffic flows and the exact data logging information. Appendix C presents the identified traffic flow type and corresponding KPI information for all UCC/USs considered in 5G-MOBIX.

3.6. Measurement data processing methodology

The raw data gathered from the different PCOs have to be processed, firstly converting it to a more convenient format to facilitate the processing phase that results in the KPI values. As illustrated in Figure 14, all the results of the measurements are also stored and conveniently formatted to facilitate a plot process to generate graphical representations, maps, etc. to better understand the resulting values.

These processing steps have to take into account some statistical good practices to get not only the value, but also more descriptive information about the variable under study, gathering also the following indicators:

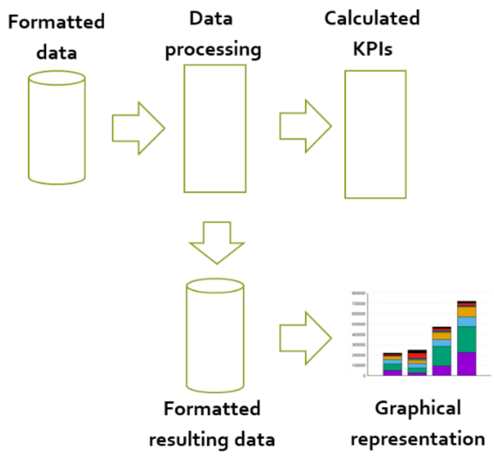

Figure 14: Data processing workflow

- **Maximum and minimum**: the sample maximum and sample minimum, also called the largest observation and smallest observation, are the values of the greatest and least elements of a sample. The sample maximum and minimum are the least robust statistics: they are maximally sensitive to outliers. It is important to note that in several occasions, the target KPI values identified by use cases refer to the maximum allowed values, subject to the functional requirements of the applications e.g., maximum E2E latency tolerable in remote driving.
- **Average (arithmetic mean)**: also called the expected value, is the central value of a discrete set of samples: specifically, the sum of the values divided by the number of samples.
- **Variance**: Informally, it measures how far a set of samples are spread out from their mean value. For example, the variance of a constant is zero. It is important to remark that this variance is not expressed in the same units of the value. To avoid this drawback, Standard Deviation is preferred.
- **Standard Deviation**: a measure of the amount of variation or dispersion of a set of values. A low standard deviation indicates that the values tend to be close to the mean of the set, while a high standard deviation indicates that the values are spread out over a wider range. The Standard Deviation can be calculated as the square root of the Variance. One important advantage of the Standard Deviation is that, unlike the Variance, it is expressed in the same units as the input data.

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

Figure 15: Standard deviation formula

The formula for the sample standard deviation is exposed in equation in Figure 15 where $\{x_1, x_2, \ldots, x_N\}$ are the observed values of the sample items, $\bar{x}$ is the mean value of these observations, and N is the number of observations in the sample.

Taking into account theses statistical considerations, the evaluation methodology will proceed with the processing of the logged information (see Section 3.2.1). The logged data should be in an easy-to-parse format. The processing of this logged data can be performed easily using Perl or Python scripting, languages that are provided with regular expression pattern recognition that helps to perform an efficient data parsing and the corresponding calculations. Two outputs are produced by this processing step. The main outputs are, first, the values of the studied variables in a clear text file, like CSV comma-separated-values file format. This is the most appropriate way to provide output in order to easily generate graphs with, for example, Gnu-Plot or Python graph libraries. Second, the statistical information of each variable under study: min, max, mean, average and standard deviation at least. This can be provided in a separate plain text file. Those statistical values could also be represented in mentioned graphs, so it is very convenient to store them in a plain text file format.

3.7. Generalization methodology

As introduced in section 3.1, some KPIs cannot be obtained from the user stories execution, and additional methods need to be implemented to obtain a deep evaluation of the performance of CCAM applications in cross-border corridor 5G environments. Three complementary approaches are proposed to cope with this objective: i) stress the network by traffic injection to obtain the maximum performance the network is able to offer, ii) inject traffic in the network to set the network in traffic conditions equivalent to the real conditions expected in the use cases developed (i.e. with a realistic number of users, background traffic, etc.) and iii) perform simulations (outside of the network) to analyse the behaviour of the 5G network under different conditions.

3.7.1. Network performance on real traffic conditions

One key objective defined by the 5G-MOBIX project is to obtain 5G performance results when CCAM traffic is supported especially in the CBC environments, usually areas presenting lack of coverage, interference among MNOs and roaming issues. Therefore, testing the 5G network performance is vital to understand these telecommunications issues and propose solutions accordingly. To test and measure the 5G performance with just a few autonomous vehicles traffic sessions, using few OBU/5G mobile terminals do not represent a significant result, in the sense that these measurements are more realistic when more terminal nodes stress the network and when these mobile terminals, perform multiple sessions. This approach goes beyond the simple autonomous vehicle CCAM data traffic test at the CBC. Aiming to investigate real traffic by achieving a massive traffic test, and, therefore, getting statistical relevance out of these measurements, two approaches will be followed:

- Replay Data Traffic

- Traffic Generation

Both types can be complementary and will be used together to better study their impact on the identified KPI and other telecommunications issues that are key to enable most of the use cases identified. These two approaches are located between the network layer and application layer.

3.7.1.1. *Replay data traffic*

The replay data traffic approach is divided into two steps:

- The first step is the real CCAM traffic collection that can have more complex behaviour at packet modelling level, such a 4k video streaming. This is performed without having any negative impact on the measured system (OBU installed on a real autonomous vehicle). A protocol capture/analyser tool will be used, that besides capturing exchanged traffic from and to the 5G network, it also allows to export a file with the entire captured traffic (*pcap* format).
- As a second step, the exported data will be used to replicate/replay the traffic by other OBUs. This process allows the generation of many different applications, even of the more complex ones (when compared with CAM packets behaviour), for example 4k streaming. Also, it allows traffic replaying using originally data sessions captured by partners from TSs, that can replay a given service in the CBC.

This procedure enables a statistical relevance performance measurement and it can be further used by regular vehicles with no need to close the road for trials.

3.7.1.2. *Traffic generation*

The first step in traffic generation is understanding the traffic behaviour, such as packet frequency, packet size, or other features. The identification of relevant parameters enables the traffic source modelling characterization, and the creation of procedures capable of replicating the previous observed and modelled real traffic - the traffic generator. To this end, the project will build on the capturing of real data traffic, as previously discussed, and the subsequent statistical processing for the identification of the relevant parameters. In a second step, the development of an OBU-based component that mimics CCAM traffic, including CAM, DENM and CPM messages behaviour will betargeted. The OBU will also inject other synthetic traffic increasing the stress on the 5G RAN. Additionally, using the several available OBUs, the access to the network in parallel will be mimicked. This approach provides a more realistic test, since other vehicles/OBUs are competing for the 5G radio resources on the radio access network, enabling, or getting close, to the massive test approach. One more advantage of using this approach is the process governance capability, since it is dedicated to testing proposes. The process will follow a given test plan, that will be manually, geographic or timely controlled.

3.7.1.3. *Technical approach*

Both previous solutions require the existence of OBUs using 5G modems and a cloud-based server to exchange all these data traffic flows. The test architecture depicted in Figure 16 is defined in deliverables

D2.3 and D2.4. The main idea is to push each 5G modem to the physical limits using a QoS OBU (Quality of Service On Board Unit), and multiple traffic session flows, aiming to drive the 5G access network to "massive", test conditions. The QoS OBU is used to generate traffic and compute performance indicators at the vehicles. As shown in Figure 16, legacy cellular networks (3G/4G) will be used to transmit the performance parameters under test, this procedure avoids disturbance in the 5G network interface. The traffic injection will run several times during the testing procedure, while crossing the border, in order to record relevant data for KPIs extraction by previously defined PCOs at Levels 0, 1 and 2 on different elements (Figure 6). This approach allows the evaluation of the network performance without the need of using a real autonomous vehicle by using a specific 5G QoS Probe (defined in D2.3 and D2.4) that can mimic real UCC-CS traffic. Thus, two fixed probes QoS FSU (Quality of Service Fixed Side Unit) in each MNO will be considered, one installed in the MEC and the other at the ITS Center. The QoS FSU is used to generate traffic and compute performance indicators at the ITS Center and MEC. It will be possible to cover all measurements scenarios defined in Section 3.2. These fixed units are a simplified version of the OBU, consisting on a software component which will not use any interface hardware (Modems, GNSS receiver, etc.) and will be hosted on existing physical servers.

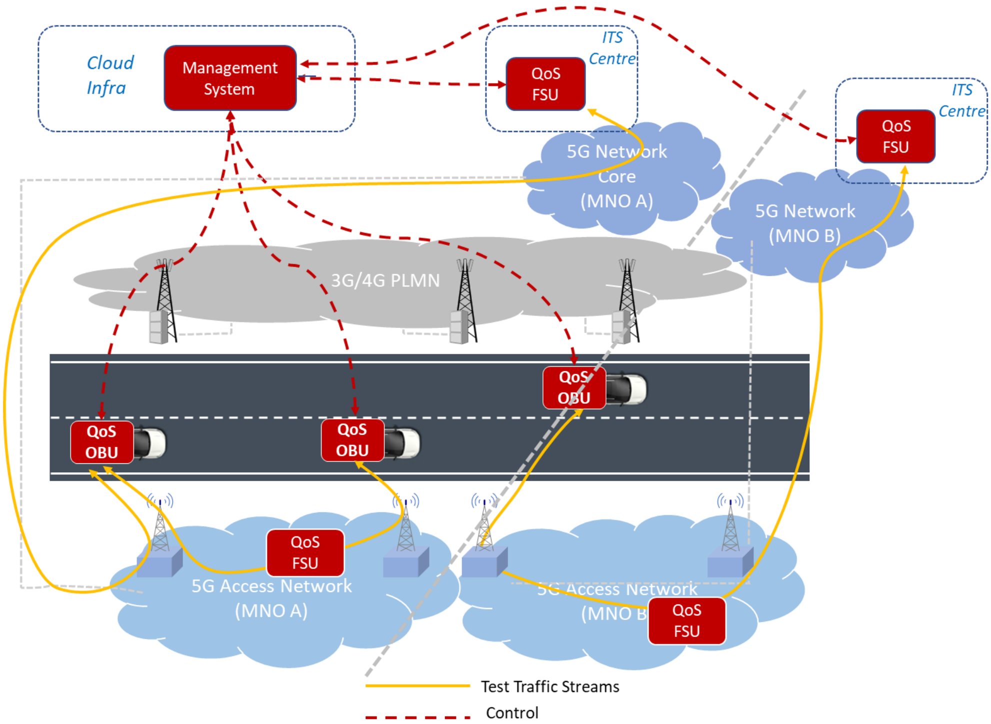

Figure 16: Test architecture supporting traffic generation.

Figure 17 presents the data traffic generation flow along with KPI processing and corresponding building blocks. This figure is a vertical view of the system architecture presented in Figure 16, where all key functional blocks are highlighted such as: test plan, traffic generation (both solutions), geographical sensors, measurements procedures, server end point and KPI visualisation subsystem.

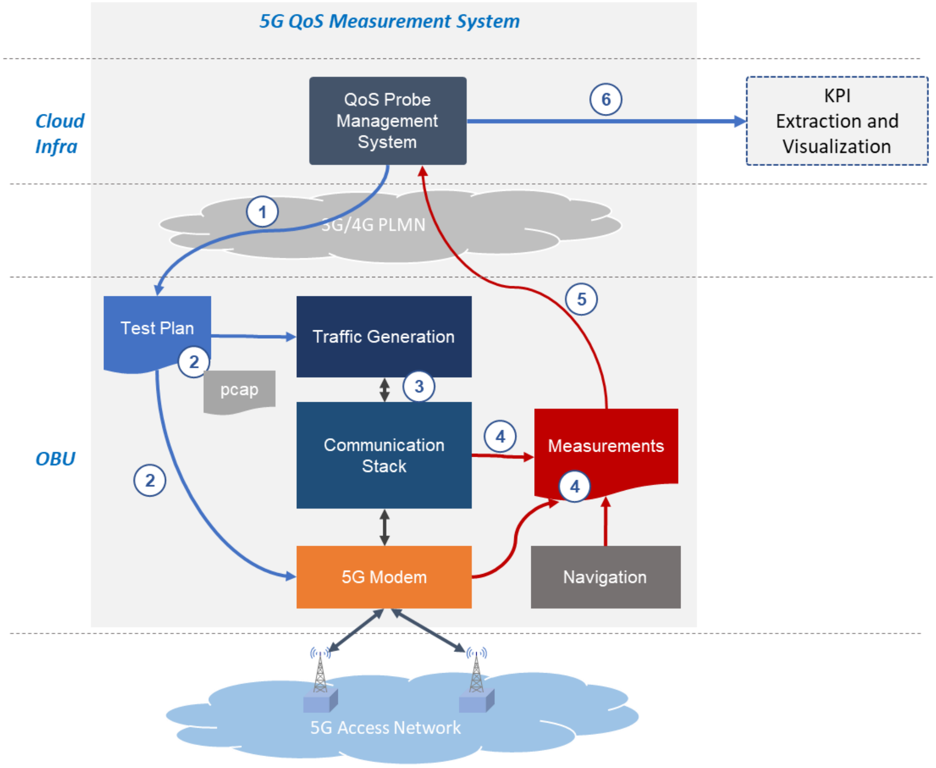

Figure 17: 5G traffic generation and performance measurements acquisition flow on OBU side.

3.7.2. Network evaluation by simulation

The 5G-MOBIX evaluation plan covers a wide range of experiments, thanks to the diversity of its trial sites and the subsequent UCC/US conducted on them. However, not all situations can be fully reproduced yet, thus making it impossible to evaluate all aspects of the network behaviour and limiting the interpretation of the KPIs. These situations include scalability issues (e.g. large number of network nodes and packet transmissions), complex road and infrastructure topologies, and the implementation of different data traffic scenarios. For this reason, the project foresees a complementary activity towards the generalization of results, based on simulations. Simulations are indeed an affordable and timely solution for reproducing complex situations dynamically and enabling a thorough evaluation of the project.

The **simulation framework** to be implemented in the project is expected to control three complementary components:

1. **Network traffic**. The total network traffic generated within the simulation environment can be controlled (through the number of vehicles and the selected applications). This makes it possible to investigate specific data flows that would be difficult or even impossible to reproduce through the real deployments, whether due to physical, infrastructure, or security limitations. For example, network

capacities can be extensively used for several types of scenarios and applications and the behaviour of the resources evaluated accordingly.

2. **Road traffic**. The impact of mobility can be assessed with the controlled variation of vehicle mobility parameters such as speed, acceleration, direction, etc.

3. **Network (radio) topology**. Both the communication network topology (e.g., radio coverage, base station location) and the road network topology, which has a direct influence on the effective communication capabilities of vehicles, can be changed in order to examine various deployment strategies. The same applies to the type of environment considered (e.g., urban area, highway, presence of tunnels, cross-border area between two, three, four countries, etc.). As part of this simulation framework, a limited set of scenarios will be reproduced.

While these evaluation environment *knobs* give ground to the generalization of the project results, at the same time they pose a series of **challenges** must be addressed. In essence, the value of this simulation-based generalization approach depends on the degree of abstraction introduced in the simulations, as the objective is to create an evaluation environment as rich as possible. Namely:

1. The road traffic generated in the simulation must consider realistic cases for the type of road and historical conditions.

2. The communications network traffic must follow the patterns defined by the applications (UCC/US) at hand.

3. The particular cross-border issues considered in the project, such as those attending handover implications, should be considered in the simulation environment.

4. The network capabilities and configuration should follow the base real deployment of the 5G-MOBIX network architectures broadly described in D2.2.

It is understood that results to be obtained in simulations will be estimative and cannot reflect with high degree the real performance of the network deployment, but they will provide **indicative results to be considered in future deployment decisions** and support the development process when time and budget restrictions do not allow testing different configurations and using particular data flows and traffic. Having said that, the next two **specific objectives** are initially identified regarding simulation efforts in the project:

1. Evaluate the **scalability issues** that emerge when a large number of road and network nodes come together in a cross-border area. The simulation framework will need to check the expected (indicative) behaviour of the network under different configurations and loads e.g., number of traffic generating vehicles simultaneously served by the infrastructure.

2. Determine impacts of different **frequency coordination** approaches on the support of CCAM services in cross-border areas, with the consequent work on analysing the propagation features of 5G equipment under particular simulated scenarios.

3.7.2.1. Investigating network scalability with trace-based traffic models

Network scalability is a fundamental element that must be considered to fully evaluate network and system performances in 5G-MOBIX. It is inherited from fundamental concepts, such as those described in the literature by the Amdhall law [21] and through the general theory of computational scalability[23]. However, it is still difficult today to reproduce complex situations, such as the introduction of a large number of nodes or packet transmissions. For this reason, and as complementary activity to the trials, we will rely on simulation framework to assess these situations as a preparation for evaluating network scalability constraints.

The network scalability problem will be stated as network flow multi-criteria optimization. These criteria will include network capacity, packet size and structure, data flow paths and routing protocols. Real traffic data (at vehicles and servers, uplink and downlink) and models will be integrated from ISEL (ES-PT corridor), so as to define realistic package structures and traffic characteristics. Missing data will be extrapolated or simulated used 3GPP reference implementation as main input.

This activity will implement at least one UCC/US, to be selected depending on the quality and quantity of data received from the ES-PT trial site. Special attention will be paid to the two following use-cases/user stories, which are both implemented on the ES-PT trial site and are offering two complementary network scalability issues: *(a)* vehicle quality of service (US: public transport with HD media services and video surveillance); *(b)* remote driving (US: automated shuttle remote driving across borders).

The simulation framework will be used as a first input to integrate real traffic data and models, and reproduce the ES-PT trial site. This trial site will be reproduced within the simulation framework by the partners. Wherever possible, supervision tools will be developed so as to facilitate the coordination of the simulation components (calculation and execution time). This framework combines the capabilities of a state-of-the art traffic generator, and an event-based network simulator. The main components of the simulation framework/architecture are described next:

- **Road traffic simulation**. The main components are based on the Simulation for Urban Mobility (Eclipse SUMO), which is a microscopic and mesoscopic road traffic simulator, reproducing realistic vehicle behaviours for urban and extra-urban/highway scenarios. Free OpenStreetMap data will be systematically used to produce scenarios with a realistic topology. An appropriate number of vehicles launched with a statistical distribution according to the scenario will be generated, involving a suitable mix of types of vehicles.

- **Communication network simulation**. Considering the 5G network deployment of the project as much as possible, the network resources, path loss models and high-level network behaviours will be developed with OMNeT++. SimuLTE will be the OMNeT++ component used to recreate the 3GPP network deployment, importing the radio propagation model previously described. The vehicular network scenario will be carried out using the Veins component of OMNeT++, in charge of taking the traffic model and road topology managed by SUMO as input and then create the mobile network nodes.

