



# 5GMOBIX

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

## D2.5

### Initial evaluation KPIs and metrics

Dissemination level	Public (PU)
Work package	WP2: Specifications
Deliverable number	D2.5
Version	V1.4
Submission date	31/10/2019
Due date	31/10/2019



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 825496.

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## Control sheet

Version history			
Version	Date	Modified by	Summary of changes
0.1	24/01/2019	ICCS	Table of contents.
0.2	30/01/2019	ICCS	Inclusion of editors per section.
0.3	31/03/2019	ICCS, CCG	First set of KPIs circulated to consortium.
0.4	31/05/2019	ICCS, CCG	Updated set of KPIs based on consortium comments.
0.5	14/06/2019	ICCS, CCG	Final version for review from the site leaders and WP2 members.
0.6	21/06/2019	ICCS	Consolidation following the comments received from the site leaders and WP2 members.
0.7	19/07/2019	ICCS	Consolidation following the comments received from reviewers.
0.8	09/08/2019	ICCS, COSMOTE	Updated structure following the 1 <sup>st</sup> project review; Updated KPI definition template, added target KPI values.
0.9	10/09/2019	ICCS, CCG, VTT	Consolidation of additional input (content and review comments) from WP2 members, following the updated structure.
1.0	27/09/2019	ICCS, CTAG	Updated User Story naming, consolidation of additional input (KPI Target Values) from WP2 members.
1.1	07/10/2019	ICCS, SIEMENS	Consolidation of additional input (KPI Target Values, metrics) from WP2 members.
1.2	17/10/2019	ICCS	Finalization of Target KPI Values.
1.3	22/10/2019	ICCS, COSMOTE, DEKRA, CTAG, LIST	Consolidation following the comments received from reviewers.

1.4	22/10/2019	ICCS, COSMOTE, DEKRA, CTAG, LIST	Final version, addressing all the comments received from reviewers and quality management.
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Peer review		
	Reviewer name	Date
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<b>Review 2</b>	Diana Blanco (CTAG) Eva García (CTAG) Marta Miranda (CTAG)	11/07/2019 (v0.6), 17/10/2019 (v1.1)
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<b>Review 4</b>	Qiang Tang (LIST)	11/07/2019 (v0.6), 17/10/2019 (v1.1)

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## ABBREVIATIONS

Abbreviation	Definition
3GPP	3rd Generation Partnership Project
5G-PPP	5G Infrastructure Public Private Partnership
AD	Automated Driving
CBA	Cost Benefit Analysis
CBC	Cross Border Corridor
CCAM	Cooperative, Connected and Automated Mobility
CP	Control Plane
C-V2X	Cooperative-Vehicle-to-Everything
DL	Downlink
DoA	Description of Action
E2E	End-to-end
EC	European Commission
GA	General Assembly
HMI	Human-Machine Interface
ICT	Information and Communication Technologies
KPI	Key Performance Indicator
MAMCA	Multi-Actor Multi-Criteria Analysis
MTTR	Mean Time To Repair
NG-RAN	Next Generation – Radio Access Network
OBU	On-Board Unit
OSS	Operational Support System
PLMN	Public Land Mobile Network
QoL	Quality of Life
RAT	Radio Access Technology
SA	Stand Alone
SAE	Society of Automotive Engineers



S-GW	Serving Gateway
TAM	Technology Acceptance Model
TS	Trial Site
TSL	Trial Site Leader
UCC	Use Case Category
UE	User Equipment
UL	Uplink
UP	User Plane
UPF	User Plane Function
US	User Story
VNF	Virtual Network Function
WP	Work Package
WPL	Work Package Leader
X-border	Cross-border

## EXECUTIVE SUMMARY

This document is deliverable D2.5 “Initial evaluation KPIs and metrics” of the 5G-MOBIX project. The main objective of the deliverable is to provide an extended set of Key Performance Indicators (KPIs) and metrics for evaluation and analysis of the 5G-MOBIX test sites and corresponding Use Case Categories (UCCs) / User Stories (USs), as these are specified in D2.1. Targeting a holistic evaluation process, the deliverable specifies KPIs aimed to guide the technical performance evaluation of the 5G-MOBIX solution, along with appropriate metrics to support evaluation on the fronts of impact assessment and user acceptance.

To this end, the deliverable initially provides the KPI and metric definition frameworks, identifying key aspects of the selected KPIs and metrics. Special attention is put to the technical performance evaluation, with respect to the effect of handover events<sup>1</sup> (and corresponding technical realizations/solutions) on the user perceived performance. At the same time, the deliverable presents the framework for the Impact Assessment and User Acceptance evaluation activities, paving the way for the definition of the corresponding metrics.

Along the lines of the presented frameworks, the deliverable identifies a series of KPIs and metrics aimed to capture the impact of cross-border mobility on the selected UCC/US. The KPIs primarily focus on capturing user perceived performance and ultimately the effects of cross-border mobility on the application level. However, finer grained KPIs are also selected to support a closer look on the final results and therefore enable the identification of potential limitations of the technological solutions presented by 5G-MOBIX.

Taking a step further, the deliverable proceeds to the identification of a preliminary set of UCC/US-specific KPI target values that will eventually guide the KPI evaluation process. Building on D2.5, D5.1 will subsequently elaborate on the methodological framework for the evaluation process that will guide the actual implementation of the monitoring /measurement mechanisms.

The rest of the document is organised as follows:

- **Section 1**, describes the purpose of the document and its intended audience.
- **Section 2**, presents the **framework** for the definition of the selected KPIs and metrics.
- **Section 3**, presents an extended list of **Technical Evaluation** KPIs.
- **Section 4**, presents an extended list of **Impact Assessment** metrics.
- **Section 5**, presents an extended list of **User Acceptance** metrics.
- **Section 6**, presents the **conclusions**.

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<sup>1</sup> In the context of 5G-MOBIX, the term is broadly used to express inter-PLMN handover events, including radio/access, control plane, as well as application-level handover aspects i.e., transferring a data session from one application instance to another.

## 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 automated driving to the next level of vehicle automation (SAE L<sub>4</sub> and above). To do this, 5G-MOBIX will demonstrate the potential of different 5G features on real European roads and highways and create and use sustainable business models to develop 5G corridors. 5G-MOBIX will also utilize and upgrade existing key assets (infrastructure, vehicles, components) and 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 (x-border) and urban corridors using 5G core technological innovations to qualify the 5G infrastructure and evaluate its benefits in the CCAM context. The Project will also define deployment scenarios and identify and respond to standardisation and spectrum gaps.

5G-MOBIX will first define critical scenarios needing advanced connectivity provided by 5G, and the required features to enable 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 and operational conditions 5G-MOBIX is expected to actively contribute to standardisation and spectrum allocation activities.

### 1.2. Purpose of the deliverable

The purpose of this deliverable is to prepare the ground for the quantitative and qualitative evaluation of 5G-MOBIX solutions for cross-border mobility in the context of advanced automated driving (AD) applications, by providing an extended set of KPIs and metrics that will guide the evaluation process. KPIs/metrics are an essential part of the evaluation strategy of different technological applications and approaches. CCAM solutions have far-reaching implications and, to understand them properly, one must address several issues such as validation, impact assessment, user acceptance and security aspects. KPIs capture and detail performance measurement results, helping stakeholders to evaluate the performance of a deployment, pilot or experiment. The challenge is to select the proper set of KPIs to ensure that all the

deployments and trials are using indicators aligned with their goals. It is, therefore, crucial to research and understand the KPIs that are important and specific to the 5G-MOBIX ecosystem.