3.7.2.2. Analyzing impact of cross-border frequency coordination approaches

The support of different CCAM services across borders requires continuous connectivity with a quality level that meets the QoS requirements of the services, regardless of road or network conditions. One of the main limiting factors from the network performance perspective is *interference*. In this specific case there is the intercellular (co-channel) interference between cells of the same operator, but also possible interference from cells of an operator on the other side of the border, utilizing the same spectrum bands (but in a different jurisdiction).

The cross-border interference is generally a challenge for all kinds of radio-communications systems (both fixed and mobile) and necessitates cross-border frequency coordination among neighbouring countries. This typically relies on interaction between national regulators, mobile network operators and regional bodies, such as, The European Conference of Postal and Telecommunications Administrations (CEPT). For instance, CEPT has produced recommendations ECC (15)01[20] for cross-border coordination of a number of spectrum bands including pioneer 5G bands 3400-3600 MHz and 3600-3800 MHz. The recommendations (and similar documents) provide guidelines for propagation models (usually empirical models from the International Telecommunication Union (ITU), etc.) and formulae to be used to determine permissible interferences, contours of coordination, etc., which in turn may restrict some cross-border deployments (or site configurations) and also inform how spectrum bands are shared between operators on either side of the border.

The simulations to be performed for this objective will use similar components as described above but will also integrate a **network propagation** simulator. Here it is proposed a realistic channel modelling using 3D ray tracing software combined with different radio technology developments (mmWave band operation, beamforming, MIMO, radio resource management algorithms, etc.). This will be dependent on the final NR capabilities of the real deployments to be carried out in the CBC. For ray tracing, we will use WinProp or internally developed Matlab ray tracing tools to import realistic topographical and surrounding infrastructure maps from any corridor as long as we have the map data available.

With the aforementioned practical realities of cross-border frequency coordinator, simulation provides an opportunity to determine impacts of different frequency coordination approaches on the support of CCAM

[20] ECC Recommendation 15(01) Cross-border coordination for mobile / fixed communications networks (MFCN) in the frequency bands: 694-790 MHz, 1452-1492 MHz, 3400-3600 MHz and 3600-3800 MHz. June 2016 amendment. https://www.ecodocdb.dk/download/08065be5-1c0b/REC1501.PDF

services in these areas. Such simulations are not specific to particular 5G-MOBIX use cases, but rather seek to understand how different frequency coordination measures may hinder or enhance the ability of the network to achieve required KPIs (particularly throughput related). Some of the questions framing the simulation studies may include:

- To what extent do current propagation models utilised in defining cross-border frequency coordination result in coordination measures that are overly conservative and constrain 5G-V2X deployments? For instance, do coordination measures limit the dense site deployments required to provide certain network performance for CCAM services?
- Are there alternative approaches for coordination of cross-border spectrum allocations between operators, in way that is more optimised (or even dynamically responsive) to road traffic densities and flows between neighbouring countries?

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4. IMPACT ASSESSMENT METHODOLOGY

This section presents the methodology for the Quality of Life (QoL) and Business Impact assessment of 5G-MOBIX that will be conducted in Task 5.3. The main focus will be on the regions, conditions and networks of the 5G-MOBIX cross-border corridor sites. All local trial sites are linked to those and will contribute to CBC trials. Inputs from the local trial sites will be used as a part of the CBC impact assessment. Development needs and objectives for future mobility of the key stakeholders at the CBC will be studied. The goal is to explore, how the 5G-MOBIX (enabled) solutions respond to the most relevant development needs in the context of cross-border mobility. The focus will be on cross-border context, not just general impacts of CCAM. Impact assessment will mainly focus on wider societal impacts and how those contribute to business impacts. Therefore, the scenarios to be used in impact assessment need to describe future overall solution(s) that will be a result of combination of 5G-MOBIX enabled services, and where assumptions about the future circumstances, such as penetration rates of the services, will be made.

4.1. Methodological approaches and focus in the assessment

The procedure and recommendations of FESTA handbook[21] is recognized when defining the methodologies but the approach is adapted based on the scope and scale of the trials and the most relevant impact categories. Furthermore, the latest results from the European projects AUTOPILOT, L3Pilot, CARTRE and ARCADE[22,23] will be used in defining the methodology for impact assessment.

In 5G-MOBIX, both qualitative and quantitative approaches are used and data are going to be collected and analysed. In the assessment of QoL the main focus is on subjective and qualitative measures. The baseline in the assessment will be the current situation with no CCAM services available. In a qualitative study typically, there is no separate data collection phase for the baseline data but the idea of the baseline is implicitly built into the measures (such as interviews and surveys). In case of more objective data such as logged vehicle data, a separate baseline data collection phase is needed to be able to conclude anything regarding the impacts of CCAM. The baseline needs to be similar with the treatment data regarding all circumstances and conditions except the availability of CCAM. Therefore, collecting baseline data is quite resource demanding. Usually, it is challenging to focus in one study at the same time both on measuring the effects on behaviour (with baseline data collection) and measuring the effects on user acceptance and preferences. In 5G-MOBIX, the focus is on user acceptance, business models and deployment. In addition, a limited set of data is planned as a case study to develop methods, observe and measure detailed traffic safety parameters in real traffic. As also indicated in FESTA, an assessment starts with setting the research questions and research hypotheses, followed with the definition of the relevant KPIs and measures. Typically, this is an iterative process which proceeds in parallel with the detailed planning of the trials - the

[21] https://connectedautomateddriving.eu/wp-content/uploads/2019/01/FESTA-Handbook-Version-7.pdf
[22] https://connectedautomateddriving.eu/wp-content/uploads/2019/09/Barnard-et-al-ERSA-paper-final.pdf
[23] https://connectedautomateddriving.eu/wp-content/uploads/2018/03/Trilateral_IA_Framework_April2018.pdf

KPI originally planned are modified to better respond to the possibilities of the test sites and trials. At the same time, each trial needs to define their experimental procedures and study designs.

An overall scheme of the impact assessment methodology is presented Figure 18. A more detailed description of the methodology for Quality of Life impact assessment is presented in Section 4.3 and for Business impact assessment in Section 4.4.

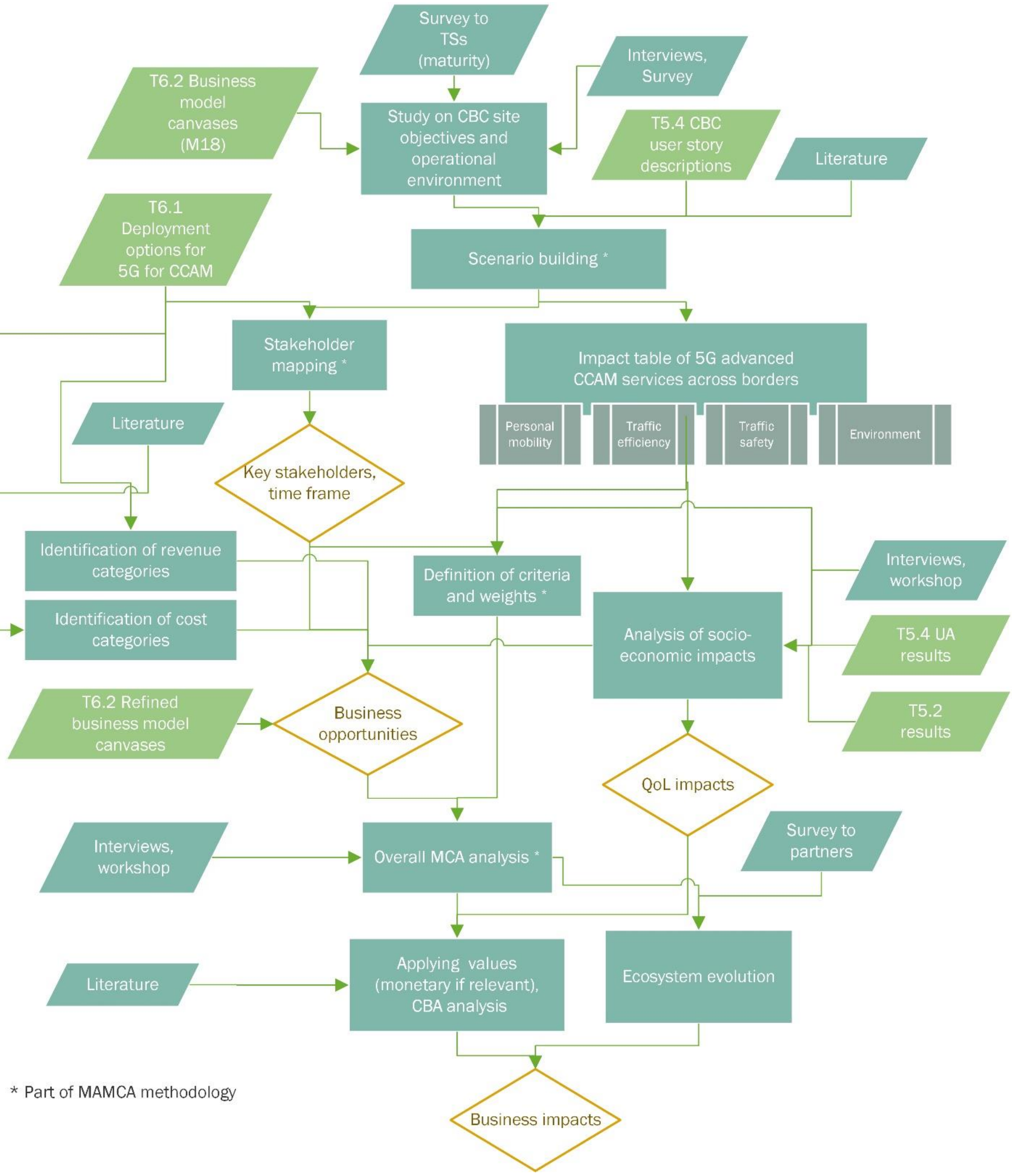

Figure 18: An overall scheme of 5G-MOBIX impact assessment methodology

4.2. Refined Key Performance Indicators (KPI) and metrics for Quality of Life and Business Impact assessment

D2.5 provided an extended set of KPIs and metrics for the evaluation and analysis of the 5G-MOBIX test sites and corresponding UCCs/USs. Special attention was put on the technical performance, but the deliverable also presented an initial framework for the impact assessment activities. This initial framework has been assessed with more specific information of the planned trials, and with regard to the data requirements of the impact assessment methodologies.

Since submitting D2.5, new evidence has arisen regarding impact assessment of automated driving, especially taking into account recent small-scale field tests of automated driving (L3Pilot deliverables D3.1-3.3, AUTOPILOT D4.6). The FESTA handbook was written for larger scale field operational tests with high maturity (TRL levels) with vehicles/functions in daily use in real traffic by ordinary users. Many of the metrics suggested in D2.5 are very detailed and interesting, but their assessment requires a great amount of data which is not possible to get from the small scale trials targeted in 5G-MOBIX. Therefore, we suggest and aim to conduct a higher level assessment of QoL and business impacts, which is feasible to carry out in the scope of the trial circumstances.

The focus in business impact assessment will be on analysing advances in identification of new business opportunities and development of conditions for deployment of cross-border CCAM services. Business impact assessment builds on business opportunities that can be derived from the QoL impacts, such as improvements to traffic efficiency, safety or decrease in environmental impacts. If it is not possible to quantify QoL impacts, also cost-benefit assessments will be challenging, since the benefits need to be given some values (monetary if relevant) to be compared with costs. Business impacts can also arise from improved operational efficiency but assessment of such impacts would require thorough analysis of individual organizations' processes which is not in the scope of this project. On the other hand, business impacts in innovation activities may emerge through wide collaboration within the consortium, shared knowledge and joint efforts for decreasing barriers to business development. The metrics for business impact assessment presented in D2.5 have been adjusted to be aligned with the scale of the trials, planned Quality of Life methodology and to reflect the objective to assess business impacts of the innovation ecosystem.

The detailed metrics that relate to traffic flow would require large scale pilots with several 5G-MOBIX vehicles, that are not in the scope of 5G-MOBIX trials. The same applies for the safety related metrics that were suggested in D2.5. Data from the technical evaluation may provide information about risks and perceived safety during the trials, but that does not relate to safety impacts of the mature solutions in full scale. The energy consumption is very much dependent on the type and size of vehicles used in the trials. The current traffic situation would also need to be included in the impact assessment to be able to draw conclusions on impact on environment. Therefore, the metrics for Quality of Life impact assessment are reduced to cover the main impact categories and to reflect the methodology for a high-level impact assessment. The more detailed metrics presented in D2.5 will be used as input for the main categories whenever possible.

The metrics for business impact assessment have also been refined and adjusted to better cover a wide perspective for business impacts within the ecosystem and business potential that may emerge from joint efforts. Instead of assessing monetary benefits on individual level, which would require large set of statistically representative data, the fit of the 5G-MOBIX enabled solutions to the customer needs for improving cross-border mobility will be assessed. Quantitative assessment of environmental benefits does not seem feasible in the project, and thus the metric will not be included in business impact assessment. Environmental aspects will be included in the overall impact table that will be compiled, and thus those will be taken into account if relevant. For other metrics minor adjustments have been made, in order to cover several stakeholders and to avoid overlapping work with T6.2 that focuses on development of business models from individual organization's point of view.

The refined set of metrics for Quality of Life and Business impact assessment is presented in Table 12. The Quality of Life focuses on assessing impacts of 5G-MOBIX enabled solutions in cross-border contexts on mode choice, travel time and throughput, traffic safety and emissions. The business impact assessment focuses on evaluation of impacts on costs, revenues, identification of customer needs and progress in readiness for deployment within the ecosystem. More detailed descriptions of the metrics are presented in sections 4.3 and 4.4.

Table 12: Refined set of metrics for Quality of Life and Business Impact Assessment

Class		ID	Description
Quality of Life	Personal mobility	IA- M1.1	Mode choice
	Traffic efficiency	IA-M2.1	Travel time and throughput
	Traffic safety	IA-M3.1	Traffic safety
	Environment	IA-M4.1	Emissions
Business	Customer need	IA-M5.1	Strategic fit of 5G-MOBIX solutions (CCAM services across borders and in context of national roaming)
	Costs	IA-M6.1	5G infrastructure building costs
		IA-M6.2	Capital expenses
		IA-M6.3	Operating costs
	Revenues	IA-M7.1	Revenue streams

	Progress towards commercial deployment	IA-M8.1	Number of mature solutions entering the market
		IA-M8.2	Development of capabilities within the ecosystem
		IA-M8.3	Evolution of business models

4.3. Quality of Life (QoL) KPIs and assessment methods

In order to assess the potential impacts of 5G-MOBIX services on the society, a qualitative assessment will be carried out. The assessment of all quality of life KPIs (for personal mobility, traffic efficiency, traffic safety and the environment) will be tailored to the scope of the project and will use an approach combining information from different sources, i.e. stakeholder workshops and interviews, user surveys, trial sites, literature and other projects (such as AUTOPILOT, L3Pilot, CARTRE and ARCADE). Finally, the results will be synthesized and elaborated by expert assessment. Where possible, the likely directions of influence will be determined for each metric (e.g. slight increase, significant increase, slight decrease, significant decrease) and the most important factors (mechanisms) affecting these directions and their size will be identified.

The impact assessment methodology takes use of the methodology and results of the quality of life assessment carried out in the AUTOPILOT project, which focused on automated driving enhanced by IoT. The aim is to identify potential impact mechanisms leading to changes in the different areas related to (societal) quality of life. The impact framework created by the impact assessment subgroup of the Trilateral Working Group between the EU, US and Japan on Automation in Road Transportation (ART WG) [28] will also be utilised. Due to the scope of the trials and the focus on technical evaluation, the impact assessment will mainly focus on qualitative results. Quantitative results will be produced if sufficiently representative data will be collected in the trials. The work will be carried out as expert assessment by the consortium partners utilizing external stakeholders' expertise where possible. Data from the trials and technical and user evaluation will be used if available and feasible.

The metrics and their preliminary assessment methodologies are presented below.

Table 13: Impact Assessment: Personal Mobility metrics

IA-M1.1-Mode choice
New mobility options, such as services enabled by automated driving may have an impact on the preferred choice of travel mode and therefore the modal split of a transport network. These changes in travel behaviour are an important indicator for assessing the other impacts of AD (travel time, safety and emissions).

Assessment method: The cross-border services of 5G-MOBIX enable seamless mobility across borders in automated vehicles. This has potential to change travel behaviour of people living or working close to a border. These potential changes in mode choice due to the 5G-MOBIX systems in the cross-border context will be assessed. Methods (i.e., interviews, surveys, focus groups) have been proposed to assess mode choice in the context of automated driving for example in L3Pilot and will be applied also within 5G-MOBIX.

Table 14: Impact Assessment: Traffic Efficiency metrics

IA-M2.1-Travel time and throughput
A qualitative assessment will be made on the potential impacts of the proposed technologies on traffic efficiency (in terms of travel times and throughput), taking into account changes in speed and manoeuvres such as lane changes. Conditions required for achieving improvements will be identified.

Assessment method: Potential changes in travel time and throughput will be assessed through the changes in indicator M1.1 by expert assessment and using, where feasible, data from the trials. Literature and expert assessment will also be used in determining conditions necessary for achieving improvements to travel times and traffic efficiency. In addition, results from user acceptance evaluation may provide valuable input.

Table 15: Impact Assessment: Traffic Safety metrics

IA-M3.1-Traffic safety
The concept of traffic safety consists of three dimensions: exposure, accident risk and consequences [40]. Exposure is related to the amount of travel: the higher the total distance travelled, the higher the probability for accidents. Risk is related to driving behaviour, such as speed, and mode choice: different travel modes have different exposure adjusted crash risks [8]. This is estimated to be the factor of main relevance for 5G-MOBIX. Consequences are related to changes in severity of injuries.

Assessment method: The high-level potential of the 5G-MOBIX systems to affect the three dimensions of road safety, specifically risk, will be studied on a qualitative basis through expert assessment. In addition, the accident mitigation potential of the services will be explored. Potential changes in traffic safety will be assessed through the potential changes in indicator M1.1 by expert assessment and using, where feasible, data from the trials. Video data collected by drone from the ES-PT CBC for the use cases lane merge, automated overtaking and last mile electric shuttles will provide indications on more detailed indicators such as time to collision, post encroachment time and time headway, which provide additional input to the assessment. Further, accident databases such as CARE[24] (Community database on road accidents resulting in death or injury) can be used to study potential accident types most likely affected, as well as find out the maximum potential of the services on accident reduction.

[24] https://ec.europa.eu/transport/road_safety/specialist/observatory/methodology_tools/about_care_en

Table 16: Impact Assessment: Environment metrics

IA-M4.1-Environment
Automated driving can have implications on energy consumption and therefore CO_2 emissions of vehicles, as well as air and noise pollution. The potential of 5G-MOBIX services in mitigating emissions will be explored, and conditions required for achieving improvements will be identified.

Assessment method: The potential of reducing CO_2 emissions will be assessed through the changes in indicator M1.1 and M2.1 by expert assessment.

4.4. Business impact assessment

Several methods can be used to identify the future business consequences of the implementation of a solution. The *International Association for Impact Assessment*[25] mentions methodologies like (but not only):

- Scoping (e.g. results chain analysis ...)
- Qualitative analysis (e.g. case studies, focus groups, through workshops and or interviews)
- Quantitative analysis (e.g. life-cycle assessment, material flow accounting, modelling, using surveys etc....)
- Aggregation and comparison of options (e.g. Cost-Benefit Analysis or economic valuation methods, and Multi-Criteria Analysis, like MAMCA)
- Supporting participation and involvement (e.g. internet consultation)
- Data presentation and involvement (e.g. GIS)
- Monitoring and evaluation (e.g. indicators)

In order to perform the business impact assessment, we will combine aspects from several impact assessment methodologies, to adapt the assessment to our specific project (trials sites, stakeholders involved, project focus).

Table 17: Impact Assessment: Customer need metrics

IA- M5.1 Strategic fit of 5G-MOBIX solutions (CCAM services across borders and in context of national roaming)
Profound understanding of customer's entire needs will provide a basis for mapping the network and elements that will be needed for developing solutions and services, and thus assessing potential costs and benefits.

[25] https://www.iaia.org/index.php

Assessment method: Business model canvases that will be created in T6.2 will provide value propositions, costs, revenues and stakeholders. Representatives of the most relevant customers for these value propositions will be interviewed and their objectives for developing traffic system will be discussed. Fit of the 5G-MOBIX business models to the identified customer needs will be assessed.

4.4.1. Stakeholder mapping

The value network map notation [4] supports discussing visually the creation of value in an ecosystem of actors. It differs from typical business model formulation approaches, such as the Business Model Canvas of Alexander Osterwalder [42], because it allows to model the whole ecosystem and allows to grasp the stakes of many revenue streams of interest to multiple partners relating to different transactions and it enables presentation of roles of stakeholders in the ecosystem. The value network map provides a common language that enable to easily communicate between stakeholders from different backgrounds. It is composed of: Blocks to visualize your ecosystems actors, building blocks proposed to visualize the key elements of an ecosystem. Value object can be products, services or money, but also intangible such as quality of life, experience, security, exposure, data, right and risk mitigation.

Using the concepts above, a value network map is constructed and it illustrates visually the exchanges of value objects among economic actors in a single economic system. It draws arrows to explain the exchange of value objects, with no regard for the related physical (logistic) flow. Emphasis is on ensuring that satisfactory counterparts are provided to each stakeholder, to design more sustainable ecosystems.

These highly visual concepts are meant to be used in collaborative interactive modelling session to progressively create a common understanding of an economic system, either existing or fictitious, by explaining the exchanges of value objects amongst economic actors, the value network map. It can also be used for interaction, effects and goals modelling in the ecosystem.

4.4.2. Cost-Benefit Analysis (CBA) methodology

A core element of the business impact evaluation is the cost benefit analysis, comprising both the economic and financial analysis of the 5G-MOBIX x-border pilot cases. Comparing the short-term deployment costs with the longer-term positive impacts resulting from the adoption of 5G is critical for the exploitation and large-scale market uptake. A refined set of quantitative and qualitative KPIs is presented in Table 12. Deriving financial and economic benefits from technical performance indicators is not always a straightforward task. For some pilot cases, productivity gains or travel time savings are foreseen to be directly measured and monetized, for other measures, this might imply the need to monetize other resource savings, using information on prices for energy and other resources. In yet another set of cases the economic gains and wellbeing created are worth measuring. In these cases, the quantification of the generated benefits based on measured technical improvements in trials (such as reduced latency and improved reliability for safety applications, higher throughput and data rate for entertainment applications) will have to rely on commonly used guidelines and empirically tested methodologies.

The economic and financial analysis will follow a 4-step process, as follows:

i) **Characterization and identification of benefits and costs:** a clear understanding of the functioning of the technology is crucial for the identification of the main benefits created and the main costs incurred with their deployment.

ii) **Collection of data for benefit estimation:** from all the collected technical performance indicators, a selection of the most relevant for the economic and financial analysis will be made. In the cases in which the available data was considered not sufficient to answer project commitments in terms of the economic and financial assessments, additional data might be requested.

iii) **Collection of data on deployment costs:** in most cases, the implementer of the technologies has not only a larger upfront deployment cost, but also incurs in continuous running expenses to be able to keep them fully operational throughout their expected lifetime. As such, this set of costs is expected to be obtained for both the infrastructure operators and transport operators.

iv) **Analyses:** a financial analysis, which focuses on the estimation of the net-benefits of each technology for the implementing entity (operator), and an economic analysis, which focuses on the estimation of the net-benefits of each technology for the whole of society, therefore including non-monetary costs and benefits.

The level of availability and quality of the data needed for the conduction of the CBAs, at the demonstration level, is a key determinant for the number of tests/ pilots for which CBA is carried out. This means that it is possible that some test results of the x-border pilots will not be reverted into the CBA, if sufficiently representative data for assessment on the level of end-user services is not available.

The Economic and Financial Analysis will follow the European Commission's methodologies for Cost-Benefit Analyses (CBA), particularly the guidelines found in the Commission's Guide to Cost-Benefit Analysis of Investment Projects[26] (2014).

Scenario building

In order to demonstrate the convenience for society of a particular project in relation to other alternatives, the scenario of the analysis (i.e. which project is being evaluated and what alternative it is being compared to) needs to be clearly defined as included in other project deliverables. The evaluation will calculate the impact of the new technologies relative to the actual situation. That is, there will be a comparison between two scenarios: the actual case (No 5G-MOBIX), and the (5G-MOBIX scenario) once the x-border pilots are implemented.

[26] https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

Time Horizon

Each technology's cash-flow forecasts should cover a reference period of 20 years (15 to 25 years is the standard benchmark applied to research and innovation projects, as recommended by the European Commission's Guide to Cost-Benefit Analysis of Investment Projects (2014)).

Financial Analysis

In general terms, the financial analysis is an integral part of any cost-benefit analysis (CBA). It aims at assessing the financial profitability of a project for the implementing entity by measuring the extent to which the project net revenues are able to repay the investment. It also outlines the cash-flows that underpin the calculation of the socio-economic costs and benefits. From the onset, each test is expected to be assessed individually and further for the x-border pilot.

Cash flow calculation

The financial analysis methodology used in this report is the Discounted Cash Flow method[26]. As such, a yearly cash flow resulting from the application of the technology during the 20-year period of analysis will be calculated.

Financial return indicators

The following financial indicators will be calculated:

- Financial Net Present Value (FNPV): the sum of the yearly financial cash flows, after these have been discounted at a rate that reflects the opportunity cost of capital – the financial discount rate (FDR);
- Financial Rate of Return (FRR): the financial discount rate that produces a zero FNPV;
- Financial Benefit to Cost Ratio (F B/C): the ratio between the discounted financial benefits (cost-savings and revenue gains) and costs (deployment and running costs);

Economic Analysis

The economic analysis aims at assessing the economic performance of a project, that is, its contribution to social welfare. It is therefore not focused on the project's implementing entity but rather on the whole of society. It does so by measuring the extent to which the socio-economic benefits outweigh the socio-economic costs of the project.

Price corrections and non-market impacts

It is an internationally accepted practice that the appraisal of a project's contribution to welfare should always take into consideration the social opportunity cost of goods and services, instead of prices observed in the market, which may be distorted. In order to achieve this, the standard approach recommended by the

European Commission's Guide to Cost-Benefit Analysis of Investment Projects (2014) is adopted. For the fiscal corrections, the prices used in the CBA are corrected for VAT, using the rates from the European commission.

Cash flow calculation

The economic analysis methodology to be adopted follows the Discounted Cash Flow method. As such, a yearly cash flow resulting from the application of the technology during the 20-year period of analysis will be calculated. The calculation of the yearly economic cash-flow will account for the same parameters used to compute the yearly financial cash flow, with the exception of the revenue gains, and only after both the fiscal corrections and the valuation of inputs and outputs at their shadow prices are made. Additionally, it will account for the non-market impacts and externalities generated by the technology in analysis.

Economic return indicators

The following economic indicators are to be calculated:

- Economic Net Present Value (ENPV): the sum of the yearly economic cash flows, after these have been discounted at a rate that reflects the social view on how future benefits and costs should be valued against present ones - the social discount rate (SDR);
- Economic Rate of Return (ERR): the social discount rate that produces a zero ENPV;
- Economic Benefit to Cost Ratio (E B/C): the ratio between the discounted economic benefits and costs.

Social discount rate

The social discount rate adopted to calculate the economic net present value of the future cash flows is 5%, as recommended by the European Commission's Guide to Cost Benefit Analysis (2014).

Deployment costs and running costs

The one-off, initial capital costs of the fixed and non-fixed assets needed to implement the technology, and the yearly costs necessary to keep the technology operational throughout its life time, are two of the most relevant figures for the financial and economic analyses.

The information on deployment and running costs is expected to be provided by the pilot cases in the form of fixed costs – costs needed for the deployment of the technologies, regardless of the number of vehicles served, and variable costs – thus costs per vehicle.

Cost-savings

In most cases, the technical evaluation's KPIs are not expressed in monetary terms, and instead take the form of other units of measurement (in 5G-MOBIX e.g. decrease in latency in ms and increase in data throughput in Mbps). In such cases, it is necessary to value and price the inputs being saved as accurately as possible. This means to translate in terms of time or cost the gains or the losses resulting from a decrease in latency (i.e. a decrease of *x* in latency, allows to reduce time to answer in *y* and with this under the same road section *z* more cars can travel and traffic flow is optimised - distance between vehicles is minimised)

The reference data for the benefits (Value of time, accidents, air pollution, climate change, noise, etc.), will be based on the most recent update of the European Handbook on the external costs of transport - version 2019[27].

Potential challenges related to CBA in 5G-MOBIX

The CBA methodologies are traditionally designed for the evaluation of heavy infrastructure investments (rail, roads, ports, metros, etc.). A key challenge under 5G-MOBIX is to adapt these methodologies to soft measures as it is the case for innovative technologies to be tested in some x-border pilots. This means that we will be able to get short-term deployment costs and direct results for some impact areas (as identified in D2.5) and compare those with the longer-term impacts they might generate.5G-MOBIX trials focusing on mobile network performance are not likely to provide measured evidence on impacts that could be directly extrapolated to quantitative metrics on time savings, improved safety or decreased emissions in traffic. The impacts need to be assessed mostly through data gathered in interviews and workshops as well as transport modelling. Assigning monetary values to (descriptive) results from expert assessments would require numerous assumptions and simplifications to be made. If numerical values will be provided, results can be easily interpreted as conclusive, even when limitations are explained. Moreover, a close articulation with the technological developers in the x-border pilots to clearly understand the data that will be collected and the formats in which this is turned available is needed.

The CBA could be complemented with a CEA (cost effectiveness analysis) whenever the data available do not allow for a proper monetisation of the benefits. Cost effectiveness analysis (CEA) is another economic tool that can help to ensure an efficient use of investment resources when benefits are difficult to value, in particular to value in monetary terms. The objective of a cost effectiveness analysis (CEA) is thus to evaluate the effectiveness of a project, that is its capacity to achieve desired objectives (i.e. the solution that for a given cost maximises the output level).

Metrics related to economic analysis (CBA)

The metrics that are relevant for conducting a CBA and initial plan for assessing the metrics are presented below.

Table 18: Impact Assessment: Cost and revenue related metrics

IA- M6.1 5G infrastructure building costs

[27] https://ec.europa.eu/transport/sites/transport/files/studies/internalisation-handbook-isbn-978-92-79-96917-1.pdf

Costs to network operators and government will be estimated, including investments in R&D and in implementation of 5G cross-border mobility systems. The mobile network operators' investments include improvements to radio interfaces and antennas to increase efficiency of new spectrum, radio access network (RAN) infrastructure, additional macro sites and small cells and core networks (virtualization, slicing).

Assessment method: Values will be collected by interviewing trial site experts and consortium operator partners, through surveys and literature.

IA- M6.2 Capital expenses

In addition to building 5G network, also other types of capital expenses, such as those for OEM and road operators, need to be assessed for a full economic analysis. Investments and purchases related to fixed assets of the organizations for developing and maintaining the technological solutions and services needed for deploying 5G enabled cross-border CCAM services will be estimated.

Assessment method: Other capital expense categories related to deployment of CCAM services than building 5G infrastructure will be outlined (e.g. for OEMs and road operators). Values will be collected from trial sites, through expert assessment and literature. Inputs from T6.2, e.g. related to financing schemes and procurement models, will also be used. T6.1 will provide important information about current options and challenges in 5G for CCAM deployment which may affect capital expenses.

IA- M6.3 Operating costs

The costs of different stakeholders for running the business operations related to 5G enabled cross-border CCAM services (e.g. maintenance, energy, service hosting, salaries).

Assessment method: Inputs from T6.2, expert assessments (interviews, focus groups) and data from trial sites and literature will be used for estimating operating costs for main stakeholders.

IA- M7.1 Revenue streams

Based on the identified customer needs and the defined value propositions (T6.2), revenue streams for main stakeholder will be estimated via interviews and questionnaires.

Assessment method: Inputs from T6.2, expert assessments (interviews, focus groups) and data from literature will be used for estimating revenue streams for main stakeholders. User studies in T5.4 may also provide inputs for assessing potential revenue streams from consumers. If positive impacts of the scenarios (and as a consequence, created value) cannot be quantified, estimation of revenue streams will not be feasible in monetary values but merely as categories of business opportunities.

4.4.3. Multi-Actor Multi-Criteria Analysis (MAMCA)

The Multi-Actor Multi-Criteria Analysis (MAMCA) has been developed at the MOBI Research Centre at the Vrije Universiteit Brussel (VUB) [35]. It is a scientifically sound approach to consult a broad stakeholder community representing the main societal actors in Europe on the identification, evaluation and prioritization of future user needs, new transport concepts, implications and potential societal resistance and adoption. The MAMCA methodology adds an extra layer to the Multi-Criteria Decision Analysis (MCDA) method, namely the actor layer [55]. Indeed, a Multi-Actor Multi-Criteria is built per stakeholder. All these models are aggregated to the final step.

A number of workshops with the stakeholders contributes to the MAMCA, providing direct input in a democratic way for the whole process, including the construction of the scenarios, validation of objectives, weighting of stakeholder criteria as well as the final consensus building and selection of the best-ranking scenario.

The methodology consists of seven steps (see Figure 19 below). The first step is the definition of the problem and the identification of the alternatives **(step 1)**. The various relevant stakeholders are then identified as well as their key objectives **(step 2)**. Second, these objectives are translated into criteria and then given a relative importance (weights) **(step 3)**. For each criterion, one or more indicators are constructed (e.g., direct quantitative indicators such as money spent, number of lives saved, reductions in CO2 emissions achieved, etc. or scores on an ordinal indicator such as high/medium/low for criteria with values that are difficult to express in quantitative terms, etc.) **(step 4)**. The measurement method for each indicator is also made explicit (e.g. willingness to pay, quantitative scores based on macroscopic computer simulation, etc.). This permits the measurement of each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. **Steps 1 to 4** can be considered as mainly analytical, and they precede the "overall analysis", which considers the objectives of all stakeholder groups simultaneously and is more "synthetic" in nature. Here, an evaluation matrix is constructed aggregating each alternative contribution to the objectives of all stakeholders **(step 5)**. In the next step, decision-makers are supported in the evaluation and ranking or selection of different alternatives using MCDA. This yields a ranking of the various alternatives and gives the strong and weak points of the proposed alternatives **(step 6)**. The stability of this ranking can be assessed through a sensitivity analysis. The last stage of the methodology **(step 7)** includes the actual implementation.

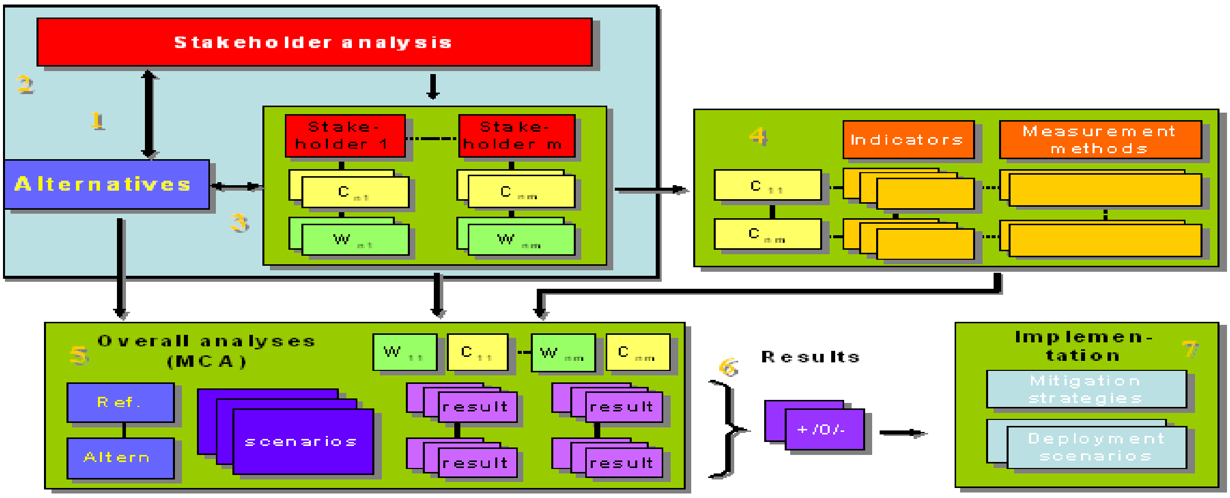

Figure 19: Multi-Actor Multi-Criteria analysis (MAMCA) [35]

- **Define alternatives:** The first stage of the methodology consists of identifying and classifying the possible alternatives submitted for evaluation. These alternatives can take different forms according to the problem situation. They can be different technological solutions, possible future scenarios together with a base scenario, different policy measures, long term strategic options, etc. There should be minimum two alternatives to be compared. If not, a social cost benefit analysis might prove to be a better method for the problem.
- **Stakeholder analysis:** In step 2 the stakeholders are identified. Stakeholders are people who have an interest, financial or otherwise, in the consequences of any decisions taken. An in depth understanding of each stakeholder group's objectives is critical in order to appropriately assess the different alternatives. Stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders to be consulted and whose views should be taken into account in the evaluation process. Once identified they might also give new ideas on the alternatives that have to be taken into account.
- **Define criteria and weights:** The choice and definition of evaluation criteria are based primarily on the identified stakeholder objectives and the purposes of the alternatives considered. A hierarchical decision tree can be set up. Several methods for determining the weights have been developed. The weights of each criterion represent the importance that the stakeholder allocates to the considered criterion. In practice, the pair-wise comparison procedure proves to be very interesting for this purpose. The relative priorities of each element in the hierarchy are determined by comparing all the elements of the lower level in pairs against the criteria with which a causal relationship exists. The applied multi actor multi criteria analysis method and software (see step 6) allow an interactive process with the stakeholders in order to perform sensitivity analysis.
- **Criteria, indicators and measurement methods:** In this stage, the previously identified stakeholder criteria are "operationalized" by constructing indicators (also called metrics or variables) that can be used to measure whether, or to what extent, an alternative contributes to each individual criterion. Indicators provide a "scale" against which a project's contribution to the criteria can be judged. Indicators are usually, but not always, quantitative in nature. More than one indicator may be required to measure a

project's contribution to a criterion and indicators themselves may measure contributions to multiple criteria.