To this end, the proposed KPI/metric set aims to be extensive enough to enable the thorough assessment of the involved 5G technology and all the UCC/US defined in D2.1, and spans from purely technical KPIs to user acceptance and impact assessment metrics. On the technical domain, the impact of (cross-border) mobility events on the perceived performance is prevailing, significantly affecting the design of the evaluation approach. It is noteworthy that in the context of 5G-MOBIX and this specific deliverable, the term *handover* encompasses inter-PLMN handover aspects as well as application-level handover aspects i.e., transferring a data session from one application instance to another. As each UCC/US presents its own specificities in what concerns the importance of the various KPIs, D2.5 presents an initial mapping to preliminary target KPI values. The final KPIs/metrics set, and target values, that will be considered for the actual evaluation stage of the project, will be finalised by the corresponding partners based on the implemented UCC/US at each test site and will be reported in D5.1 "*Evaluation methodology and plan*" along with all related local/global parameters and constraints. Furthermore, information related to the particular technical approach for establishing the corresponding measurement mechanisms for each KPI will be presented in D3.5 "*Report on the evaluation data management methodology and tools*". Finally, detailed trial plans i.e., presenting scope, storyboard, agenda, test scenarios (e.g., speed/platoon distance), will be reported in D4.1 "*Report on all the corridor and trial site plans*".

Beyond Technical Evaluation, the deliverable further identifies the metrics required for the Impact Assessment aspects of the overall 5G-MOBIX evaluation process. This sets the scene for the subsequent Impact Assessment activities (in the context of T5.3), based on the methodology defined in T5.1 i.e., the Multi-Actor Multi-Criteria Analysis (MAMCA) methodology, which will facilitate the Cost-Benefit Analysis (CBA). By performing a CBA based on the identified metrics, the goal is to generate a broader picture of the 5G-MOBIX solutions covering the whole spectrum of the most influential perspectives and support decision making. This will be achieved in close collaboration with T6.2 by analysing deeper business opportunities within the 5G-MOBIX.

### 1.3. Intended audience

The dissemination level of D2.5 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 aims to serve not just as an internal guideline and reference for all 5G-MOBIX beneficiaries, especially the Trial Site (TS) and the UCC/US leaders, but also for the larger communities of 5G and CCAM development and testing.

## 2. KPI AND METRICS FRAMEWORK

The KPIs aim to capture important performance aspects reflecting on the quality of the service perceived by the end user and are selected based on the high-level project objectives, the UCC/US goals and the impact requirements, as well as, their applicability to the different pilot sites. Furthermore, the identified KPIs aim to be Specific, Measurable, Attainable, Relevant, Timed (SMART), and simple to understand:

- **Specific:** Target a specific domain or field.
- **Measurable:** Quantifiable evaluation.
- **Attainable:** Achievable with the resources, technology and the time available.
- **Relevant:** Evaluation and success relevant.
- **Timed:** Values can be collected within time-frames well-aligned with the project course e.g., facility readiness.

The SMART characteristics of the selected KPIs are ensured by the compliance to 5G PPP [5][6][11], 3GPP [1][3] and ITU-R [15] work on the selection and definition of appropriate KPIs for 5G networks. Timeliness aspects of the corresponding measurements will be documented in detail in D4.1 and D5.1.

### 2.1. Technical Evaluation KPI Framework

The selection of technical evaluation KPIs builds on previous work in the context of 5G PPP and 3GPP activities e.g., [1][3][5][6][11], as well as ITU-R [15]. For each selected KPI, a series of information elements are provided as described in Table 1 below, in accordance to the 5G PPP practices [5][6][11] .

**Table 1: Technical Evaluation KPI definition template<sup>2</sup>**

<b>Title</b>	<i>Title of the KPI: TE-KPIx.y-ShortTitle</i>  <i>TE: Technical Evaluation</i>  <i>x: Technical Evaluation sub-category index i.e., General: 1, Handover: 2</i>  <i>y: KPI index within sub-category</i>
<b>Description</b>	<i>High level description of KPI</i>
<b>Context/Use Case</b>	<i>Associate the KPI with a particular application context / use case.</i>  <i>(Note: we associate all UCC/US with the corresponding KPIs in Section 3.3, where the identified Target Values are presented. As such, and further facilitating presentation</i>

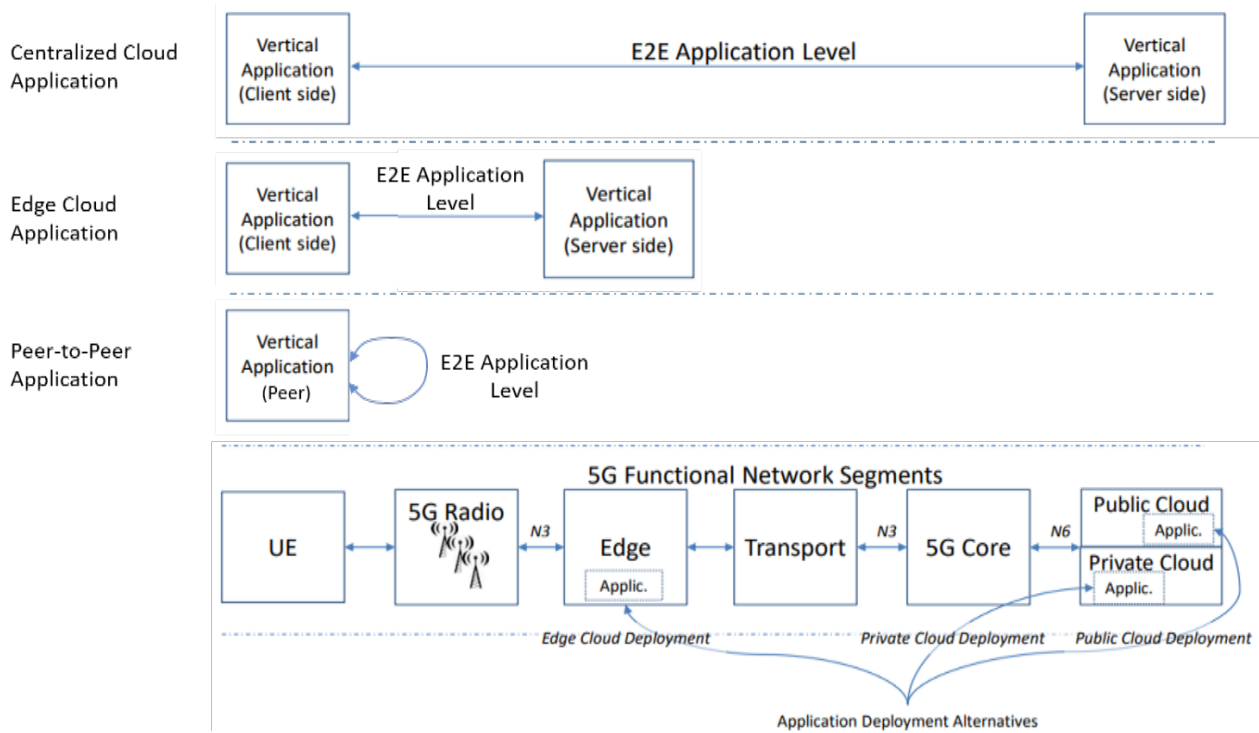
<sup>2</sup> The 5G-PPP KPI definition template further refers to Enhancement Work aspects, expressing the particular solution components, developed within the context of a 5G-PPP project, that are aimed to support the particular KPI. This information will be provided in D5.1, where detailed per UCC/US (and TS) material will be delivered.