- **Overall analysis and ranking:** The MCDA method used to assess the different strategic alternatives can be any MCDA-method. Most of the cases discussed below are analysed with the Analytical Hierarchical Process (AHP). This method, described by Saaty [44], allows to build a hierarchical tree and to work with pair wise comparisons. The consistency of the different pair wise comparisons as well as the overall consistency of the whole decision procedure can easily be tested in AHP that can handle both quantitative and qualitative data, the latter being very important for transport evaluations. Certain criteria in transport concern ecological impact or road safety issues. These criteria are difficult to quantify. Moreover, the method is relatively simple and transparent to decision makers and to the public. The method does not act like a black box since the decision makers and the stakeholders can easily trace the way in which a synthesis was achieved.
- **Results:** The multi criteria analysis developed in the previous step eventually leads to a classification of the proposed alternatives. A sensitivity analysis is in this stage performed in order to see if the result changes when the weights are changed. More important than the ranking, the multi criteria analysis allows to reveal the critical stakeholders and their criteria. The multi actor multi criteria analysis provides a comparison of different strategic alternatives and supports the decision maker in making his final decision by pointing out for each stakeholder which elements have a clearly positive or a clearly negative impact on the sustainability of the considered alternatives.
- **Implementation:** When the decision is taken, steps have to be taken to implement the chosen alternative by creating deployment schemes. This implementation process can be complemented by a cost benefit analysis for well-defined projects.

Challenges and limitations of MAMCA

MAMCA has been developed to facilitate the decision making process by the different stakeholders, by providing an overview of the advantages and disadvantages of the different options, or an overview of the impacts of the options for each of the stakeholders. The first step in the methodology is identification of alternatives. In 5G-MOBIX, it needs to be further clarified which are the options that will be considered in decision making processes related to the x-border sites. Alternatives based on high-level project objectives could be: 1) Current situation without CCAM services available, 2) CCAM services only in coverage of single operator and 3) CCAM services with full coverage, also across borders. However, this may lead to evaluating just general benefits of CCAM services. D6.1, presenting deployment options, will provide important input for clarifying the alternatives to be analysed in MAMCA.

In MAMCA, we should take care that in critical steps of the methodology, such as the choice of the stakeholders, the choice of the criteria or the choice of the weights of the stakeholders, bias is avoided. We will now take a look at these steps in more detail and indicate how bias could take place and be coped with.

The choice of the stakeholders and how to cluster them into groups is a delicate process. A stakeholder can be defined as an actor in the range of people who are likely to use a system or be influenced either directly or indirectly by its use. In other words, stakeholders are people who have an interest, financial or otherwise, in the consequences of any decisions taken. An in-depth understanding of each stakeholder group's objectives is critical in order to appropriately assess different choice alternatives. Stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders that need to be consulted and whose views should be taken into account in the evaluation process.

The choice of criteria: If stakeholders have only one or a few criteria, their point of view might be more extreme and again weigh more heavily in the final decision.

The choice of criteria weights by the actors: The choice of the weights of these criteria is mainly the same as the problem stated above. If all weights are given to a single criterion, this will lead to more extreme results. If the weights are evenly distributed, more moderated choices will be the result. So also here, the analyst can check the weights of the criteria, and see if these correspond to the real priorities of the stakeholders.

4.4.4. Approaches for assessing business impacts of an innovation ecosystem

Individual solutions to be developed in 5G-MOBIX probably need to be combined with other solutions (offered by other actors) in order to achieve the full benefits and business opportunities. Markendahl et al. [37] point out that this implies that the stakeholders need to understand the customer's entire needs and how different actors can cooperate. In such cases ecosystems, networks of actors (business networks) and how the actors interact need to be studied. The current business model thinking needs to be widened from a single company point of view to an ecosystem perspective [32]. Different types of ecosystems and their characteristics have been actively studied and discussed in research literature (e.g. [4]) for more than ten years, but examples of systematic approaches for evaluation of ecosystems and their business impacts are not easy to find.

National Growth Programme for the Transport Sector 2018-2022 by the Ministry of Economic Affairs and Employment in Finland [38] presents criteria for evaluating the ecosystem's business potential. The criteria focus on business impacts on national level. The main criteria suggested for evaluation are:

- Common vision and objectives
- Need for an ecosystem
- Advantage and competitiveness
- The skills needed for critical tasks
- Requirements for a key role
- Systemic barriers and structural bottlenecks
- The potential for growth and attracting foreign experts and companies.

Although the criteria and the related questions have been formulated for evaluation of a national ecosystem and its competitiveness, it includes elements of ecosystem evaluation that are relevant also for other types of ecosystems and can be adjusted for other purposes. There is not yet information, if the criteria have been applied in assessment of the Finnish transport ecosystem.

In the EU-funded project NordicWay2 an evaluation of C-ITS pilot ecosystems is currently being conducted [39]. The main focus in the evaluation is on analysing ecosystem actors´ perception on viability, feasibility, resiliency and profitability of providing C-ITS services as a group. Roles of actors and connections between them, in the form of data, service, goods or monetary flows, are described. The aim is to identify business potential, attractiveness of business case and potential challenges in the ecosystem and in implementing the service. Final results of that work are expected to be reported by the end of the year 2020.

In addition to assessing business impacts from perspectives of individual organizations, a couple of metrics are suggested for assessing business impacts from ecosystem point of view. These will provide understanding on how capabilities for commercial deployment of 5G-MOBIX enabled solutions and services evolve in the 5G-MOBIX ecosystem, and what is the role of the ecosystem in creating business opportunities and well-being in long-term. The MAMCA process will provide a starting point for the ecosystem analysis by mapping the stakeholders, their roles and priorities and the connections between the actors in the ecosystem. Ecosystem business impact assessment aims to identify opportunities and bottlenecks for deployment from the innovation ecosystem point of view, and to evaluate how 5G-MOBIX contributes to development of business ecosystems.

Shared understanding of the goals and a roadmap to reaching them has been identified as an essential factor for an ecosystem to reach concrete results [47]. 'Common vision and objectives' is also among the business impact evaluation criteria in National Growth Programme [38]. In addition to 5G-MOBIX objectives that the consortium has committed to, the work on business models and the metric IA-M5.1 Strategic fit of 5G-MOBIX solutions can be used for further refining common goals and how actors can cooperate to reach those.

Specific metrics that can be used in assessing business impacts of the ecosystem are presented below:

Table 19: Impact Assessment: Metrics on progress towards commercial deployment in the ecosystem

IA- M8.1 Number of mature solutions entering the market
Number of 5G-MOBIX solutions that are technologically mature and for which viable business model has been developed and that can be commercialized during or right after the project. This value stands for the exploitable results of the project, but also indicates that the ecosystem has succeeded in decreasing barriers to deployment.

Assessment method: Survey to trial sites and consortium partners (interviews); inputs from T7.3. Need to specify first, however, how maturity will be assessed and what will be the expected time-to-market that will be used in assessment.

IA- M8.2 Development of capabilities within the ecosystem
Capabilities needed for deployment can be developed in an ecosystem through sharing of knowledge, through partnerships and joint efforts for developing new solutions, services or business models or for tackling obstacles. A qualitative assessment will be made on identification of new business opportunities in the ecosystem (based on customer need), and how skills needed and the actors with key roles have been identified, and what kind of connections there are between the actors.

Assessment method: Surveys and workshops with the consortium members. Lessons learnt from the ongoing work on ecosystem impact assessment will be gathered and applicable methods and inputs will be used, MAMCA process and results on stakeholder mapping, their roles, connections and preferences will be an essential input for this metric.

IA- M8.3 Evolution of business models
There are still many open questions before the 5G-MOBIX solutions can enter market. The project focuses e.g. on technical validation, exploring financing schemes and regulatory aspects, and developing business models. All these inputs contribute that number of uncertainties and open questions in business models will decrease and thus they become more well-defined and mature, or new business model innovations may result.

Assessment method: Preliminary business models and final business models from T6.2 will be used as inputs. Tools such as Strategyzer's business model canvas, value proposition canvas and innovation readiness scorecard and Business readiness by KTH are acknowledged and applied if useful for 5G-MOBIX impact assessment. Qualitative assessment of improvements in specificity of the model and thoroughness of analysis of costs and benefits will be conducted. What are the next steps towards deployment, what kinds of resources are needed, and is there an actor that will lead the work after the project? Have business ecosystems started to emerge? Additionally, business model innovations will be surveyed.

5. USER ACCEPTANCE METHODOLOGY

This section describes the methodology that will be employed for assessing the user acceptance indicators associated with the CBC's user-stories. Focus on CBCs is explained by the central role they assume in the project and by the fact that their user-stories cover all the user-stories categories addressed by the project.

Assessment will be done through two main methods. The first is based on user data collection or empirical research mainly at the cross-border sites. This will provide insights on how actually experiencing the user-stories affects acceptance. The second will take advantage of inquiries that will be developed for each CBC user-story to be answered by the participants and create online versions that can be answered by populations of interest throughout Europe. It must be noted, that this effort will also target the 5GCroCo and 5G-CARMEN, counterpart projects. While responses will lack the "real-feel" that the trial participants will experience (i.e., indicating *acceptance*), they can provide a broader picture of what to expect in terms of general *acceptability*.

Assessment at the CBCs will take into consideration observed and measured events and seek to derive knowledge from test experience. Usually, the empirical research approach is concerned with testing the theoretical concepts and relationships to verify how well they exhibit our observations of reality [9]. Data collection of this research could be obtained through several techniques such as questionnaires, surveys or observation.

A key purpose of empirical research is to test hypotheses deduced from research questions. As was mentioned before, D2.5 (Initial evaluation KPIs and metrics) specifies a set of User Acceptance metrics to obtain answers to the research questions proposed for the 5G-MOBIX project (see Table 20). General Technology Acceptability metrics and measures of trust and perceived safety will be obtained using psychometric scales contained in the inquiries mentioned above. Objective system usability will be measured by observation of the interaction between driver and autonomous car.

Table 20: List of user acceptance metrics (see D2.5 for more details)

Class	ID	Description
General Technology Acceptability metrics	UA-M1.1	Acceptance Intention (statement of interest)
	UA-M1.2	Perceived Technology Usefulness
	UA-M1.3	Perceived Technology Ease-of-use
	UA-M1.4	Affinity for Technology Interaction
	UA-M 1.5	Acceptability difference between prior and post-contact with technology

Trust on the System metrics	UA-M2.1	Perceived Safety
	UA-M2.2	Perceived Trust
	UA-M2.3	Perceived Reliability
Systems Usability metrics	UA-M3.1	General usability metric
	UA-M3.2	Effectiveness
	UA-M3.3	Efficiency
	UA-M3.4	Satisfaction
Error tolerance metrics	UA-M4.1	Error dealing effectiveness
	UA-M4.2	Error dealing efficiency
	UA-M4.3	Error dealing satisfaction

According to the FESTA handbook [19] after the formulation of the hypothesis and definition of metrics, it will be necessary to define how to test the hypotheses. With this aim one must first define the experimental design that will be performed in each trial site, mainly in the cross borders (ES-PT & GR-TR) and having in mind the different user stories and their scenarios. As the tests of this project will be carried out with autonomous cars, these will be conducted mostly by professional or authorized drivers. If allowed, potential users can be selected to go as co-drivers and experience how the vehicle works in different situations. In such case, demographic issues and driving profile are variables that should be considered. For each controlled test, the experimental environment must be described with the aim to determine the global situation of testing. Moreover, the geographical location of the test is an important variable having in consideration that some of the trials take place in cross borders locations. In these studies, traffic conditions and interactions with other road users will be controlled variables. In the course of the trials, human factors experts should be responsible of the usability evaluation, providing the same instructions to the participants and registering all the information for a posterior analysis. A pilot study should be performed before carrying out the studies with participants in order to be sure that all the issues are considered, and all the information and instructions are well understood.

The next section (5.1) introduces the concept of User Acceptance modelling and describes the general model that will be used in the project. Section 5.2 describes the evaluation methodology to be applied.

5.1. User Acceptance modelling

Over the last few years several models have been proposed to explain human behaviour and the acceptance of new technologies. These models are based on the theoretical principle that the person's belief and perception about a technology can shape acceptance, with the behavioural intention (BI) of using a technology and actual use as measures of acceptance [56]. One of most popular models, the Technology Acceptance Model (TAM) (Figure 20) was introduced by Fred Davis in 1989 [20]. It is a well-validated cross-domain framework specifically developed to model user acceptance of systems or information technologies. The basic TAM model included and tested two specific user's opinions on technology: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) [31]. PU is the degree to which the potential user believes that the technology will enhance his/her performance on a given task, and Perceived Ease of Use refers to the degree to which the potential user expects the target system to be easy to use [13]. A person's conviction about a system can be influenced by other factors referred to as external variables.

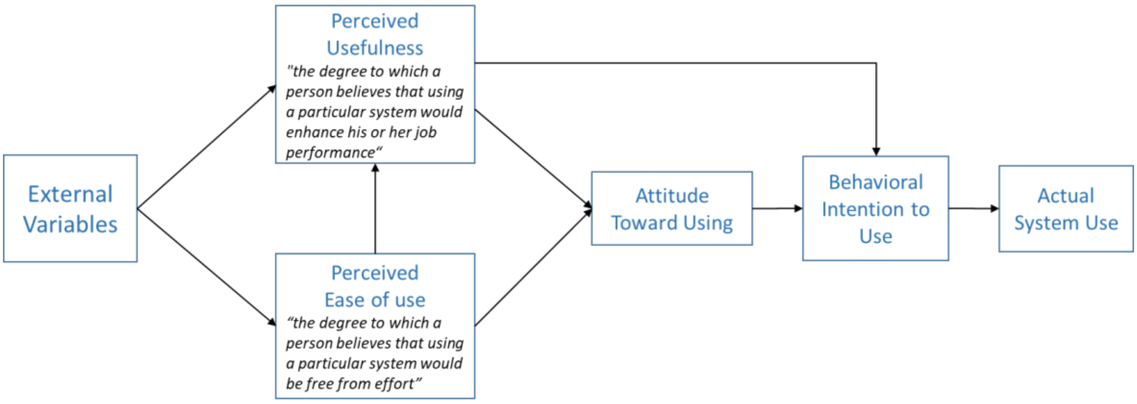

Figure 20:Technology Acceptance Model (TAM) adapted from Davis (1989)

The evolution of technologies and the more frequent presence of intelligent autonomous systems led Ghazizadeh et al. [22] to propose the Automation Acceptance Model (AAM) based on the perspectives of information system and cognitive engineering considering the dynamic and multilevel nature of the use of automation systems. At AAM, TAM's original relationships remain unchanged, while *trust* and *compatibility* impact attitude and BI through PEOU and PU. While AAM takes the first step in providing a theoretical framework for the acceptance of automation systems and proposes trust as an important determinant, the validity of this model has never been verified.

5.1.1. Acceptance in transport systems

Vlassenroot et al. [53] presented a different approach in a study on acceptability of Intelligent Transport Systems (ITS), in this case Intelligent Speed Adaptation (ISA). Based on different socio-psychological theories and methods, 14 relevant indicators were defined and divided into general indicators (related to people's psyche, values and social norms) and device specific indications (factors directly related to the device itself). Figure 21 shows the two dimensions defined by the authors and their respective indicators, which are very similar to the factors determined in TAM.

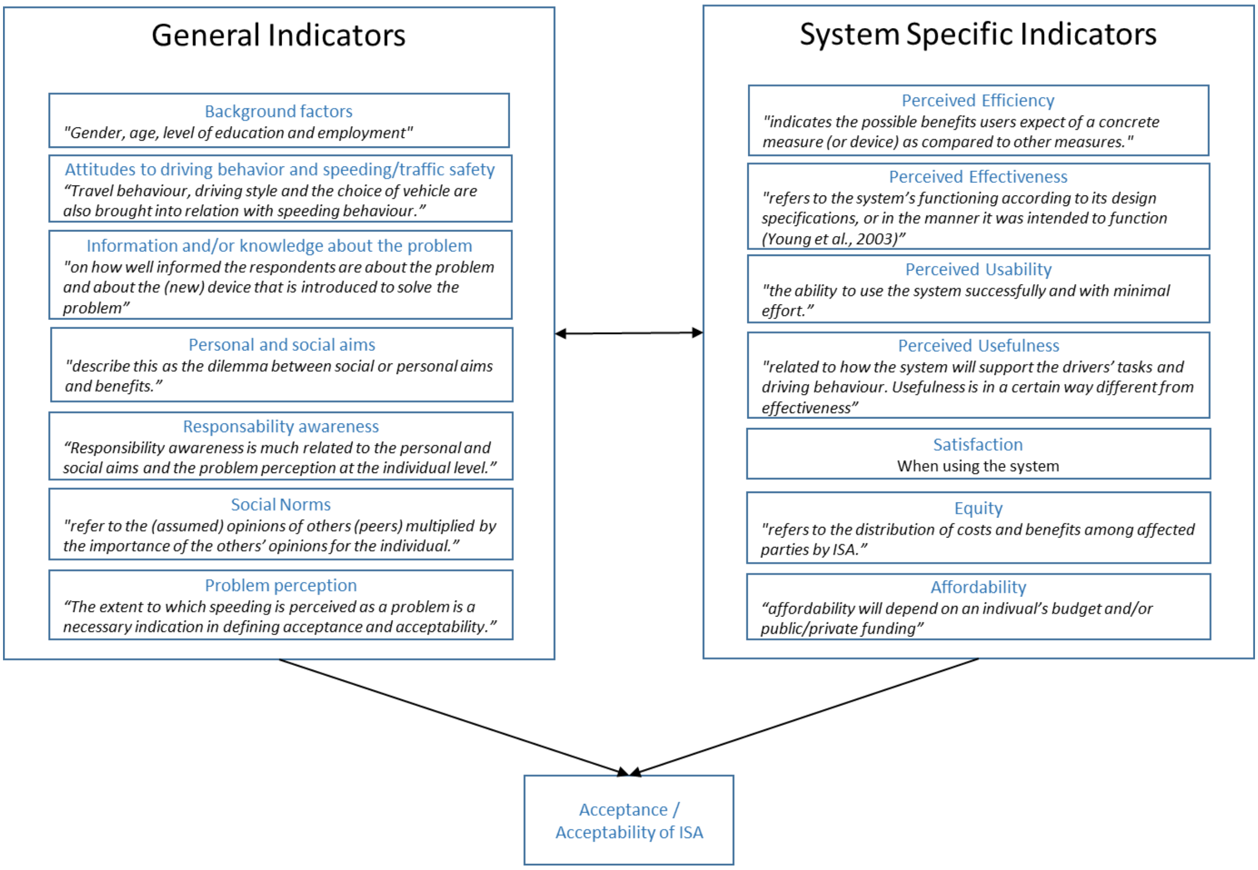

Figure 21: Model proposed by Vlassenroot et al. (2008)

Based on Vlassenroot and colleagues model and other models derived from TAM, Osswald et al. [41] proposed a technology acceptance model for cars, the Car Technology Acceptance Research Model (CTAM). The CTAM evaluation items were written focusing on conventional in-vehicle technology. Thus, they are not directly applicable to self-driving vehicles. Nevertheless, the CTAM is one of the first user acceptance models to include a perceived safety-related factor. A more recent proposal by Zhang et al. [56](2019), also has the TAM as a base structure but incorporates the construct of *initial trust* (assessed before the use of the system), the *perceived safety risk* and the *perceived privacy risk* as new factors. Trust, is defined as the belief that a system will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability. The construct is identified as the most critical factor in promoting a positive attitude towards autonomous vehicles.