	<i>clarity, we omit this field from the KPI definitions in Sections 3.1 and 3.2. Detailed per UCC/US KPI descriptions will be provided in D5.1.)</i>
<b>Where to measure</b>	<i>Points of measurement e.g., UEs/OBUs, Application Server, etc.</i>
<b>How to measure</b>	<i>A high-level description of the measurement methodology, including (where applicable):</i> <ul style="list-style-type: none"> <li><i>Detailed definition of KPI e.g., what timestamps to use for latency, which packets to consider for throughput, etc.</i></li> <li><i>Key (functional) requirements for the measurements e.g., endpoint synchronization, background, traffic generation (if any), etc.</i></li> <li><i>Key varying parameters e.g., background traffic, vehicle speed, video encoding, etc.</i></li> </ul>
<b>How to Evaluate</b>	<i>Definition of comparison approach i.e., what values the measured KPI data points are compared against. This can include Target Values or results retrieved by identified alternative setups/experiments.</i>  <i>(Note: 5G-MOBIX identifies Target KPI Values for this purpose. For presentation clarity reasons, we present this information separately in Section 3.3 and we therefore omit this field from the KPI definitions in Sections 3.1 and 3.2).</i>
<b>Comments</b>	<i>(Optional)</i>

Unless otherwise stated, the identified KPIs refer to the performance perceived on an end-to-end (E2E), application level. It is noteworthy, that since an application may comprise of various types of traffic flows e.g., platoon control traffic flow vs. see-what-I-see video stream traffic flow, the identified KPIs will be used to assess the performance of multiple traffic flows per application. As schematically shown in Figure 1 for the example case of a typical 5G Stand Alone (SA) deployment, this corresponds to high-level view depicting the aggregate result of the performance of a series of individual segments in the overall network [5]. Subject to the exact nature of the application and the deployment scenario, the E2E Application level scope may terminate at the “Edge” segment or even beyond the infrastructure edge e.g., in V2V communications. In the case of V2V communication, the notion of E2E performance confines between the Application components residing at the involved vehicles.

Where appropriate, individual, per segment incarnations (and corresponding measurements) of the KPIs shall be realized to shed further light on the perceived performance e.g., end-to-end user perceived data rate vs. per segment throughput; E2E latency vs. Control Plane (CP) and User Plane (UP) latency components. In such cases, it is noteworthy that the corresponding measurements may take place below the application layer e.g., measuring the transport segment throughput at the network layer.

The detailed definition of the measurement points in each communication scenario shall be provided in D5.1 where the overall evaluation methodology will be presented, including a finer grained analysis of the KPIs employed on a per UCC/US basis, taking into account the detailed system architecture (and corresponding solutions) in the involved testbeds. D5.1 will further also present a holistic data collection methodology, detailing the protocol stack layers where KPI measurements will take place. We explicitly however note this aspect in the following KPI definitions.



**Figure 1: 5GPPP Reference Network Architecture used for the 5G-MOBIX KPIs definition. Figure adapted from [5].**

Having provided the definitions of the selected KPIs along the lines of the aforementioned reference architecture diagram, we further associate them with the particular UCC/US along with the identification of the corresponding Target Values for each related KPI (where applicable), in Section 3.3<sup>3</sup>. This serves the purpose of denoting the importance/relevance of each KPI for each UCC/US.

The KPI selection (and definition) plays a highly important role in capturing the capabilities of 5G networks for the support of CCAM applications. Of equal importance is when addressing the evaluation process: to consider (i) the effects of mobility on a cross-border setup, which is the actual focus area of 5G-MOBIX, and (ii) the dimensioning of the network in the trial sites. In the following section, we present 5G-MOBIX considerations on these fronts.

<sup>3</sup> For simplicity reasons, the specified Target Values refer to the traffic flows, within each UCC/US, that present the most stringent performance requirements. The traffic composition of each UCC/US, along with the corresponding KPI values will be detailed in D5.1.

### 2.1.1. Cross-border mobility aspects

Mobility when crossing the administrative borders of operators triggers roaming interactions and potential service disruption. Obviously, a rigorous evaluation of 5G-MOBIX solutions leading to the corresponding quantification of aspects with regard to smooth mobility and service continuity is mandatory and necessitates the establishment of an assessment process explicitly tailored to capture the effects of mobility.

In practice this first translates to the fine-grained processing of the measurement data related to the identified KPIs, which will take into account the course of network events occurring during a defined mobility scenario, with the purpose of characterizing performance during different time periods defined by these events. Namely, 5G-MOBIX aims to engage into a statistical analysis of the retrieved KPI measurement data so as to characterize performance, prior, during and after a handover event taking place at a cross-border corridor (CBC). It must be noted that this approach is expected to provide (statistical) confidence to the retrieved results, isolating mobility/handover effects and capturing the impact of the applied solutions. For instance, consider the case of a simplified throughput measurement scenario with the following events in time:

- $t_0$ : start of measurements (passive monitoring)
- $t_1$ : start of the handover/roaming procedure
- $t_2$ : end of the handover/roaming procedure
- $t_3$ : end of throughput measurements

Obviously, applying statistical analysis e.g., deriving the probability distribution function, min/max/average, etc., choosing arbitrary  $t_0$  and  $t_3$  values (points in time) would result in an erroneous result and conclusion, especially when  $t_0 \ll t_1$  and/or  $t_2 \ll t_3$ , as this would fail to isolate the impact of the handover event on the selected KPI. At the same time, this approach reveals the necessity to precisely identify points  $t_1$  and  $t_2$  above, which relates to the broader requirement for the identification of all handover related events, states and transition processes. This identification is an explicitly identified work item for WP5, and as such the corresponding results will be presented in D5.1, in the context of the overall evaluation methodology description.

In addition to the above considerations, and with respect to the focus on cross-border mobility, it is also important to note the 5G-MOBIX KPI collection is aligned with 3GPP practices in what concerns the evaluation of mobility related aspects, as it adopts the *NG-RAN handover success rate* KPI [1]. However, as presented in Section 3, we take a step further by considering two additional KPIs related to handover events, namely (i) application layer handover aspects (TE-KPI2.2) in the particular context of cross-border mobility, which aims to capture service continuity aspects as well, e.g., session transfer/transition, and (ii) mobility interruption time (TE-KPI2.3), focusing on the explicit quantification of the handover disruption duration at the network layer.



### 2.1.2. Network dimensioning and scalability aspects

The identified KPIs aim to capture the performance of the overall 5G-enabled setup (including the 5G networks, the CCAM infrastructure and on-vehicle components) in supporting the identified CCAM UCC/US in the context of cross-border mobility. As such, they primarily intent to capture key performance aspects as perceived on an end-to-end basis, thereby getting closer to what end users perceive. The value however of the overall evaluation process, and the corresponding validity and value of the extracted conclusions, substantially relies on the dimensioning of the network in what concerns the provisioning of network, computing and storage resources for the support of certain resource demand (as this is manifested by the services in operation). Assuming that the overall ICT infrastructure in the trial sites will be dedicated to the purposes of the trials, resource demand is not expected to be affected by background traffic/services. Hence, the scale of the envisioned trials, expressed in number of participating UEs and corresponding applications (UCC/US), is expected to define resource availability and to correspondingly shape the KPI values to be collected. At the current phase of the trial planning, it is estimated that only a limited number of vehicles (and UEs) will be available, rendering stress testing of the network impractical. We note this as an inherent practical limitation of the evaluation process, that does not allow the evaluation of 5G-MOBIX solutions in the context of heavyweight load owing to the pursued UCC/US.