5.1.2. 5G-MOBIX proposed model

For the purpose of evaluating acceptability in the 5G-MOBIX project, TAM will be chosen as the basic theoretical framework, due to its parsimony and effectiveness in explaining the technological acceptance of various information systems [36], as well as its adaptability to the context of autonomous vehicles. The proposed model (see Figure 22) will incorporate the constructs of *perceived safety* and *perceived trust* in the TAM framework to try to understand how they influence other constructs within the model. Additionally, empirical elements will also be incorporated, such as *output quality* (quality of system performance), in order to validate the theoretical data, especially in the PEOU dimension.

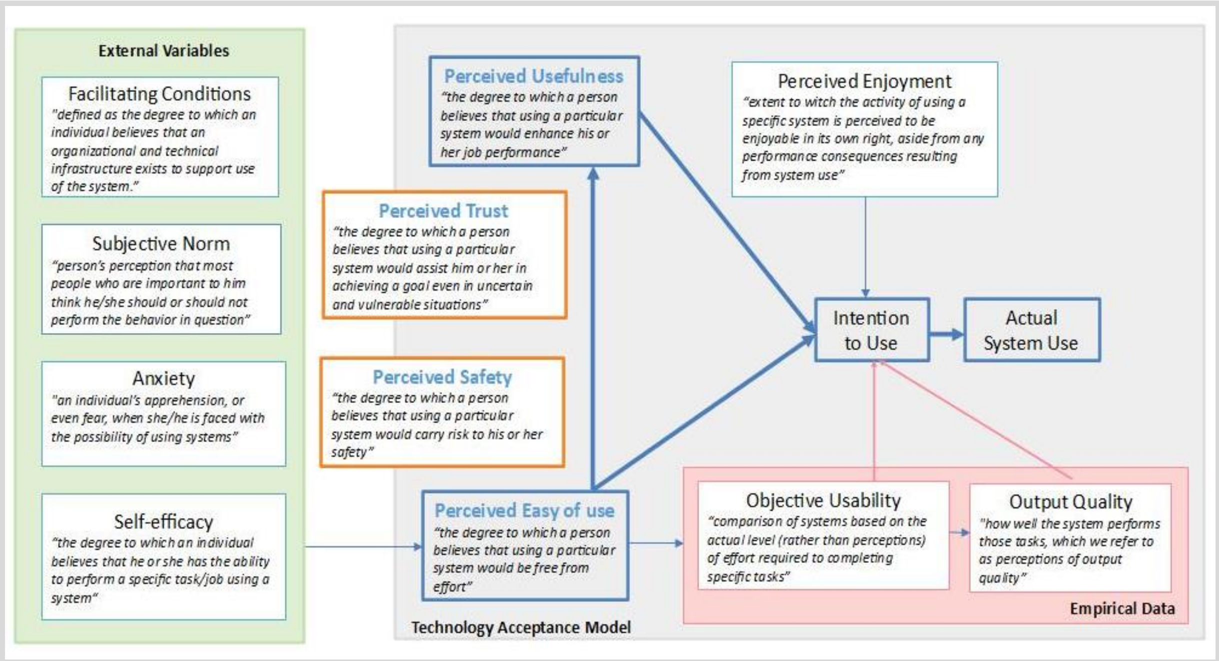

Figure 22: 5G-MOBIX proposed User Acceptance Model

Overall, the model described above will be translated into an acceptability survey in which the different constructs will be evaluated by separate scales translated into groups of questions. Normally, acceptability surveys should be filled by participants before they experience the technology (evaluating acceptability) and after they experience it, since the variations in the scales after use may hint to the actual level of acceptance. However, the particular scope of the 5G-MOBIX project implies a different approach.

Zhang et al. [56] (2019) suggest that, in order to promote public acceptance of autonomous vehicles, related organizations should aim at improving the reliability of autonomous vehicles. 5G-MOBIX aims to do that by testing and proposing solutions, based on an important enabling technology (5G connectivity), at particular challenging environment: the border between countries. It may be considered that, in the overall, its end-goal is to enable and improve the user-experience of CCAM end-users. It thus becomes imperative to understand how the connectivity and handover challenges posed by the border may affect their general perception of each of the proposed user-stories.

In that regard, 5G-MOBIX evaluation methodology should, whenever possible, test the acceptability of the user-stories by confronting data from local trials (in which cross-border issues are not at stake) with data obtained in cross-border trials. It should also collect additional information that allow understanding the intricacies of the different factors affecting acceptability. If baseline user trials cannot be conducted due to technical or logistic limitations, information must come solely from the main trials. In this case, interviews and individual user enquiries should help to clarify what were the main factors affecting the acceptability KPIs and if they were consequence of the connectivity issues.

5.2. User data Collection methodology

The evaluation procedure should begin before the trials, with participants filling the acceptability questionnaire and through other complementary qualitative methods (such as focus groups and interviews). In a second phase, the test subjects should take part on the local trials after which they provide information regarding their evaluation of the technology with a post-test acceptability questionnaire and interview. In the third phase, the same test subjects should participate in the CBC trials followed by a second post-test acceptability questionnaire and interview. In cases in which the test subjects are not allowed to drive the car, authorized drivers will also provide information about their evaluation of the technology, from the stand-view of a professional drivers. Figure 23 exemplifies this approach for the ES-PT corridor, where participants will experience the user-stories locally first, in Spain and Portugal, and then later in the border between the two countries.

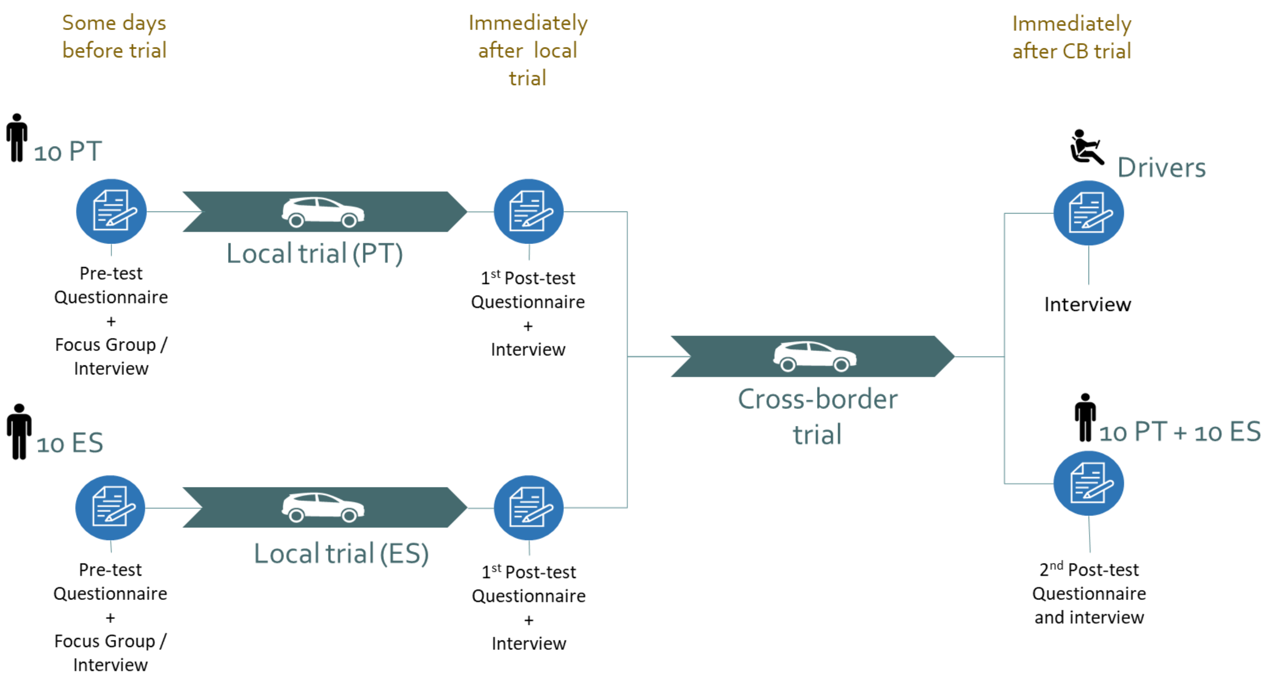

Figure 23: Overview of Last Mile Automated Shuttle user acceptance evaluation procedure for ES-PT

Information collected from the questionnaires will be confronted with empirical data extracted from real-use situations on the trial sites. The purpose of this approach is to validate the self-assessed data collected to identify factors that may interfere with trust and PEOU. Both *User Inquiring* and *User Testing* techniques are described and detailed in the following sections.

5.2.1. User inquiring

The use of psychometric scales has generalized in social and human sciences partly because they are easy and simple to apply, and they assume the subject is capable of some sort of objectivity in a self-assessment situation. In psychology, an evaluation scale refers to an instrument made of several items, embracing one or several dimensions, organized in a scalar fashion, in which the participant's answer can be translated according to several degrees of intensity [18]. These scales should aim at three characteristics: a) they should have additivity, i.e., we should be able to add the answer the participants give to the several items that constitute the scale, and obtain a total measure of the construct under evaluation (total or in each subscale); they should have interval measures, allowing the graduation of the answer to one item in regular intervals; and they should discriminate participants exposed to the construct under evaluation.The process of creating a scale follows three main stages: 1) theoretical procedures; 2) empirical procedures and 3) analytical procedures. They will be detailed in the following sections.

1) Information about which construct to evaluate

The main objective of this stage is to understand the theoretical framework of the construct and collect data regarding its operationalization in behavioural dimensions which will be represented in the scale through a to-be-defined number of items. It is assumed we know exactly what we want to measure or evaluate, if it is uni- or multi-dimensional, and how the construct expresses itself in the behaviour of the individuals. As an outcome of this initial work, an exhaustive list of items to be submitted to the appreciation and evaluation of experts in the area should be produced. The decision of how many items we want to include in the final version of the instrument is important, because on this preliminary stage, the number of items should at least double the number of desired items. Loewenthal [33] suggests a number of items between 6-15 per dimension in the final version of the instrument.

In the case of 5G-MOBIX, the scale's main purpose is to evaluate the acceptability of a large number of 5G-related technologies. The project has 18 User Stories divided into 5 Use Cases Categories. It is our intention to create a different evaluation scale for each category. These categories are:

- Advanced Driving
- Vehicles Platooning
- Extended Sensors
- Remote Driving
- Vehicle Quality of Service Support

This decision is based on the fact that the user-stories are too diverse to have one single scale accommodating all situations without it being excessively long. The use case categories gather all use-cases concerning similar technologies or situations, a fact that justifies the creation of five smaller scales specifically addressing the use case categories.

The theoretical framework behind the concept of acceptability was already described, along the description of the Technology Acceptance Model (TAM) which serves as groundwork for our scales. Previous work was made to fully understand the dimensions that might affect the acceptability of a technology. A vast number of variations of the TAM exist, and we have performed an effort to select the most adequate dimensions and items for our scales. Out of this work, we have selected dimensions and items from the following TAM models or derivatives: UTAUT [48], TAM 3 [6], UTAUT 2 [51], CTAM [41], and AV adopting [11] (Figure 23). They are the following:

- Perceived ease of use (PEOU) (UA-M1.3)
- Perceived usefulness (PU) (UA-M1.2)
- Subjective Norm (UA-M1.1)
- Perceived enjoyment (UA-M1.4, user-testing methods)
- Intention to Use (UA-M1.1)
- Perceived Trust (UA-M2.2)
- Self-efficacy (user-testing methods)
- Anxiety (UA-M1.4)
- Perceived safety (UA-M1.4)
- Perceived risk (UA-M2.3)

	T	M	R	UTAUT *Venkatesh et al (2003)*	*TAM 3* *Venkatesh et al (2008)*	UTAUT 2 *Venkatesh et al (2012)*	CTAM *Osswald et al. (2012)*	AV adopting *Choi and Ji (2015)*
Perceived usability / Perceived easy of use (PEOU) / Effort Expectancy								
I will find the system easy to use.	**9**	4	5	✓	✓	✓	✓	
My interaction with the system would be clear and understandable.	**9**	4	5	✓	✓	✓	✓	
Learning to use the system will be easy for me.	**8**	4	4	✓		✓	✓	✓
I will find it easy to get the system to do what I want it to do.	**4**	2	2		✓			✓
It will be easy for me to become skillful at using the system.	**4**	3	1	✓		✓	✓	
Interacting with the system would not require a lot of my mental (or physical) effort	**3**	2	1		✓			✓
Perceived usefulness (PU) / Performance Expectancy								
I would find the system useful in my job.	**7**	3	4	✓	✓		✓	
I find the system useful in my daily life.	**1**	1	0			✓		
Using the system in my job **would increase** my productivity.	**6**	4	2	✓	✓	✓		✓
Using the system in my job **would enable** me to accomplish tasks more quickly.	**5**	3	2	✓		✓	✓	
Using the system **would improve** my job performance.	**5**	3	2		✓		✓	✓
Using the system **would enhance** my effectiveness on the job.	**3**	2	1		✓			✓
Using the vehicle **would enable** me to reach my destination safely.	**1**	1	0				✓	
If I use the system, **I will increase** my chances of getting a raise.	**2**	1	1	✓				
Using the system **increases** my chances of achieving things that are important to me	**2**	1	1			✓		
Social Norm / Social Influence / Subjective Norm								
People who influence my behavior think that I **should use** the system.	**5**	3	2	✓	✓	✓		
People who are important to me think that I **should use** the system.	**5**	3	2	✓	✓	✓		
People whose opinions that I value **prefer that I use** the system	**1**	1	0			✓		
People who I like would **encourage me to use** the system	**1**	1	0				✓	
People whose opinions are important to me would like the system too	**1**	1	0				✓	
The organization has **supported the use** of the system.	**4**	2	2	✓	✓			
The senior management of this business **has been helpful in the use** of the system.	**3**	2	1	✓	✓			

Figure 24: Table crossing dimensions, items and technology acceptance models

The steps on this first stage about construct definition consist in defining the domain to evaluate by understanding the properties of the attribute, confront theoretical positions and present a first sample of items. After the items are defined, the next step is to present the items to a small group of people matching the target sample of the instrument. Usually the used method is the spoken reflection, where respondents individually answer the items out loud and make comments about the items and instructions' comprehensibility, and the interpretation of some terms and expressions. This method allows to trace ambiguity in the content, poorly constructed items, their difficulty, stereotypical answers, central tendency answers, and, in general, the time it takes to answer to the full questionnaire.

With this information, we can make the proposed changes and create the preliminary version of the scale which will be tested with a different sample of participants. This version will already include the instructions, demographic data and the final decision regarding the scale format.

In summary, the qualitative analysis of the first sample of items should include expert consultation (for the first selection of items), spoken reflection with groups of recipients, analysis of the instructions, the relevance and representativity of the items and finally, the definition of the first version of the instrument

2) Administration of the scale and psychometric study

At this stage, it is critical to clearly know our target population. The sample for this stage should be 10 times the number of items under analysis or, at least 250 respondents [34][54]. In 5G-MOBIX's case, we should aim for a European population, gender and age balanced. Depending on the use-case categories (for instance, vehicle platooning), this balance might be harder to achieve.

When all the answers are gathered, the statistical analysis ensues. On a first stage, this analysis refers to the items in isolation and on a second stage the analysis refers to the results on the dimensions under evaluation. For the items in isolation we want to understand: a) the dispersion or variability of the answers and b) the twofold coherence of this dispersion: regarding the connection of this item to the other items in a given dimension (internal validity), and regarding its association with behaviours external to the scale but equally associated with the dimensions under evaluation (external validity).

The values of fidelity should be given special attention. The fidelity of the scale refers to the proportion of the variance which can be attributed to the real result of the variable. The most common measure is Cronbach's Alpha, and there are several recommendations as to its value (from a minimum of .80 to a minimum of .60 depending on the number of items). DeVellis [15] proposes intervals such as: under .60 is unacceptable, between .60 and .65 is undesirable, between .65 and .70 is mildly acceptable, between .70 and .80 is respectable, between .80 and .90 is very good, and above 0.90 a reduction on the size of the scale should be considered.

Another important aspect concerns the *unidimensionality* of the scale. One can affirm unidimensionality when all items belong to one and only scale, and the construct is evaluated with the sum of the items, or when one scale is formed by several autonomous subscales. The study of the unidimensionality is achieved through factorial analysis.

In summary, the statistical analysis of the first version items should study of the results' dispersion on the items, make a study of the index of discrimination of the items, study of the internal validity of the items, calculate the coefficient of internal consistency, study the external validity of the items and, finally, define the final version of the instrument

3) Item selection and construction of the final version

Once we have a final proposal, and whether we have a uni- or multidimensional scale, all items should be randomly distributed. Reading the items should not make the respondent think about underlying groups or dimensions.

Also on the final version we should consider the positive or negative formulation of the items. It is necessary that for the same construct/dimension the participant has the opportunity to answer in a positive and in a negative way, so it is important that part of the items are inverted in order to avoid a specific and stereotypical pattern of answers by the respondents.

The instructions are also an important part of the scale, and they should make the respondent at ease to avoid any social desirability answers. The most used type of scale is the agree/disagree scale, but other scales may make more sense depending on the population, for instance, very different from me/just like me.

The analysis of the final version's results should include study of the sensibility, study of the fidelity (stability and consistency), study of the validity (content, criteria and construct), parameters for the interpretation of the results, differential studies and capacity of differential evaluation (subgroups of subjects or situations).

5G-MOBIX's studies of acceptability will include the construction of five psychometric scales adapted to each one of the five use cases categories. The following studies will include crossing the use-cases of each category with the user-acceptance KPI's and define which TAM dimensions are adequate for each scale. As suggested, we will have at least 6 items for each dimension and intend to have psychometric scale between 20 and 30 items long.

5.2.2. User Testing

Other metrics, related with usability and error tolerance (UA-M3.1, UA-M3.2, UA-M3.3, UA-M3.4, UA-M4.1, UA-M4.2, UA-M4.3), will be obtained using user testing techniques, like observation.

For the different tests performed, real time observation data should be collected by a researcher with the help of video recording. This real-time data will provide more information, for example, about error tolerance metrics. An observer can use a custom-made app to register some of the metrics having in mind that the analysis of video is a time-consuming task. This structured observation needs the formulation of rules for registering the behaviour of the driver [10] (Bryan, 2012). The cameras installed in the car should register the driver interaction with the HMI, mainly with reference to the metrics "number of user errors" or the "inappropriate use of automated driving functions".