In order to address this limitation, the project will assess the following evaluation approaches:

- (i) Use of synthetic data, generated to stress the network to its maximum capacity limits.
- (ii) Simulation/emulation efforts, adopting/replaying experimentally generated data e.g., traffic flow traces, at a larger scale.

The corresponding methodology is subject to work carried out in the context of WP5 and will be elaborated in D5.1.

## 2.2. Impact Assessment Metrics Framework

The purpose of Impact Assessment is to assess the potential business and societal impacts of the systems and applications demonstrated in the CBCs and trial sites in the context of 5G-MOBIX project. To this end, a series of metrics are identified for the support of a qualitative analysis on the corresponding benefits related to mobility. As detailed in Section 4, the identified metrics aim to capture aspects related to the improvement of personal mobility, traffic flow efficiency, environment (reduction of pollution), traffic safety, and business impacts. Unless otherwise stated, the identified metrics will be assessed through means of interviews with end-users and stakeholders, and as such, they present a common, unified measurement methodology. Table 2 below presents the Impact Assessment metric definition template, including the adopted naming convention.

**Table 2: Impact Assessment metric definition template**

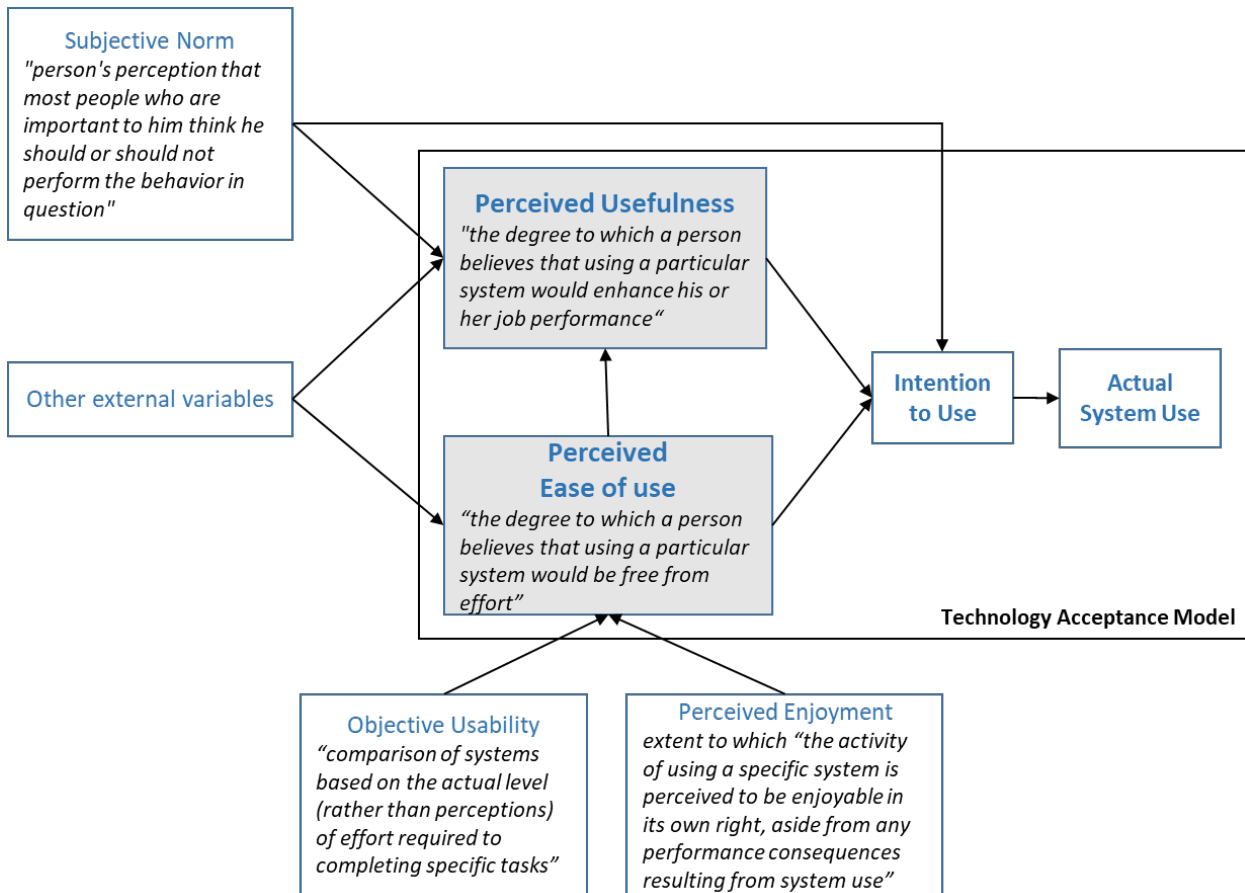
<b>Title</b>	<p><i>Title of the KPI: IA-Mx.y-ShortTitle</i></p> <p><i>IA-M: Impact Assessment-Metric</i></p> <p><i>x: Impact Assessment sub-category index i.e., Personal Mobility: 1, Traffic Efficiency: 2, Traffic Safety: 3, Environmental: 4, Business: 5</i></p> <p><i>y: metric index within sub-category</i></p>
<b>Description</b>	<p><i>High level description of KPI</i></p>

### 2.3. User Acceptance Metrics Framework

The objective of the User Acceptance metrics is to determine the acceptability of different kinds of mobility services. Using Shade and Schlag definitions [22] we describe acceptability as the “prospective judgement” made by a group of potential users regarding the adoption of a given service or technology, whereas acceptance, refers to the actual adoption behaviour demonstrated by them when the service or technology is available. The assessment will build on the user-acceptance models proposed by Venkatesh and colleagues [23] that correlate acceptance with the constructs of *perceived usefulness* and *perceived ease-of-use*. Figure 2 shows a graphical depiction of the assessment model. The blocks represent the model constructs while the arrows highlight the known correlations. The evaluation will focus on the TAM blocks plus the objective usability. Given the safety-critical nature of the to-be-tested technologies, metrics of trust and perceived safety are also determined, as well as the system’s usability and user error tolerance. Unless otherwise stated, a psychometric scale composed of a set of questions answered through a Likert scale [23] will be used to assess each identified metric. The complete set of questions addressing all metrics will be contained in a questionnaire provided to end-users, adhering to the common, unified measurement methodology that will be presented in D5.1. Questionnaires will be typically answered before and after the CBC (and/or local) site experiments take place. When possible, objectively measured KPIs addressing the system’s usability and error handling capacity<sup>4</sup> will serve as a complement to the self-assessed results.

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<sup>4</sup> To be identified in D5.1.



**Figure 2: Technology Acceptance Model (TAM), simplified version. Adapted from [16].**

For each of the metrics evaluated through a psychometric scale (as indicated in Section 5), a group of questions/statements will be defined based on pre-validated user-acceptance scales, with adaptations (if required) for each specific use-case. For instance, for the first metric (Acceptance intention), the following questions/statements will be used, based on [23]:

- Given that I have access to the system, I predict that I would use it.
- Assuming I have access to the system, I intend to use it.

The respondent will answer to each questions/statement through a 5-point Likert Scale ("Strongly Disagree -> Strongly Agree"). The use of multiple questions per construct allows for a stronger internal validity and reliability of the scale [17]. The metrics depending on objective evaluation of user interaction (see Sections 5.3 and 5.4) are only applicable to user-stories that imply interaction between the users and the Human-Machine Interface (HMI) system available on the vehicle. Where applicable these metrics will require a clear understanding of the sequence of interchanges between system and user. This will be developed based on:

- Data from the system's event log, that should contain information on all interactions of the user with the Human-Machine Interface (HMI) system, namely inputs from the user (button presses or screen touches,

retake actions), outputs from the system (system's events in response to user input), and all messages from the system to the users (visual and auditory warnings and information).

- Video recording of the participants' interaction with the system (when applicable), which can help the evaluators to comprehend the full sequence of interaction events occurring during the trials.

Due to logistic and safety limitations, the large majority of trial sites only plans to conduct the trials with a reduced number of drivers, limiting the representativeness of the sample. Thus, a larger base of potential users that can answer the questionnaires will be sought after, further taking advantage of the multiplicity of local test sites in 5G-MOBIX. Since this second line of respondents will not actually interact with the systems, they will not be able to evaluate all the metrics, particularly, the ones related with the *perceived ease-of-use*. Questionnaires will thus have to be adapted to evaluate those dimensions that can be judged from a potential user perspective, such as perceived usefulness and trust.

### 3. TECHNICAL EVALUATION RELATED KPIS

The following (sub-)sections present the set of KPIs selected for the technical performance evaluation in 5G-MOBIX, following the framework presented in Section 0. Section 3.1 presents general KPIs typically selected for the characterization of 5G network performance [5][6]. Section 3.2 presents KPIs focused on capturing the effects of cross-border mobility and corresponding handover events on performance. However, as noted in Section 2.1.1, the assessment of cross-border mobility is not fully covered by these KPIs, and will be complemented by the appropriate evaluation methodology (and statistical analysis) of the General KPIs of Section 3.1. Finally, it is important to note that while interoperability aspects across borders and involved networks are certainly within scope of 5G-MOBIX, their assessment has been considered as part of the solution verification process (WP3).

#### 3.1. General KPIs

**Table 3: TE-KPI1.1- User experienced data rate**

Title	TE-KPI1.1-User experienced data rate
Description	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 <i>goodput</i> ).
Where to measure	UEs/OBUs and/or Application Server, subject to UCC/US communication end-points (see also Figure 1). A distinction shall be made between uplink (UL) and downlink (DL) KPI measurements.
How to measure	<p>Measurements will follow a passive approach targeting traffic generated by the applications at hand i.e., UCC/US. As such, measurements will focus on sampling the user experienced data rate over a long observation interval (e.g., lasting as long as a reasonable communication session in the context of a US scenario lifetime), with granular sampling of arrival rate at the receiver UE/OBU (application component / client) or Application Server (e.g., 100ms window averages). The data points (samples) will be derived by dividing the total data volume received correctly at the destination side, by the time duration of the corresponding slot. The observed values depend on the actual data rate at the sender side, which will also be measured. Sender/receiver synchronization is required for the time alignment of the measurement slots. The use of synthetic data will also be considered so as to stress the network to its maximum capacity limits.</p> <p>The KPI will be measured under different conditions i.e., possibly:</p>

1. Under different coverage/radio network quality conditions, i.e. different locations.
2. Under different vehicle speeds.
3. Under different network traffic conditions.

**Table 4: TE-KPI1.2Throughput**

Title	TE-KPI1.2Throughput
Description	<p>The instantaneous data rate / throughput as perceived at the <i>network layer between two selected end-points</i>. The end points may belong to any segment of the overall network topology, as discussed in Section o.</p> <p>It corresponds to the amount of data (bits) received per time unit.</p>
Where to measure	<p>The KPI will be first assessed on an end-to-end basis i.e., UEs/OBUs and/or Application Server, subject to UCC/US communication end points (see also Figure 1)<sup>5</sup>. A distinction shall be made between uplink (UL) and downlink (DL) KPI measurements. Depending on the final network architecture and deployment, intermediate measurement points will be selected in order to identify potential bottlenecks e.g., edge computing server ingress/egress throughput measurements, throughput measurements between border sites interconnection, backhaul network throughput, etc. D5.1 will elaborate on the related methodology, providing details regarding the points of observation and data collection, and the corresponding protocol stack layers.</p>
How to measure	<p>The measurement methodology will be similar to the <i>User experienced data rate</i> KPI however targeting network level performance i.e., reflecting the effects of network congestion as manifested through retransmissions. The use of synthetic data will also be considered so as to stress the network to its maximum capacity limits.</p> <p>The KPI will be measured under different conditions (see Table 3).</p>

<sup>5</sup> The key difference against TE-KPI1.1 in this case, is the focus on the network layer, rather than on the application layer.

**Table 5: TE-KPI1.3-End to End Latency**

<b>Title</b>	<b>TE-KPI1.3-End to End Latency</b>
<b>Description</b>	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).
<b>Where to measure</b>	UEs/OBUs and/or Application Server. The selection of the exact end-points depends on the application deployment specifics, for instance with regard to the availability/usage of a MEC solution for the deployment of the Application Server, the use of V2V communications, in which case the two application ends reside, both, on vehicles, etc.
<b>How to measure</b>	<p>Latency is measured by considering the timestamp of the application packet at the moment that the packet is delivered to the local node (data source) OS/network stack for transmission and the moment the packet is received at the application layer at the destination node. This requires the synchronization of the source and destination points.</p> <p>As different network segments e.g., backhaul vs. core vs. access segments (see also Figure 1), contribute to the overall end-to-end latency captured by this metric, further measurements may optionally further, additionally focus on intermediate points in the network e.g., measuring the latency component of the backhaul network segment. In such cases, measurements take place on the network or link layer, rather than the application layer (see also TE-KPI1.5).</p> <p>The KPI will be measured under different conditions (see Table 3).</p>
<b>Comments</b>	<p>This KPI aims to capture the end-to-end latency as perceived at the application layer. As such, the measurement values will also include delay components owing to local processing i.e., from the moment the packet is received at the link layer up until its delivery to the application layer.</p> <p>Separate KPIs are defined to isolate the contribution of the control plane to the aggregate end-to-end latency (see next).</p> <p>On another front, work on latency assessment will also use the captured latency data to characterize performance on the application level through second-order metrics such as the amount of time between two successive successful packet receptions (CCAM messages) from a single transmitter. In essence, this corresponds to the <i>inter-packet gap</i> KPI as defined in [4]. We refrain from directly including such expressions of latency in the set of adopted KPIs, as these are subject</p>

to the application level sending rate and, as such, are considered as an application-specific transformation of general latency data.

**Table 6: TE-KPI1.4-Control plane Latency**

Title	TE-KPI1.4-Control plane Latency
Description	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) [1]. 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.
Where to measure	UE/OBU.
How to measure	This KPI will timestamp and log the corresponding state transition events at the UE/OBU. The KPI will be measured under different conditions (see Table 3).