Other important source to obtain information about subjective data is audio recording. From it, it should be possible to register verbal manifestations with the aim of enriching the subjective information collected (thoughts, feelings while driving...). For the registration of the video, it should be necessary to have in mind data backup and informed consent for registering driver behaviour. Moreover, sometimes it will be necessary to define a process of linking the events with the driver behaviour (e.g. if drivers must recover the control after a signal).

After evaluating the data quality of all the measures registered it will be necessary to obtain the different metrics to accept or reject the hypotheses proposed in the project. If comparisons between different situations are necessary, inferential statistic techniques will be performed, in this case, it is possible to make predictions. If not, an exploratory analysis will be run. Descriptive analysis display or summarize data in a meaningful way. These statistics report how many observations were recorded and how often each score or category of observations occurred in the data[43]. Descriptive statistics include measures of central tendency (e.g. mode, median or mean) or measures of dispersion (e.g. range, variance and standard deviation).

6. CONCLUSIONS

This document (D5.1) sets the ground for the 5G-MOGIX evaluation activities, by defining the corresponding methodologies involved in all considered evaluation fronts, namely, the Technical Evaluation, Impact Assessment and User acceptance. In doing so, the deliverable specifies the evaluation objectives, and the corresponding technical means to achieve them. This includes, the identification of the required evaluation data and the related methodologies for their collection and further processing. The document comprises a continuation of D2.5, where the initial set of KPIs and metrics were identified; as such, and in view of the selected and described methodologies, the deliverable refines the selected KPIs and metrics, setting the framework for the evaluation process in 5G-MOBIX. On the technical evaluation front, this constitutes the necessary input both for the further development of the data collection tools and the following processing of the collected measurement data towards the evaluation of the selected KPIs. At the same time, the deliverable paves the way for the project activities on the Impact Assessment and User Acceptance fronts, elaborating on the specific methodological tools to be employed, identifying their scope and applicability in the context of 5G-MOBIX.

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APPENDIX A: USE CASE CATEGORIES / USER SCENARIOS OVERVIEWS

The following table summarizes all UCCs and USs considered across the trial sites in 5G-MOBIX.

Table 21: 5G-MOBIX Use Case Categories and User Stories

Trial site	Advanced Driving	Vehicles Platooning	Extended Sensors	Remote Driving	Vehicle QoS Support
ES-PT	Complex manoeuvres in cross-border settings *Scenario 1: Lane merge for automated vehicles* *Scenario2: Automated Overtaking*		Complex manoeuvres in cross-border settings *Scenario3: HD maps*	Automated shuttle remote driving across borders *Scenario 2: Remote Control*	Public transport with HD media services and video surveillance
	Automated shuttle remote driving across borders *Scenario 1: Cooperative automated operation*		Public transport with HD media services and video surveillance		
GR-TR		Platooning with "see what I see" functionality in cross-border settings	Extended sensors for assisted border-crossing		
			Platooning with "see what I see" functionality in cross-border settings		
DE		eRSU-assisted platooning	EDM-enabled extended sensors with surround view generation		
FI			Extended sensors with redundant Edge processing	Remote driving in a redundant network environment	
FR[28]	Infrastructure-assisted advanced driving				

[28] Based on received feedback during the second technical review of 5G-MOBIX, VEDECOM has decided to only keep the infrastructure-assisted advanced driving use and withdraw the use case of remote driving. This decision came after the PO and reviewer's recommendation to concentrate efforts on 5G contributions and also to remove the police and security features since it's out of the scope of the project and their feedbacks on satellite communications. In this new specification of the user story, we will test two different approaches on how the infrastructure can assist advanced manoeuvres: the first phase will allow to carry out a MEC assisted lane change manoeuvre, while the second step will test a far-MEC approach (cloud-assisted) where the V2X application server will assist the lane change operation..This

NL	Cooperative Collision Avoidance		Extended sensors with CPM messages	Remote driving using 5G positioning	
CN	Cloud-assisted advanced driving	Cloud-assisted platooning		Remote driving with data ownership focus	
KR				Remote driving using mmWave communication	Tethering via Vehicle using mmWave communication

new design of the user story is different compared to what was already specified in previous deliverables (D2.1-D2.4) and is considered as un update of the FR site user stories. In addition, these changes will be reflected in the upcoming deliverables.

APPENDIX B: LIST OF TECHNICAL EVALUATION KPIS

Table 22: Summary of processing methods for KPIs calculation

KPI	Description
TE – KPI 1.1 **User experienced data rate**	Data rate as perceived at the application layer. It corresponds to the amount of application data (bits) correctly received within a certain time window (also known as *goodput*).
TE – KPI 1.2 **Throughput**	The instantaneous data rate / throughput as perceived at the network layer between two selected end-points. The end points may belong to any segment of the overall network topology, as discussed in Section 0. It corresponds to the amount of data (bits) received per time unit.
TE – KPI 1.3 **End to End Latency**	Elapsed time from the moment a data packet is transmitted by the source application to the moment it is received by the destination application instance(s).
TE – KPI 1.4 **Control plane Latency**	Control plane latency refers to the time to move from a battery efficient state (e.g., IDLE) to start of continuous data transfer (e.g., ACTIVE). This is a KPI aimed to shed further light on the end-to-end latency components i.e., identify the contribution of control plane processes to the overall perceived latency.
TE – KPI 1.5 **User plane Latency**	Contribution of the radio network to the time from when the source sends a packet to when the destination receives it. It is defined as the one-way time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface in either uplink (UL) or downlink (DL) in the network, assuming the mobile station is in the active state.
TE – KPI 1.6 **Reliability**	Amount of application layer packets successfully delivered to a given system node within the time constraint required by the targeted service, divided by the total number of sent network layer packets.
TE – KPI 1.7 **Position accuracy**	Deviation between RTK-GPS location information and the measured position of a UE via 5G positioning services. Applies only to the NL trial site.
TE – KPI 1.8 **Network Capacity**	Maximum data volume transferred (downlink and/or uplink) per time interval over a dedicated area.
TE – KPI 1.9	Statistic mean downtime before the system/component is in operations again. The MTTR here refers to failing software components e.g., a virtual network function (VNF).

Mean Time to Repair (MTTR)	
TE – KPI 2.1 **NG-RAN Handover Success Rate**	Ratio of successfully completed handover events within the NR-RAN regardless if the handover was made due to bad coverage or any other reason.
TE-KPI2.2-Application Level Handover Success Rate	Applies to scenarios where an active application level session (e.g., communication between application client at UE/OBU and the Application Server) needs to be transferred from a source to a destination application instance (e.g., located at MEC hosts at the source and destination networks respectively) as a result of a cross-border mobility event. The KPI describes the ratio of successfully completed application level handovers i.e., where service provisioning is correctly resumed/ continued past the network level handover, from the new application instance.
TE-KPI2.3-Mobility interruption time	The time duration during which a user terminal cannot exchange user plane packets with any base station (or other user terminal) during transitions. The mobility interruption time includes the time required to execute any radio access network procedure, radio resource control signalling protocol, or other message exchanges between the mobile station and the radio access network.
TE-KPI2.4-International Roaming Latency	Applies to scenarios of cross-border mobility, where mobile UEs cross the physical borders between the involved countries, eventually triggering a roaming event. The KPI describes the duration of the roaming procedure, from initiation till completion and eventual continuation of communication sessions.
TE-KPI2.5-National Roaming Latency	Applies to inter-PLMN handover scenarios, where the involved networks operate within the national boarders i.e., alternative operators. This KPI applies to the case of the NL trial site, where such a trial setup will be available. On a technical front, this KPI is equivalent to TE-KPI2.3.

APPENDIX C: MEASUREMENT DATA COLLECTION PER UCC/US

C.1 UCC-1: Advanced Driving

C.1.1 Complex manoeuvres in cross-border settings (ES-PT)

Table 23: *Complex manoeuvres in cross-border settings* UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT1.1.1-CAM	CAM messages between connected vehicles and MEC	UL, DL
TFT1.1.2-DENM_UL	DENM messages from radar to MEC (only for SC1, lane merge for automated vehicles)	UL
TFT1.1.3-DENM_DL	DENM messages from MEC to host vehicle (only for SC1, lane merge for automated vehicles)	DL

Table 24: *Complex manoeuvres in cross-border settings* UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 -User experienced data rate	TFT1.1.1 TFT1.1.2 TFT1.1.3	TC1 AI1	UE (vehicles) RSU (radar) MEC	L2	MQTT	10Hz	Message, payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.2 – Throughput	TFT1.1.1 TFT1.1.2 TFT1.1.3	TC1 AI1	UE (vehicles) RSU (radar) MEC	L1	TCP	10Hz	Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.3 - End to End latency	TFT1.1.1 TFT1.1.2 TFT1.1.3	TR1 TC1 AC1 AI1	UE (vehicles), RSU (radar) MEC	L2	MQTT	10Hz	Message, timestamp, station ID	200 ms
TE-KPI1.6 - Reliability	TFT1.1.1 TFT1.1.2 TFT1.1.3	TC1 AI1	UE (vehicles), RSU (radar) MEC	L2	MQTT	10Hz	Message, timestamp, station ID	99,9%
TE-KPI1.8 – Network Capacity	TFT1.1.1 TFT1.1.2	TC1 AI1	UE (vehicles), RSU (radar)	L1	TCP	10Hz	Payload, timestamp, station ID, GPS location	1Gbps

	TFT1.1.3		MEC					
TE-KPI2.1-NG-RAN Handover Success Rate	TFT1.1.1 TFT1.1.2 TFT1.1.3	TR1 TC1 AC1 AI1	UE (vehicles), RSU (radar) MEC	L0	IP	10Hz	Message, timestamp, station ID	99-100%
TE-KPI2.2- Application Level Handover Success Rate	TFT1.1.1 TFT1.1.2 TFT1.1.3	TR1 TC1 AC1 AI1	UE (vehicles), RSU (radar) MEC	L1, L2	TCP/MQTT	10Hz	Message, timestamp, station ID	99-100%
TE-KPI2.3-Mobility interruption time	TFT1.1.1 TFT1.1.2 TFT1.1.3	TR1 TC1 AC1 AI1	UE (vehicles), RSU (radar) MEC	L0	IP	10Hz	Message, timestamp, station ID	< 10 s

C.1.2 Infrastructure-assisted advanced driving (FR)

Table 25: Infrastructure-assisted advanced driving traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT1.2.1-CAM	CAM messages	UL, sidelink
TFT1.2.2 CPM	CPM messages	DL
TFT1.2.3-MCM	MCM messages	DL, sidelink
TFT1.2.4-Sensor	Roadside Video streaming, Lidar raw data	UL

Table 26: Infrastructure-assisted advanced driving KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*

TE-KPI1.3 E2E Latency	TFT1.2.2 TFT1.2.3	TN1,TN3, AP1, AC1	OBU, RSU, MEC V2X application server	L2	CPS, MCS, IVI service	1 / message	GenerationDeltaTime[29], Timestamp, Station ID , PCO ID	5-20 ms
TE-KPI1.6 Reliability	TFT1.2.1 TFT1.2.2 TFT1.2.3	TN2,TH2, AC1, TN1	OBU RSU MEC V2X application server	L2	CAS, CPS, MCS, IVI service	1 / message	GenerationDeltaTime,Timestamp, Station ID, PCO ID	>97 %
TE-KPI1.7 Position Accuracy	TFT1.2.1 TFT1.2.2	TN1	OBU, MEC	L2	CAS, CPS	**OBU:** 1 per GNSS record (GPS RTK and normal GNSS). **MEC:** 1 per received / transmitted message	**OBU:** Timestamp, position obtained from GNSS and GPS-RTK, PCO ID **MEC:** Received messages: GenerationDeltaTime, Timestamp, ReferencePosition **Transmitted CPM**: GenerationDeltaTime, objectId, timeOfMeasurement, ObjectClass, PCO.	< 1m

C.1.3 Cooperative collision avoidance (NL)

Table 27: *Cooperative Collision Avoidance* UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT1.3.1-C-ITS	C-ITS Messaging	UL & DL

[29] Time corresponding to the time of the reference position in the CPM/MCM, considered as time of the CPM/MCM generation.

Table 28: *Cooperative Collision Avoidance* UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT1.3.1	TC2	OBU, gNB, MEC	L2	UDP / TCP	1 / message	Timestamp	> 1/1 Mbps
TE-KPI1.3 E2E latency	TFT1.3.1	TR2	OBU, gNB, MEC	L2	UDP / TCP	10 Hz	Timestamp	< 10 ms
TE-KPI1.6 Reliability	TFT1.3.1	TC2	gNB, MEC	L2	UDP / TCP	1 / message	Number of successful messages	> 90 %
TE-KPI2.2 Application-level handover success rate	TFT1.3.1	TC2	OBU, MEC	L2	UDP / TCP	1 / message	Timestamp	> 99 %
TE-KPI2.3 Mobility interruption time	TFT1.3.1	TC2	OBU, gNB	L1	IPv4/IPv6	10 Hz	Timestamp	< 15 ms

C.1.4 Cloud-assisted advanced driving (CN)

Table 29: Cloud-assisted advanced driving flow types (following China standard: T/CSAE 53-2017 and JT/T 1078-2016)

Title	*Description*	*UL/DL/Sidelink*
TFT1.4.1-BSM	Basic Safety Message for the vehicle's state and its sensing information. The message body includes the identification information, location and moving information, inside state information, and some extension information. BSM is used for exchanging traffic safety messages between vehicles and it supports series of the applications for traffic safety. It is usually broadcasted 10Hz periodically.	UL, DL
TFT1.4.2-MAP	MAP is broadcasted by the RSUs. Passing the local map information to the nearby vehicles, MAP includes the intersection information, road information, lane information, the traffic sign information, and the connection information between	UL, DL

	roads. The MAP data structure is designed as "node - road connection - lane", while in addition there are some special features like steering information for supplementary.	
TFT1.4.3-RSI	RoadSide Information, which is broadcasted to the nearby vehicles by RSUs. It contains traffic sign information and traffic incident messages. Traffic sign information is a notification or warning written on the roadside sign. Traffic incident messages can be announced in text, and it focuses on the dynamic and temporary traffic incidents like "Accident Ahead Warning" or "Ice Ahead Warning". When an OBU receives a RSI, it will judge if it is in its effective zone according to its own location and driving direction.	DL
TFT1.4.4-RSM	RoadSide Message, which is gathered by RSUs. After detecting the real time traffic participants' condition nearby, RSUs pack up the information into RSMs, then usually broadcast 1Hz periodically to the vehicles in neighbour.	UL
TFT1.4.5-SPAT	Signal Phases And Time, which contains the traffic signals in one or more intersections. The SPAT data structure is designed as "traffic light - phase - color" to describe the moment's traffic light information. Coordinated with MAP, the real time and phase of the frontage traffic light can be sent to the vehicles.	DL
TFT1.4.6-VIDEO	Video streaming among vehicle-mounted video terminals (OBUs) and video cloud platform (ITS-Center)	UL,DL

Table 30: Cloud-assisted advanced driving KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT1.4.1 TFT1.4.2 TFT1.4.3 TFT1.4.4 TFT1.4.5 TFT1.4.6	SO1	OBU, gNB, RSU, MEC, Cloud	L2	MQTT, WebRTC	1 / message	Timestamp	> 100/100 Mbds

TE-KPI1.3 E2E latency	TFT1.4.2 TFT1.4.3 TFT1.4.4 TFT1.4.5	SO1	OBU, RSU, gNB, MEC	L2	MQTT	10 Hz	Timestamp	< 20 ms
TE-KPI1.6 Reliability	TFT1.4.1	SO1	gNB, MEC, Cloud	L2	MQTT	1 / message	Number of successful messages	> 95 %
TE-KPI2.2 Application-level handover success rate	TFT1.4.1	SO1	OBU, MEC, Cloud	L2	MQTT	1 / message	Timestamp	> 95 %

C.1.5 Automated shuttle driving across borders (ES-PT)

Table 31: Automated shuttle driving across borders flow types

Title	*Description*	*UL/DL/Sidelink*
TFT1.3.1-CAM	CAM messages between shuttle and MEC	UL, DL
TFT1.3.2-DENM	CAM messages from VRU to MEC	UL
TFT1.3.3-DENM	DENM messages from camera to MEC	UL
TFT1.3.4-DENM	DENM messages from MEC to shuttle	DL

Table 32: Automated shuttle driving across borders KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 -User experienced data rate	TFT1.3.1 TFT1.3.2 TFT1.3.3	TC1 AI1	Shuttle (OBU), Smartphone (VRU), RSU (camera), MEC	L2	MQTT	10Hz	Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.2 – Throughput	TFT1.3.1 TFT1.3.2 TFT1.3.3	TC1 AI1	Shuttle(OBU), Smartphone (VRU), RSU (camera), MEC	L1	TCP	10Hz	Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.3 - End to End latency	TFT1.3.1 TFT1.3.2 TFT1.3.3	TR1 TC1 AC1 AI1	Shuttle(OBU), Smartphone (VRU), RSU (camera), MEC	L2	MQTT	10Hz	Message, timestamp, station ID	200 ms

TE-KPI1.6 - Reliability	TFT1.3.1 TFT1.3.2 TFT1.3.3	TC1 AI1	Shuttle(OBU), Smartphone (VRU), RSU (camera), MEC	L2	MQTT	10Hz	Message, timestamp, station ID	99,9%
TE-KPI1.8 – Network Capacity	TFT1.3.1 TFT1.3.2 TFT1.3.3	TC1 AI1	Shuttle(OBU), Smartphone (VRU), RSU (camera), MEC	L1	TCP	10Hz	Payload, timestamp, station ID, GPS location	1 Gbps
TE-KPI2.1-NG-RAN Handover Success Rate	TFT1.3.1 TFT1.3.2 TFT1.3.3	TR1 TC1 AC1 AI1	Shuttle(OBU), Smartphone (VRU), RSU (camera), MEC	L0	IP	10Hz	Message, timestamp, station ID	99-100%
TE-KPI2.2- Application Level Handover Success Rate	TFT1.3.1 TFT1.3.2 TFT1.3.3	TR1 TC1 AC1 AI1	Shuttle(OBU), Smartphone (VRU), RSU (camera), MEC	L1, L2	MQTT/IP	10Hz	Message, timestamp, station ID	99-100%
TE-KPI2.3-Mobility interruption time	TFT1.3.1 TFT1.3.2 TFT1.3.3	TR1 TC1 AC1 AI1	Shuttle(OBU), Smartphone (VRU), RSU (camera), MEC	L0	IP	10Hz	Message, timestamp, station ID	< 10 s

C.2 UCC-2: Vehicles platooning

C.2.1 Platooning with "see what I see" functionality in cross-border settings (GR-TR)

Table 33: Platooning with "see what I see" functionality in cross-border settings traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT2.1.1-Platoon	C-V2X based platooning coordination messages such as dissolve, merge, split, maintain platoon etc. Platoon leader <--> gNB <--> Cloud <--> gNB <-->Platoon follower	UL / DL
TFT2.1.2-SWISA	Video streaming messages transmitting from leader vehicle to follower vehicle Platoon leader <--> gNB <--> Cloud <--> gNB <--> Platoon follower	UL / DL
TFT2.1.3-Truck Routing	Raw lidar data transfer from RSU to cloud, vehicular state information transfer from vehicle to cloud and safe waypoint transfer from cloud to vehicle. Vehicle → gNB → Cloud (UL) RSU → gNB → Cloud (UL)	UL / DL

	Cloud → gNB → Vehicle (DL)	

Table 34:Platooning with "see what I see" functionality in cross-border settings KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT2.1.1	AC1	Vehicle Controller Unit / OBU	L1/L2	TCP/UDP	1/message	Incoming bits per unit of time at OBU and at VCU.	0.05 Mbps
TE-KPI1.3 E2E Latency	TFT2.1.1	AC1	Vehicle Controller Unit / OBU	L1/L2	TCP/UDP	10Hz	Timestamps of incoming and outgoing data packets	100ms
TE-KPI1.6-Reliability	TFT2.1.1	AC1	Vehicle Controller Unit / OBU	L1/L2	TCP/UDP	1 / message	Ratio of received packets over transmitted packets	90%
TE-KPI1.1 User experienced data rate	TFT2.1.2	AC1	HMI / OBU	L1/L2	TCP/UDP	1 / message	Incoming bits per unit of time.	100 Mbps
TE-KPI1.2 Throughput	TFT2.1.2	AC1	LEVIS client / Cloud	L1/L2	TCP/UDP	1 / video frame	Transmitted and received video frames	150 Mbps
TE-KPI1.3 E2E Latency	TFT2.1.2	AC1	HMI / OBU	L1/L2	TCP/UDP	1 / video frame	Timestamps of video frames	20ms
TE-KPI2.2-Application Level Handover Success Rate	TFT2.1.2	AC1	HMI / OBU	L1/L2	TCP/UDP	1 / video frame	Timestamps of video frames	90%

TE-KPI1.1 User experienced data rate	TFT2.1.3	AC1	Vehicle Controller Unit / OBU / RSU	L1/L2	TCP/UDP	1 / message	Incoming bits per unit of time at OBU and at VCU.	0.05 Mbps
TE-KPI1.3 E2E Latency	TFT2.1.3	AC1	OBU/RSU	L1/L2	TCP/UDP	1Hz	Timestamps	100ms
TE-KPI1.6-Reliability	TFT2.1.3	AC1	OBU / RSU	L1/L2	TCP/UDP	1 / message	Ratio of received packets over transmitted packets	90%

C.2.2 eRSU-assisted platooning (DE)

Table 35: eRSU-assisted platooning traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT2.2.1-eRSU-UP	Edge Dynamic Map (EDM) protocol message (3D map fragment exchange JSON-based message) (eRSU ⟵ ⟶ platooning leader, see: UCC description) – User Plane	UL / DL
TFT2.2.2-eRSU-UP	EDM with HD video sensor flow (eRSU ⟶ platooning leader) – User Plane	DL
TFT2.2.3-eRSU-CP	Platooning Service Area handover message (Core Domain 1 ⟶ Core Domain 2) – Control Plane	Core to Core
TFT2.2.4-eRSU-UP	Platooning Service Area handover message - RSU1 ⟶ RSU2 – User Plane	Cloud to Cloud
TFT2.2.5-eRSU-UP	C-V2X-based platooning coordination message – User Plane	Sidelink

Table 36: eRSU-assisted platooning KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.3 E2E Latency	TFT2.2.1	TR1, TN2, AC1, AC2	RSU / OBU	Edge Cloud Application L1&L2	TCP/UDP	1 / message	Timestamps of incoming and outgoing data packets	40ms

TE-KPI1.6-Reliability	TFT2.2.1	TN2, AC1, AC2	OBU / RSU	Edge Cloud Application L1&L2	TCP/UDP	1 per lost / successful message	Transmitted packets over received packets	100%
TE-KPI1.1 User experienced data rate (DL)	TFT2.2.2	AC1, AC2	OBU	L2	IPv4/ RTP/ RTCP	Lost video frames are logged, consecutive lost frames are aggregated in a single log entry	Received data rate	200 / 100 Mbps
TE – KPI 1.11 **End to End Jitter**	TFT2.2.2	AC1, AC2	OBU	L2	IPv4/ RTP/ RTCP	Unsteady latency producing high jitter can produce bottlenecks and dropped frame from computer vision-based driving functions	Received jitter	40ms
TE-KPI2.2-NG-RAN Handover Success Rate	TFT.2.2.3	TN2, AC1, AC2	RSU1, RSU2, Core1, Core2	5G Edge & Core L1	TCP/UDP	1 per received handover control message	Timed out / failed handover requests	100%
TE-KPI2.2-Application Level Handover Success Rate	TFT2.2.4	TN2, AC1, AC2	RSU1, RSU2, Core1, Core2	RSU L1	TCP/UDP	1 per received handover control message	Timed out / failed handover requests	100%
TE-KPI1.3 E2E Latency	TFT2.2.4	TR1, TN2, AC1, AC2	RSU1, RSU2, Core1, Core2	RSU L1	TCP/UDP	1 per beginning of Platooning Area handover procedure and 1 after completion	Application layer latency of platooning control handover	40ms

C.2.3 Cloud assisted platooning (CN)

Table 37: Cloud assisted platooning traffic flow types (following China standard: T/CSAE 53-2017 and JT/T 1078-2016)

Title	*Description*	*UL/DL/Sidelink*
TFT2.3.1-MAP	MAP is broadcasted by the RSUs. Passing the local map information to the nearby vehicles, MAP includes the intersection information, road information, lane information, the traffic sign information, and the connection information between roads.	UL, DL

TFT2.3.2-VIDEO	HD Video streaming among OBUs (platooning leader and follower), RSUs and video cloud platform (ITS-Center)	DL
TFT2.3.3-BSM	Vehicles' information for V2V and V2I platooning	UL, DL
TFT2.3.4-CAPM	Cloud assisted Platooning Message for Platooning MEC and Cloud servers	UL, DL

Table 38: Cloud assisted platooning KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate (DL)	TFT2.3.2	SO1	OBU	L2	WebRTC	1 / message	Timestamp	> 100/100 Mbps
TE-KPI1.3 E2E Latency	TFT2.3.1 TFT2.3.2	SO1	RSU, OBU	L2	MQTT, WebRTC	10 Hz	Timestamp	< 20 ms
TE-KPI1.6- Reliability	TFT2.3.1 TFT2.3.3	SO1	OBU, RSU	L2	MQTT	1 / message	Number of successful messages	> 95 %
TE-KPI2.2-Application Level Handover Success Rate	TFT2.3.4	SO1	RSU, MEC, Cloud	L2	MQTT	1 / message	Timestamp	>95%

C.3 UCC-3: Extended sensors

C.3.1 Complex manoeuvres in cross-border settings: HD maps and Public transport with HD media services and video surveillance (ES-PT)

Table 39: Complex manoeuvres in cross-border settings and Public transport with HD media services and video surveillance flow types

Title	*Description*	*UL/DL/Sidelink*
TFT3.1.1-CAM	CAM messages between connected vehicles and ITS Center	UL, DL
TFT3.1.2-Sensor data	Raw data from in-vehicle sensors to ITS Center	UL
TFT3.1.3-Updated HDMaps	Updated HDMaps from ITS Center to host vehicle	DL

Table 40: Complex manoeuvres in cross-border settings and Public transport with HD media services and video surveillance KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 -User experienced data rate	TFT3.1.1	TC1 AI1	UE (vehicles) ITS Center	L2	MQTT	10Hz	Message, Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.1 -User experienced data rate	TFT3.1.2 TFT3.1.3	TC1 AI1 AP2	UE (vehicles) ITS Center	L2	sFTP	NA	Message, Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.2 – Throughput	TFT3.1.1	TC1 AI1	UE (vehicles) ITS Center	L1	TCP	10Hz	Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.2 – Throughput	TFT3.1.2 TFT3.1.3	TC1 AI1	UE (vehicles) ITS Center	L1	TCP	NA	Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.3 - End to End latency	TFT3.1.1	TR1 TC1 AC1 AI1	UE (vehicles) ITS Center	L2	MQTT	10Hz	Message, timestamp, station ID	200 ms

TE-KPI1.3 - End to End latency	TFT3.1.2 TFT3.1.3	TR1 TC1 AC1 AI1 AP2	UE (vehicles) ITS Center	L2	sFTP	NA	Message, timestamp, station ID	1000 ms
TE-KPI1.6 - Reliability	TFT3.1.1	TC1 AI1	UE (vehicles) ITS Center	L2	MQTT	10Hz	Message, timestamp, station ID	99,9%
TE-KPI1.6 - Reliability	TFT3.1.2 TFT3.1.3	TC1 AI1 AP2	UE (vehicles) ITS Center	L2	sFTP	NA	Message, timestamp, station ID	99.9%
TE-KPI1.8 – Network Capacity	TFT3.1.1	TC1 AI1	UE (vehicles) ITS Center	L1	TCP	10Hz	Payload, timestamp, station ID, GPS location	Up to 1 Gbps
TE-KPI1.8 – Network Capacity	TFT3.1.2 TFT3.1.3	TC1 AI1 AP2	UE (vehicles) ITS Center	L1	TCP	NA	Payload, timestamp, station ID, GPS location	Up to 1 Gbps
TE-KPI2.1-NG-RAN Handover Success Rate	TFT3.1.1	TR1 TC1 AC1 AI1	UE (vehicles) ITS Center	L0	IP	10Hz	Message, timestamp, station ID	99-100%
TE-KPI2.1-NG-RAN Handover Success Rate	TFT3.1.2 TFT3.1.3	TR1 TC1	UE (vehicles)	L0	IP	NA	Message, timestamp, station ID	99-100%

		AC1 AI1 AP2	ITS Center					
TE-KPI2.2- Application Level Handover Success Rate	TFT3.1.1	TR1 TC1 AC1 AI1	UE (vehicles) ITS Center	L1, L2	TCP/MQTT	10Hz	Message, timestamp, station ID	99-100%
TE-KPI2.2- Application Level Handover Success Rate	TFT3.1.2 TFT3.1.3	TR1 TC1 AC1 AI1 AP2	UE (vehicles) ITS Center	L2	TCP/sFTP	NA	Message, timestamp, station ID	99-100%
TE-KPI2.3-Mobility interruption time	TFT3.1.1	TR1 TC1 AC1 AI1	UE (vehicles) ITS Center	L1	IP	10Hz	Message, timestamp, station ID	<10s
TE-KPI2.3-Mobility interruption time	TFT3.1.2 TFT3.1.3	TR1 TC1 AC1 AI1 AP2	UE (vehicles) ITS Center	L1	IP	NA	Message, timestamp, station ID	< 500 s

C.3.2 Extended sensors for assisted border crossing (GR-TR)

Table 41: *Extended sensors for assisted border crossing* UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT3.1.1-ECU	Measurements received from the vehicles ECU (speed, revs, etc.), transmitted with a frequency of 2Hz (every 0.5 sec).	UL
TFT3.1.2-OBU	Measurements from the vehicle sensors attached to the OBU (CO_2 readings, GPS coordinates, NFC IDs of cargo, acceleration), transmitted with a frequency of 1Hz.	UL
TFT3.1.3-OBUd	Measurements from the LIDAR sensor attached to the OBU, transmitted with a frequency of 100 Hz (every 10 msec).	UL
TFT3.1.4-RSI	Still-frame camera (RSI) - Pictures taken by a HD camera used to identify the license plate of the incoming vehicles.	UL
TFT3.1.5-UE	UE / wearable GPS coordinates (RSI) - GPS coordinates measured either by a UE or a wearable of the customs agent, transmitted with a frequency of 1Hz	UL
TFT3.1.6-Vehicle	Vehicle registered info - Vehicle documentation and / or manifest transmitted from a server / database to the WINGS application	UL
TFT3.1.7-OBU-GUI	CCAM instructions to OBU / GUI - Instructions & warnings (string) towards the OBU and/or driver GUI to instruct the vehicle to stop or change course. Ad-hoc transmission.	DL
TFT3.1.8-DriverGUI	Multiple strings of information including readings of the ECU and other sensors, figures (maps) and live messages, transmitted with a frequency of 1Hz	DL
TFT3.1.9-CustomsGUI	Multiple strings of information including readings of the ECU and other sensors, figures (maps & license plate pictures) and live messages, transmitted with a frequency of 1Hz (multiple GUIs on both PLMNs may be supported)	DL
TFT3.1.10-RSI	Instructions transmitted towards the smart traffic light and the smart border-bar. Ad-hoc transmission.	DL
TFT3.1.11-*LicensePlate*	Transmission of license plate picture to an external SW (UL) for text recognition & reception of response (DL) (string). Ad-hoc transmission.	DL/UL

Table 42: *Extended sensors for assisted border crossing* UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1-User experienced data rate	TFT3.1.1, TFT3.1.2, TFT3.1.4, TFT3.1.8, TFT3.1.9[30]	TC2, AC2	OBU, App server	L2	UDP/TCP	1 sec	Incoming bits per unit of time at the OBU (DL) and at the App (UL)	100 Mbps (UL) / 200 Mbps (DL)
TE-KPI1.2Throughput	{TFT3.1.1, TFT3.1.2}, TFT3.1.4, TFT3.1.8, TFT3.1.9	TC2, AC2	Packet Gateway, gNB	L1, L2	IP,UDP/TCP	15 min (possible to define)	Ericsson Logs – XML format	100 Mbps (UL) / 200 Mbps (DL)
TE-KPI 1.3-End to End Latency	All flows	TR1, TN4, AI3	OBU, App server	L2	UDP/TCP	Ad-hoc (logging on packet arrival)	Timestamps of Incoming and outgoing data packets	50 ms
TE-KPI1.5-User plane Latency	All flows	TR1, TN4, AI3	OBU, App server	L1, L2	UDP/TCP	Ad-hoc (logging on packet arrival)	Timestamps of Incoming and outgoing data packets	< 40 ms
TE-KPI1.6- Reliability	All flows	TH2, TH3, TC1, AI3, AP1, SP2, SO1	OBU, App server	L2	UDP/TCP	Ad-hoc (logging on packet arrival)	Transmitted packets over received packets	99.999%
TE-KPI2.1-NG-RAN Handover Success Rate	TFT3.1.1, TFT3.1.2,	TH2, TH3, TC1	gNB	L1	UDP/TCP	15 min (possible to define)	Ericsson Logs – XML format	99%

[30] Other flows transmit negligible size data, hence data rate is not a valid metric.

	TFT3.1.7, TFT3.1.8[31]							
TE-KPI2.3-Mobility interruption time	TFT3.1.1, TFT3.1.2, TFT3.1.7, TFT3.1.8[32]	TH2, TH3, TC1	OBU, App server	L1, L2	UDP/TCP	Ad-hoc (logging on packet arrival)	Last & First received data packet timestamp	5 s

C.3.3 EDM-enabled extended sensors with surround view generation (DE)

Table 43: *EDM-enabled extended sensors with surround view generation* UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT3.3.3-Video	Vehicle Video Streaming	DL
TFT3.3.1-EDM-UP	Local Dynamic Map (LDM) protocol message (3D map fragment exchange JSON-based message) (Vehicle OBU → MEC, see: UCC description) – User Plane	UL
TFT3.3.2-EDM-UP	Edge Dynamic Map (EDM) protocol message (3D map fragment exchange JSON-based message) (MEC → Vehicle OBU, see: UCC description) – User Plane	DL
TFT3.3.3-EDM-UP	HD video sensor flow (Vehicle OBU ← → MEC) – User Plane	UL/DL
TFT3.3.4-EDM-UP	Discovery and Extended sensors Service Area handover message (MEC1 → MEC2) – User Plane	Edge to Edge
TFT3.3.5-EDM-UP	C-V2X-based HD video sensor flow – User Plane	Sidelink

[31] The rest of the flows originate from static equipment (No HO).
[32] Rest of the flows are static.

Table 44: *EDM-enabled extended sensors with surround view generation* UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	*TFT3.3.1, TFT3.3.3, TFT3.3.5*	*TS1* *AI1*	*OBU*	*L2*	*TCP/UDP*	*1/second*	*Timestamp*	*200 / 100 Mbps*
TE-KPI1.3 E2E latency	*TFT3.3.3, TFT3.3.5*	*TS1* *AI1*	*OBU*	*L2*	*TCP/UDP*	*1/video frame*	*Timestamp*	*40 ms*
TE – KPI 1.11 End to End Jitter	*TFT3.3.3, TFT3.3.5*	*AC1, AC2*	OBU	*L2*	*IPv4/ RTP/ RTCP*	*Unsteady latency producing high jitter can produce bottlenecks and dropped frame from computer vision-based driving functions*	Received jitter	*40ms*
TE-KPI1.6 Reliability	*TFT3.3.2*	*TS1* *AI1*	*OBU*	*L2*	*MQTT/TCP/UDP*	*10 per second*	*Timestamp*	*100%*
TE-KPI2.2 Application-level handover success rate	*TFT3.3.4*	*TS1* *AI1*	*OBU*	*L2*	*TCP/UDP*	*1/video frame*	*Timestamp*	*99-100%*
TE-KPI2.3 Mobility interruption time	*TFT3.3.3, TFT3.3.5*	*TS1* *AI1*	*OBU*	*L2*	*TCP/UDP*	*1/video frame*	*Timestamp*	*40 ms*

C.3.4 Extended sensors with redundant edge processing (FI)

Table 45: *Extended sensors with redundant Edge processing* UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT3.4.1- Video	HD video from vehicle (or roadside sensor) with 1080p resolution and 30 frames per second (FPS)	UL

TFT3.4.2-Context	Context information - Data structure including at least identity of the vehicle, pose (longitude, latitude, and orientation), moving speed, and profiles of processing tasks (latency constraints, computing/communication workload description) in case of computation offloading.	UL
TFT3.4.3-Obj	Description of detected objects (e.g. object type, location, moving speed, size) and the confidence. b. Safety related alerts if applicable	DL
TFT3.4.4-Edge	Status of edge node (e.g. available computing capacity, coverage, provided service list)	DL

Table 46: ***Extended sensors with redundant Edge processing*** UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT3.4.1	SP2, AI2, ST2	OBU MEC	L2	WebRTC	1 / video frame	The sending time and receiving time of each frame	>15 Mbps
TE-KPI1.1 User experienced data rate	TFT3.4.3	SP2, AI2	OBU MEC	L2	HTTP + JSON	1 / video frame	timestamp and information on the detected objects	>15 Mbps
TE-KPI2.2 Application Level Handover Success Rate	TFT3.4.4	TC2, TS2, AP1	MEC MEC	L2	HTTP + JSON	every handover	The handover issuer and receiver	>99%
TE-KPI2.3 Mobility Interruption Time	TFT3.4.1	TC2	OBU gNB	L2	WebRTC	every handover	Timestamp	<80 ms
TE-KPI1.3 E2E Latency	TFT3.4.1	TC2	OBU MEC	L2	WebRTC	1 / video frame	Timestamp	<100 ms
TE-KPI1.6 Reliability	TFT3.4.4	TC2, AP1	OBU MEC	L2	HTTP+JSON	1Hz	Server reachability and server load, including RAM usage, CPU usage, network usage, disk usage, etc.	>99.99%