**Table 7: TE-KPI1.5-User plane Latency**

Title	TE-KPI1.5-User plane Latency
Description	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 [1].
Where to measure	UEs/OBUs and/or Application Server.
How to measure	The measurement methodology will be similar to the <i>End-to-End Latency</i> KPI however targeting Layer 2/3 performance, therefore isolating delay components owing to local node processing at higher (than network) layers.  The KPI will be measured under different conditions (see Table 3).



**Table 8: TE-KPI1.6- Reliability**

<b>Title</b>	<b>TE-KPI1.6- Reliability</b>
<b>Description</b>	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.
<b>Where to measure</b>	UEs/OBUs and/or Application Server
<b>How to measure</b>	<p>Measurements build on the comparison between the number of packets sent and received within a certain time constraint, thus require the logging of the corresponding information on a source-destination level. The measurement will take place on an application level. Time constraints depend on the actual application context and will be defined on a per User Scenario case (D5.1).</p> <p>The KPI will be measured under different conditions (see Table 3).</p>

**Table 9: TE-KPI1.7- Position Accuracy**

<b>Title</b>	<b>TE-KPI1.7- Position Accuracy</b>
<b>Description</b>	Deviation between the actual position and the measured position of a UE via 5G positioning services.
<b>Where to measure</b>	<i>UE, Network</i>
<b>How to measure</b>	<p>In the corresponding UE/vehicle by comparing the position estimated by the 5G network to the position retrieved from a GNSS (Global Navigation Satellite System).</p> <p>The KPI will be measured under different conditions (see Table 3).</p>

**Table 10: TE-KPI1.8- Network Capacity**

<b>Title</b>	<b>TE-KPI1.8- Network Capacity</b>
<b>Description</b>	Maximum data volume transferred (downlink and/or uplink) per time interval over a dedicated area.

Where to measure	Serving Gateway (S-GW), User Plane Function (UPF)
How to measure	<p>The measurement corresponds to the aggregate throughput in a certain network area, at a certain period of time, pertaining across individual UE/OBU sessions. Measurements will aggregate data rate results from concurrently on-going individual sessions i.e., total number of packets sent/received within a network area at a certain period of time. This can be accomplished by capturing network level traffic on an S-GW (S1-U interface) / UPF level (N3/N6 interface). As the scale of the trials may not result in stressing the network, in term of traffic reaching the overall capacity, the use of synthetic data will also be considered.</p> <p>The KPI will be measured under different conditions (see Table 3).</p>
Comments	Sometimes this KPI is associated with <i>peak (aggregate) demand</i> essentially capturing the maximum aggregate throughput in the network.

**Table 11: TE-KPI1.9- Mean Time to Repair (MTTR)**

Title	<b>TE-KPI1.9- Mean Time to Repair (MTTR)</b>
Description	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).
Where to measure	OSS
How to measure	The measurement corresponds to time period between the identification of failure and the completion of the restoration procedure. The identification of both events highly depends on the type of failing component. Failures shall be triggered as part of the measurement methodology so as to increase the density of the volume of measurement data (see also comments).
Comments	<p>In the most typical case, this KPI will focus on VNFs e.g., a User Plane Function (UPF) instance, or an application instance.</p> <p>This KPI typically complements the Mean Time Between Failures (MTBF) KPI, which however corresponds to network performance aspects in the long-run. As such MTBF cannot be practically assessed within the timeframe of the project. While the nature of MTTR is also long-run, an assessment can be more easily approached as it requires the existence of failure, regardless of its root cause i.e., artificially triggered failures can support MTTR measurements.</p>

### 3.2. Handover KPIs

**Table 12: TE-KPI2.1-NG-RAN Handover Success Rate**

Title	TE-KPI2.1-NG-RAN Handover Success Rate
Description	Ratio of successfully completed handover events within the NR-RAN regardless if the handover was made due to bad coverage or any other reason [2]
Where to measure	RAN at each side of the cross-border corridor.
How to measure	<p>This KPI is obtained by the number successful handovers from the source gNB to the destination gNB, divided by the number attempted handovers to the same or another gNB.</p> <p>The KPI will be measured under different conditions (see Table 3).</p>

**Table 13: TE-KPI2.2-Application Level Handover Success Rate**

Title	TE-KPI2.2-Application Level Handover Success Rate
Description	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 <i>application level handovers</i> i.e., where service provisioning is correctly resumed/continued past the network level handover, from the new application instance.
Where to measure	UE/OBU and/or Application Server / MEC Hosts
How to measure	<p>On the UE side, the application level components will timestamp and log all successful communication interactions with the Application Server e.g., reception of requested video chunk/frame, response to application level request, etc. (subject to the specificities of the User Story). Similar timestamping and logging at both the source and destination Application Servers shall complete the full picture of events prior, during and post-handover. Logged information will include the identification of Application Server instance, as well as user identifiers. Additionally, control plane events related to session transfer processes shall be logged as well e.g., DNS updates. Synchronization between UEs/OBUs and Application Servers is required.</p> <p>The KPI will be measured under different conditions (see Table 3).</p>

**Table 14: TE-KPI2.3-Mobility interruption time**

<b>Title</b>	<b>TE-KPI2.3-Mobility interruption time</b>
<b>Description</b>	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.
<b>Where to measure</b>	UE (gNB)
<b>How to measure</b>	<p>Measurement shall be primarily contacted on the involved UEs, taking into account their local state with respect to their association to the network. gNB logging support can be used to cross-validate UE state transitions. This KPI requires the synchronization of UE and gNBs.</p> <p>The KPI will be measured under different conditions (see Table 3).</p>
<b>Comments</b>	This KPI is related to the evaluation of a series of handover/roaming telecommunication cross boarder issues as identified in D2.1, namely: TR1-NSA Roaming Latency, TR2-SA Roaming Latency, TR3-Hybrid Roaming Latency, TH1-Hybrid Handover Latency. TE-KPI2.3-Mobility interruption time, as specified here, aims to encompass all different types of latency i.e., roaming (switching between the two cross-border domains), handover (switching between base stations), as well as SA, NSA or hybrid, subject to the particular evaluation setup.

### 3.3. Use Cases and Preliminary Target KPI Values

The objective of the Technical Evaluation process is to assess the identified KPIs in the context of the targeted Use Case Categories and individual User Stories, as they have been defined in D2.1. As such, the assessment of the KPIs goes through the identification of target KPI values i.e., values that correspond to the target performance of the network, as this adheres to the requirements of the UCC/US. Table 15 below presents the identified Target Values for a series of Technical Evaluation KPIs. The provided values are aligned with earlier works and specifications in the automotive sector [9][10][7]. However, in several cases, more advanced user scenarios place more stringent requirements, especially in what concerns end-to-end latency i.e., traditional ITS applications usually target a 100ms latency threshold, while the advanced CCAM applications targeted by 5G-MOBIX lower the threshold in several cases to the range of 10 ms. The table includes entries for the KPIs where Target Values present differentiation across UCC/US and where identification of Target Values is feasible. We elaborate on the Target Values for the remainder of KPIs in

Table 16.