TE-KPI	Traffic Flow	CB Issues	PCO	PCO Level	Protocol	Logging Frequency	Logging Information	Target Value
TE-KPI1.7 Position Accuracy	Estimated coordination	RC2, RC3	OBU MEC	L2	HTTP+JSON	1Hz	timestamp, estimate location (via vision-based techniques), and real location (GPS)	<0.5m

C.3.5 Extended sensors with CPM messages (NL)

Table 47:Extended sensors with CPM messages UCC/US traffic flow types

Title	Description	UL/DL/Sidelink
TFT3.5.1-CPM	CPM messages	DL

Table 48: Extended sensors with CPM messages UCC/USs KPIs

TE-KPI	Traffic Flow	CB Issues	PCO	PCO Level	Protocol	Logging Frequency	Logging Information	Target Value
TE-KPI1.1 User experienced data rate	TFT3.5.1-CPM	TR2, TC2, AC1	UE, Edge	L2	MQTT	1 / message	Timestamp	10 Mbps
TE-KPI1.2Throughput	TFT3.5.1-CPM	TC2	UE, Edge	L1	TCP	1 / message	Transmitted/Received messages	NA
TE-KPI1.3 E2E Latency	TFT3.5.1-CPM	TR2	UE, Edge	L2	MQTT	1 / message	Timestamp	< 20 ms
TE-KPI1.6 Reliability	TFT3.5.1-CPM	TR2	UE, Edge	L1,L2	MQTT /TCP	1 / message	Transmitted/Received messages	> 90%
TE-KPI2.1-NG-RAN Handover Success Rate	TFT3.5.1-CPM	TR2, TC2	UE, Edge	L1		1 / message	Transmitted/Received messages	> 99%

C.4 UCC-4: Remote Driving

C.4.1 Automated shuttle remote driving across borders (ES-PT)

Table 49: *Automated shuttle remote driving across borders* UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT4.3.1-4k streaming	4k streaming from the camera	UL, DL
TFT4.3.2-Cockpit control	Proprietary messages between cockpit and MEC	UL, DL
TFT4.3.3-Shuttle driving	Proprietary messages between MEC and shuttle	UL, DL

Table 50: *Automated shuttle remote driving across borders* UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 -User experienced data rate	TFT4.3.2 TFT4.3.3	TC1 AI1	Cockpit, UE (shuttle), MEC	L2	HTTP	10Hz	Payload, timestamp, station ID	10 , 1 Mbps
TE-KPI1.2 – Throughput	TFT4.3.1	TC1 AI1	Camera	L1	UDP	TBD	TBD	0.2 , 8 Mbps
TE-KPI1.2 – Throughput	TFT4.3.2 TFT4.3.3	TC1 AI1	Cockpit, UE (shuttle), MEC	L1	UDP	10 Hz	Payload, timestamp, station ID	10 , 1 Mbps
TE-KPI1.3 - End to End latency	TFT4.3.2 TFT4.3.3	TC1 AI1	Cockpit, UE (shuttle), MEC	L2	HTTP	10Hz		100-200 ms
TE-KPI1.6 - Reliability	TFT4.3.2 TFT4.3.3	TC1 AI1	Cockpit, UE (shuttle), MEC	L2	HTTP	10Hz		99,9%
TE-KPI1.8 – Network Capacity	TFT4.3.1	TC1 AI1	Camera	L1	UDP	TBD	Payload, timestamp, station ID, GPS location	

TE-KPI1.8 – Network Capacity	TFT4.3.2 TFT4.3.3	TC1 AI1	Cockpit, UE (shuttle), MEC	L1	UDP	10Hz		
TE-KPI2.1-NG-RAN Handover Success Rate	TFT4.3.1	TR1 TC1 AC1 AI1	Camera	L0	NA	TBD	Message, timestamp, station ID	99-100%
TE-KPI2.1-NG-RAN Handover Success Rate	TFT4.3.2 TFT4.3.3	TR1 TC1 AC1 AI1	Cockpit, UE (shuttle), MEC	L0	NA	10Hz		99-100%
TE-KPI2.2- Application Level Handover Success Rate	TFT4.3.1	TR1 TC1 AC1 AI1	Camera	L1, L2	UDP/IP	TBD	Message, timestamp, station ID	99-100%
TE-KPI2.2- Application Level Handover Success Rate	TFT4.3.2 TFT4.3.3	TR1 TC1 AC1 AI1	Cockpit, UE (shuttle), MEC	L1, L2	UDP/IP	10Hz		99-100%
TE-KPI2.3-Mobility interruption time	TFT4.3.1	TR1 TC1 AC1 AI1	Camera	L2	UDP	TBD	Message, timestamp, station ID	500ms

TE-KPI2.3-Mobility interruption time	TFT4.3.2 TFT4.3.3	TR1 TC1 AC1 AI1	Cockpit, UE (shuttle), MEC	Lo	IP	10Hz		< 10 s

C.4.2 Remote driving in a redundant network environment (FI)

Table 51: *Remote driving in a redundant network environment* UCC/US flow types

Title	*Description*	*UL/DL/Sidelink*
TFT4.2.1-Sensor	Data from vehicle sensors, includes LIDAR (range data as float lists of ranges and distances) and radar data	UL
TFT4.2.2-Status	Status data from the vehicle, includes position (longitude, latitude, orientation), motion state (velocity, acceleration, steering angle), internal state (executing trajectory, avoiding obstacle, stopped, ...), energy level and various temperatures (outside, CPUs, cabin, etc.)	UL
TFT4.2.3-Video	Video stream from vehicle via LEVIS platform	UL
TFT4.2.4-Command	Remote driving command messages, includes, state control command (paused, manual control, remote control, autonomous, etc.), trajectory to be executed (i.e. list of waypoints, position, velocity), command to start executing the trajectory, direct driving command (desired motion status, including velocity and steering angle, sent in fixed frequent interval)	DL

Table 52: *Remote driving in a redundant network environment* UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT4.2.1	AC1	OBU Remote control center	L2	ROS	1 / message (>=10 Hz)	Timestamp Location	>50 Mbps

TE-KPI1.1 User experienced data rate	TFT4.2.3	AC1	Video client Video server	L2	RTSP	1/ frame (tbc)	Timestamp	>6 Mbps
TE-KPI2.3 Mobility Interruption Time	TFT4.2.1	TR1, TH1, AC1	OBU Remote control center	L2	ROS	1/ message (>=10 Hz)	Timestamp Location	5 - 20 ms
TE-KPI2.3 Mobility Interruption Time	TFT4.2.1	TR1, TH1,	OBU Remote control center	L2	ROS	1/ message (>=10 Hz)	Timestamp Location	5 - 20 ms
TE-KPI2.3 Mobility Interruption Time	TFT4.2.3	TR1, TH1, AC1	Video client Video server	L2	RTSP	1/ frame (tbc)	Timestamp	<10 ms
TE-KPI1.3 E2E Latency	TFT4.2.1	TR1, TH1,	OBU Remote control center	L2	ROS	1/ message (>=10 Hz)	Timestamp Location	<80 ms
TE-KPI1.3 E2E Latency	TFT4.2.2	TR1, TH1,	OBU Remote control center	L2	ROS or Protobuf over websocket	1/ message (>=1 Hz)	Timestamp Location	<80 ms
TE-KPI1.3 E2E Latency	TFT4.2.3	AC1	Video client Video server	L2	RTSP	1/ frame (tbc)	Timestamp	<300 ms
TE-KPI1.6 Reliability	TFT4.2.1	AC1	OBU Remote control center	L2	ROS or Protobuf over websocket	1/ message (>=10 Hz)	Timestamp Location	99% – 99.999%
TE-KPI1.6 Reliability	TFT4.2.2	AC1	OBU Remote control center	L2	ROS or Protobuf over websocket	1/ message (>= 1Hz)	Timestamp Location	99% – 99.999%

C.4.3 Remote driving using 5G positioning (NL)

Table 53: *Remote driving using 5G positioning* UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT4.3.1-Sensor	Data from vehicle sensors, includes LIDAR (range data as float lists of ranges and distances)	UL
TFT4.3.2-Status	Status data from the vehicle, includes position (longitude, latitude, orientation), motion state (velocity, acceleration, yaw-rate, steering angle)	UL
TFT4.3.3-Video	Video stream from vehicle	UL
TFT4.3.4-Command	Remote driving command messages, direct driving command (desired motion status, including velocity and steering angle)	DL
TFT4.3.5-Localization	Location and accuracy information, timestamp	-

Table 54: *Remote driving using 5G positioning* UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT4.3.1-Sensor, TFT4.3.2-Status	*AC1*	*OBU* *Remote driving station*	*L2*	*UDP*	*Per message or time interval*	*Timestamp*	*10 Mbps*
TE-KPI1.1 User experienced data rate	TFT4.3.3-Video	*AC1*	*OBU* *Remote driving station*	*L2*	*UDP*	*Per video frame or time interval*	*Timestamp*	*50/1 Mbps [UL/DL]*
TE-KPI1.3 E2E Latency	TFT4.3.1-Sensor, TFT4.3.3-Video	TR2	OBU	L2	UDP	Per packet/ message/ frame	Timestamp	50 ms

TE-KPI	Traffic Flow	CB Issues	PCO	PCO Level	Protocol	Logging Frequency	Logging Information	Target Value
			Remote driving station					
TE-KPI1.3 E2E Latency	TFT4.3.4-Command	TR2	Remote driving station OBU	L2	TBD	Per packet/ message/ frame	Timestamp	5-10 ms
TE-KPI1.6 Reliability	TFT4.3.4-Command	AC1	Remote driving station OBU	L1	TBD	Per packet/ message/ frame	Packet success	99.99%
TE-KPI1.7 Position Accuracy	TFT4.3.5-Localization	AG1	OBU Remote driving station	L-2	TBD	Per received / transmitted message	**OBU:** Timestamp, position obtained from GNSS and GPS-RTK **RemoteStation:**Received messages: generation timestamp, message reception time	0.1 m

C.4.4Remote driving with data ownership focus (CN)

Table 55: *Remote driving with data ownership focus* traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT4.4.1-BSM	Vehicles' information for remote driving	UL, DL
TFT4.4.2-VIDEO	HD Video streaming among OBUs , RSUs and video cloud platform (ITS-Center)	UL, DL
TFT4.4.3-RCM	Remote control messages	DL

TFT4.4.4-MAP	MAP pass the local map information to the nearby vehicles, which includes the intersection information, road information, lane information, the traffic sign information, and the connection information between roads.	UL

Table 56: *Remote driving with data ownership focus KPI*

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT4.4.2	SO1	Cloud (ITS-Center)	L2	WebRTC	1 / message	Timestamp	>100/100 Mbps
TE-KPI1.3 E2E latency	TFT4.4.1 TFT4.4.3	SO1	OBU, RSU	L2	MQTT	10 Hz	Timestamp	<20 ms
TE-KPI1.6 Reliability	TFT4.4.1 TFT4.4.2 TFT4.4.3 TFT4.4.4	SO1	OBU, RSU, Cloud	L2	MQTT, WebRTC	1 / message	Number of successful messages	>95 %

C.4.5 Remote driving using mmWave communication (KR, KATECH)

Table 57: *Remote driving using mmWave communication* traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT4.5.1-FHDStreaming	Remote operator to access the right of control in case of automated vehicle in under malfunction or driver is in accident: FHD streaming	*UL*
TFT4.5.2-Camera	Remote operator to access the right of control in case of automated vehicle in under malfunction or driver is in accident Camera control	*DL*

TFT4.5.3-Vehicle	Remote operator to access the right of control in case of automated vehicle in under malfunction or driver is in accident: Vehicle control	*DL*
TFT4.5.4-Sensor	Remote operator to access the right of control in case of automated vehicle in under malfunction or driver is in accident: Raw sensor info	*UL*

Table 58:*Remote driving using mmWave communication* KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT4.5.1 TFT4.5.2 TFT4.5.3 TFT4.5.4	N/A	OBU	Lo	TCP/UDP	100ms	TBD	(200/1) Mbps
TE-KPI1.3 - End to End latency	TFT4.5.3	N/A	OBU	Lo	TCP/UDP	120ms	TBD	120ms
TE-KPI1.5 User Plane Latency	TFT4.5.3	N/A	OBU	Lo	TCP/UDP	-	TBD	4ms
TE-KPI1.6 Reliability	TFT4.5.3	N/A	OBU	Lo	TCP/UDP	120ms	Number of successful packets within T duration	100%

C.5 UCC-5: Vehicle QoS Support

C.5.1 Public transport with HD media services and video surveillance (ES-PT)

Table 59: Public transport with HD media services and video surveillance UCC/US traffic flow types

Title	*Description*	*UL/DL/Sidelink*
TFT5.2.1-4k streaming	4k streaming between the camera and the ITS Center	UL, DL
TFT5.2.2-Cockpit control	Multimedia contents from the Server to the tablets	UL, DL

Table 60: Public transport with HD media services and video surveillance UCC/US KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 -User experienced data rate	TFT5.2.2	TC1 AP2	Server tablets	L2	HTTP	TBD	Message, payload, timestamp, station ID	4 / 8 Mbps
TE-KPI1.2 – Throughput	TFT5.2.1	TC1 AP2	Camera ITS Center	L1	TBD	TBD	Payload, timestamp, station ID	0.2 / 0.2 Mbps
TE-KPI1.2 – Throughput	TFT5.2.2	TC1 AP2	Server Tablets	L1	UDP	TBD	Payload, timestamp, station ID	4 / 8 Mbps
TE-KPI1.3 - End to End latency	TFT5.2.2	TR1 TC1 AP2	Server Tablets	L2	HTTP	TBD	Message, timestamp, station ID	200ms
TE-KPI1.6 – Reliability	TFT5.2.2	TC1 AP2	Server Tablets	L2	HTTP	TBD	Message, timestamp, station ID	99.9%
TE-KPI1.8 – Network Capacity	TFT5.2.1	TR1 TC1 AP2	Camera ITS Center	L1	UDP	TBD	Payload, timestamp, station ID, GPS location	TBD
TE-KPI1.8 – Network Capacity	TFT5.2.2	TC1 AP2	Server Tablets	L1	UDP	TBD	Payload, timestamp, station ID, GPS location	TBD
TE-KPI2.1-NG-RAN Handover Success Rate	TFT5.2.1	TR1 TC1 AP2	Camera ITS Center	L0	IP	TBD	Message, timestamp, station ID	99-100%

TE-KPI2.1-NG-RAN Handover Success Rate	TFT5.2.2	TR1 TC1 AP2	Server Tablets	L0	IP	TBD	Message, timestamp, station ID	99-100%
TE-KPI2.2- Application Level Handover Success Rate	TFT5.2.1	TR1 TC1 AP2	Camera ITS Center	L1,L2	UDP/IP	TBD	Message, timestamp, station ID	99-100%
TE-KPI2.2- Application Level Handover Success Rate	TFT5.2.2	TR1 TC1 AP2	Server Tablets	L1,L2	UDP/IP	TBD	Message, timestamp, station ID	99-100%
TE-KPI2.3-Mobility interruption time	TFT5.2.1	TR1 TC1 AP2	Camera ITS Center	L1	IP	TBD	Message, timestamp, station ID	< 10 s
TE-KPI2.3-Mobility interruption time	TFT5.2.2	TR1 TC1 AP2	Server Tablets	L1	IP	TBD	Message, timestamp, station ID	500 ms

C.5.2 Tethering via vehicle mmWave communication (KR)

Table 61: ***Tethering via Vehicle mmWave communication*** **UCC/US traffic flow types**

Title	*US*	*Name*	*Description*	*UL/DL*
TFT5.2.1	3	Tethering via Vehicle mmWave communication	Wi-Fi traffic (e.g., online gaming, video streaming, social networks): Passengers inside a moving vehicle enjoy data consuming services such as online gaming, video streaming, social networks, etc. which is enabled by mmWave-band mobile wireless backhaul link provided to the bus	DL

Table 62: *Tethering via Vehicle mmWave communication UCC/US* KPIs

TE-KPI	*Traffic Flow*	*CB Issues*	*PCO*	*PCO Level*	*Protocol*	*Logging Frequency*	*Logging Information*	*Target Value*
TE-KPI1.1 User experienced data rate	TFT5.2.1	N/A	UE	L1/L2	TCP/UDP	1 Hz	Data rate	100 Mbps
TE-KPI1.6 Reliability	TFT5.2.1	N/A	Vehicle UE	L1/L2	TCP/UDP	1 per T duration (e.g., T can be duration of one frame)	Number of successful packets within T duration	99.90%
TE-KPI2.3 Mobility Interruption Time	TFT5.2.1traffic	N/A	gNB	LL1/L2	TCP/UDP	1 / frame	Timestamp	2 ms

APPENDIX D: EXAMPLE MEASUREMENT TOOLS

Table 63: Example of measurement tools

Exporter Name	Short Description	Features Level 0 Physical	Features Level 1 Network Transport	Features Level 2 Application	Interesting measurements examples	Related KPIs (indicative)	Link
Node Exporter	Prometheus exporter specialized in exposing Linux metrics	CPU stats,HW monitoring & sensor data, memory stats	IPVS, network interface stats, NFS, NTP, TCP, WiFi		disk space used, load average, transferred bytes, WiFi statistics	TE-KPI1.3 E2E Latency, TE-KPI1.1 U data Rate	https://github.com/prometheus/node_exporter
Blackbox Exporter	The Blackbox exporter is a tool that allows engineers to monitor HTTP, DNS, TCP and ICMP endpoints.		DNS, TCP socket and ICMP, TLS	HTTP, HTTPS (via the http prober)	HTTP requests latencies, average DNS lookup time, up status of website, current SSL status, SSL expiry date	TE-KPI1.3 E2E Latency	https://github.com/prometheus/blackbox_exporter
Kafka	Kafka is used for real-time streams of data, to collect big data, or to do real time analysis (or both)			Stream processing, website activity tracking, log aggregation, real-time analytics	Video Streaming processing, real-time relevant measurements	TE-KPI1.1 User experienced data rate (DL)	https://github.com/danielqsj/kafka_exporter
SNMP (Simple Network	It is one of the most widely accepted protocols for		bytes, packets, and errors Tx & Rx on a router, connection		Throughput, latency, failed requests	TE-KPI1.1 User experienced data rate (DL) TE-KPI2.1-	https://github.com/prometheus/snmp_exporter

Manag. Protocol)	network monitoring		speed between devices			NG-RAN Handover Success Rate TE-KPI1.3 E2E Latency	
Nagios	Application that monitors systems, networks and infrastructure. Also offers alerting services for servers, switches, applications and services.	CPU Memory Disks	Ping SNMP Service Network on Switches, Routers, Firewalls Services Programs running on servers		Throughput, latency, failed requests	TE-KPI1.1 U data Rate TE-KPI1.3 E2E Latency TE-KPI1.6- Reliability TE-KPI2.1- NG-RAN Handover Success Rate TE- KPI2.2- Application Level Handover Success Rate	https://github.com/Griesbacher/Iapetos