**Table 15: TE-KPI Target Values per Use Case Category / User Story (Part I)<sup>6</sup>**

	User Story	TE-KPI1.1 User experienced data rate (UL / DL)	TE- KPI1.3 E2E Latency	TE-KPI1.6 Reliability	TE-KPI1.7 Position Accuracy	TE-KPI2.3 Mobility Interruption Time	TE-KPI2.2 Application Level Handover Success Rate <sup>7</sup>
UCC-1: Advanced Driving	Complex manoeuvres in cross-border settings	0.2 / 0.2 Mbps	200 ms	99,9%	1 - 5 m	< 10 s	99-100%
	Infrastructure-assisted advanced driving	100 / 50 Mbps	5 - 20 ms	100.00%	0.1 m	< 5 s	N/A
	Cooperative Collision Avoidance	1 / 1 Mbps (10-20 Mbps for high resolution raw data DL)	< 10 ms	90-99.99%	0.2 m	< 1s	99-100%
	Cloud-assisted advanced driving	100 / 100 Mbps	20 - 50 ms	90-99.99%	0.2 m	< 10 s	N/A
UCC-2: Vehicles Platooning	Platooning with "see what I see" functionality in cross-border settings	100 / 50 Mbps	20 ms	99% – 99.999%	0.5 m	< 40 ms	99-100%
	eRSU-assisted platooning	200 / 100 Mbps	40 ms	100.00%	0.2 m	40 ms	N/A
	Cloud assisted platooning	100 / 100 Mbps	20 - 50 ms	90-99.99%	0.2 m	< 10 s	N/A
UCC-3: Extended Sensors	Extended sensors for assisted border crossing	100 / 200 Mbps	20 - 50 ms	100.00%	0.2 m	50 ms	N/A
	EDM-enabled extended	200 / 100 Mbps	40 ms	100.00%	0.2 m	40 ms	99-100%

<sup>6</sup> N/A stands for Non-Applicable.

<sup>7</sup> In the context of this particular KPI, the applicability of the KPI relates to the existence of Application level handovers, as defined in

Table 13. D2.1 provides an overview of the functionality in each UCC/US.

	User Story	TE-KPI1.1 User experienced data rate (UL / DL)	TE- KPI1.3 E2E Latency	TE-KPI1.6 Reliability	TE-KPI1.7 Position Accuracy	TE-KPI2.3 Mobility Interruption Time	TE-KPI2.2 Application Level Handover Success Rate <sup>7</sup>
	sensors with surround view generation						
	Extended sensors with redundant Edge processing	15 / 15 Mbps	100 ms	99.99%	N/A	10 - 80 ms	99-100%
	Extended sensors with CPM messages	10 / 10 - 20 / 20 Mbps	< 20 ms	90-99.99%	N/A	100 ms	99-100%
UCC-4: Remote Driving	Automated shuttle remote driving across borders	10 / 1 Mbps	100 - 200 ms	99,9%	1-5 m	< 10 s	N/A
	Remote driving in a redundant network environment	1 / 50 Mbps	80 ms	99% – 99.999%	N/A	5 - 20 ms	N/A
	Remote driving using 5G positioning	50 / 1 Mbps	5 - 50 ms	99.99%	0.1 m	< 1s	N/A
	Remote driving with data ownership focus	100 / 100 Mbps	20 - 50 ms	90-99.99%	0.2 m	< 10 s	N/A
	Remote driving using mmWave communication	200 / 1 Mbps	4 ms	100.00%	0.1 m	< 10 s	N/A
UCC-5: Vehicle QoS Support	Public transport with HD media services and video surveillance	4 / 8 Mbps	200 ms	99,9%	1 - 5 m	< 10 s	N/A
	QoS adaptation for Security Check in hybrid V2X environment	500 / 20 Mbps	15 - 20 ms	100.00%	0.1 m	< 5 s	N/A
	Tethering via Vehicle mmWave communication	N/A / 100 Mbps	N/A	99.90%	N/A	2 ms	N/A

**Table 16: TE-KPI Target Values per Use Case Category / User Story (Part II)**

TE-KPI1.2 Throughput (UL / DL)
<p>According to the definition provided in</p> <p>Table 4, this KPI refers to network layer data rates. The differentiation of values against <i>TE-KPI1.1 User experienced data rate</i> corresponds to the effect of higher protocol stack layers on top of network level performance, as is the case of the transport layer and the retransmissions due to errors/packet loss. In conditions of non-negligible transmission errors and loss, the data rate perceived at the application layer is expected to be lower than the data rate at the network layer (TE-KPI1.2) as the latter also includes data retransmissions. As transmission errors and loss are dynamic events subject to network conditions at measurement time, we refrain from expressing a target value, allowing TE-KPI1.1 to capture the required performance of the 5G network at the application layer. We nevertheless take TE-KPI1.2 into consideration in 5G-MOBIX overall evaluation framework as it will allow to capture the above difference during the evaluations.</p>
TE-KPI1.4/1.5 CP/UP Latency
<p>These KPIs aim to shed light on the constituent components of perceived E2E latency as this is originally perceived at the application layer i.e., <i>TE-KPI1.3 E2E Latency</i>. The inclusion of these KPIs in the overall Technical Evaluation KPI set is aimed to shed light on the contribution of Control and User Planes in the overall latency during evaluations. In the case of Control plane latency, 3GPP targets a value of 10 ms [1].</p> <p>According to [1], the target value for user plane latency should be 4ms for UL, and 4ms for DL, for eMBB, and 0.5ms for UL, and 0.5ms for DL, for URLLC. These are UCC/US-agnostic target values.</p>
TE-KPI1.8 Network Capacity (UL/DL)
<p>This KPI is inherently related to network dimensioning aspects, including radio planning, backhaul connectivity and inter-PLMN connectivity, subject to expected traffic load and geographic footprint of the network (see also Section 2.1.2). Target values are obviously subject to these aspects and orthogonal to the supported UCC/US. In any case, typical values for network capacity per cell, are often in the order of 1 Gbps.</p>
TE-KPI1.9 MTTR

This KPI is in principle aimed to capture the ability of the network operations to respond to service component failures. In the broader context of 5G, this is particularly related to the virtualization and programmability capabilities in network management and orchestration, able to support various approaches towards the mitigation of failure effects including, failsafe redundancy, where service downtimes can be in the order of a few only milliseconds, as well as re-active component restoration that can increase downtimes up to several seconds. Therefore, target values for this KPI can in principle substantially vary subject to the failure recovery mechanisms at hand. Since such mechanisms do not directly fall into the focus area of 5G-MOBIX, we refrain from identifying target values at this stage. We nevertheless include the TE-KPI1.9 as an important KPI contributing to the completeness of the overall Technical Evaluation Framework.

#### TE-KPI2.1 NG-RAN Handover Success Rate

Typically, high values are targeted for this KPI, approaching 100%. Such values are desired across UCC/US.



## 4. IMPACT ASSESSMENT RELATED METRICS

In the 5G-MOBIX context, there is a question on how project results affect cross-border mobility, traffic efficiency, safety and environmental issues, but also how businesses are being developed around the 5G-MOBIX ecosystem. As such, the impact analysis focuses on Quality of Life (QoL), Business impacts and CBA. The objective of the impact assessment is to assess the potential business and societal impacts of the systems and applications demonstrated in the cross-border corridors and trial sites. The metrics identified for impact assessment are structured under the following headings: 1) *Personal Mobility*, 2) *Traffic Efficiency*, 3) *Traffic Safety*, 4) *Environment* (reduction of pollution) and 5) *Business*. As it will be detailed in D5.1, the Impact Assessment methodology is considering the FESTA approach<sup>8</sup>, which provides an extensive set of recommendations for developing an experimental procedure for Field Operational Tests. The FESTA include several steps, which can be summarised as:

- Defining the study: Defining functions, use cases, research questions and hypotheses.
- Preparing the study: Determining performance indicators, study design, measures and sensors, and recruiting participants.
- Conducting the study: Collecting data.
- Analysing the data: Storing and processing the data, analysing the data, testing hypotheses, answering research questions.
- Determining the impact: Impact assessment and deployment scenarios, socio-economic cost benefits analysis.

However, 5G-MOBIX trials have defined their field operational test procedures, so it might be that all trials will not follow exactly FESTA approach. Still, in the impact assessment there are several applicable methodological linkages to FESTA. When the basic transportation infrastructure and services are functioning well and people have a choice in their means of travel, the quality of travel often becomes more important than the simple ability to get somewhere.

In the course of the project, and T5.3 in particular, impact assessment will be mostly realized as a qualitative analysis. Input will be collected mainly through interviews with end-users and stakeholders, and extensive literature search. The results will be quantified as input for the CBA. Additionally, T5.3 will perform an assessment of the proposed business models (WP6) to assess the costs and the benefits for the different stakeholders.

### 4.1. Personal Mobility metrics

In this section a metric relevant to the mobility impacts of the 5G-MOBIX project developments is detailed. Mobility impact assessment is closely related to user acceptance (Chapter 5). Mobility impact can be made

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<sup>8</sup> <http://fot-net.eu/Documents/festa-handbook-version-7>

mostly as a qualitative assessment to indicate in which areas of mobility there are impacts and whether the impacts are beneficial or not. The main question is what the impacts on personal mobility are, and which kind of cost benefits can be achieved with 5G-MOBIX technologies in personal mobility.

**Table 17: Impact Assessment: Personal Mobility metrics**

IA-M1.1-Increase/decrease of allocated time to travel
<p>Travel time may increase or decrease subject to the degree of automation achieved (SAE Level) and the associated service disruption in cross-border mobility environments. Values of travel time savings will be needed to assess the benefits of improved traffic flow due to the 5G-MOBIX demonstrated technologies. Values of this metric will be collected from trial sites by interviewing experts in trials. Measurements and data will be calculated to percentage time savings values.</p>

## 4.2. Traffic Efficiency metrics

In this section, the metrics that are relevant to the road traffic efficiency impacts of the 5G-MOBIX project developments are detailed.

**Table 18: Impact Assessment: Traffic Efficiency metrics**

IA-M2.1- Increase/decrease of traffic (transport) flow: speed
<p>Traffic efficiency increases when utilizing 5G-MOBIX solution compared to existing traffic, as speed increases and as standard deviation of speed decreases. This metric shall be assessed through GPS and accelerometer data generated by trials, where applicable (apart from questionnaire). Additionally, expert interviews will enhance view on the traffic flow improvement. Traffic flow speed will be turned to percentage improvement values.</p>
IA-M2.2- Increase/decrease of traffic (transport) flow: lane changing
<p>Traffic efficiency increases as lane changing decreases. Values of this KPI will be collected from trial sites by interviewing experts in trials. Amount of line changing will be turned to percentage values, when comparing traditional traffic flow and 5G-MOBIX traffic flow.</p>
IA-M2.3- Maneuver completion time

The total time it takes from when the examined manoeuvre is initiated until it has been completed. E.g. a lane merging manoeuvre can be completed within “x” seconds given certain car velocities, weather conditions, comfort aspects and safety requirements. This metric shall be assessed through data from the OBU and or Application Server, where applicable e.g., Automated Overtaking User Story (apart from questionnaire). Manoeuvre completion time will be compared to traditional driving and findings are turned to percentage values of time savings.

### 4.3. Traffic Safety metrics

In this section the metrics that are relevant to the road traffic safety impacts of the 5G-MOBIX project developments are detailed.

**Table 19: Impact Assessment: Traffic Safety metrics**

IA-M <sub>3.1</sub> -Decrease of automation level
<p>This metric aims to capture the cases where the driver took back control of the vehicle because of an unexpected safety issue. This is related to the comfort feeling of the driver. Objective aspects will be investigated e.g., automated driving Application Server/ OBU log data, in an effort to cross-validate the driver decision (where applicable). The expert interviews will be used to count the number of cases where the driver took back control of the vehicle.</p>
IA-M <sub>3.2</sub> -Collision incidents
<p>This metric aims to directly capture the cases where a collision was caused (or could have been caused if no manual corrective actions were undertaken) as a result of an AD application or network failure. Such events are obviously highly important and unwanted, so any occurrence shall be thoroughly assessed through means of both questionnaires and technical investigation e.g., Application Server, OBU logs, network node logs, etc.</p>
IA- M <sub>3.3</sub> – Time to collision
<p>Time to collision (TTC) is an important time-based safety indicator identified as the time for two vehicles to collide if they continue at their present speed and direction. It varies with the speed difference between two vehicles and is used to identify occurrences of dangerous situations. Based on studies [20], different thresholds of critical TTC values for different traffic situations have been identified, setting a TTC threshold of 1-2 seconds. The objective is to investigate the impact of cross-border mobility and potential service disruption to the associated metric values recorded during a/the handover event i.e., whether the</p>

likeliness of collision increases/decreases. This metric shall be assessed through data collected from the drone (overhead video), at key periods to apply traffic engineering methodologies using advanced video analytics.

#### IA- M3.4 – Post-Encroachment-time

When we have interactions between road users (either vehicles or vehicles and pedestrians) in a common area of potential collision, the post-encroachment-time metric captures the time difference between a vehicle/pedestrian leaving that area and a conflicting vehicle/pedestrian entering that same area. The objective is to investigate the impact of cross-border mobility and potential service disruption to the associated metric/KPI values recorded during a/the handover event i.e., whether the likeliness of collision increases/decreases. This metric shall be assessed through data collected from the drone (overhead video), at key periods to apply traffic engineering methodologies using advanced video analytics.

#### IA- M3.5 –Time Headway

This metric aims to directly capture the time, in seconds, between two successive vehicles as they pass a point on the roadway. It is aimed to allow us to compare results with the critical headway time which is the threshold between safe and unsafe driving. The Time Headway depends on many circumstances - speed, traffic conditions etc. but in general - in road traffic, the advice is to maintain a minimum distance of (2) two seconds to the vehicle in front [20]. This headway time is based on the reaction time of drivers under various circumstances, and has been seen to be sufficient for the majority of drivers to prevent a rear-end collision with the vehicle in front. The objective is to investigate the impact of cross-border mobility and potential service disruption to the associated metric/KPI values recorded during a/the handover event i.e., whether the likeliness of collision increases/decreases. This metric shall be assessed through data collected from the drone (overhead video), at key periods to apply traffic engineering methodologies using advanced video analytics.

## 4.4. Environmental metrics

This section presents the metrics that are relevant to the environmental impact of the 5G-MOBIX project.

**Table 20: Impact Assessment: Environmental metrics**

IA-M4.1- Vehicle Energy Consumption
<p>Focused on the average energy consumption reduction after the enablement of an automated function, and especially the support of the corresponding service continuity in cross-border mobility events. This metric shall be assessed through OBU/vehicle data regarding energy consumption (litres/100km or electric equivalent). Results will express the reduction of CO<sub>2</sub> emissions per 100 km. The reduction will be assessed against measurements with reduced automation e.g., manual driving. Improvements with 5G-MOBIX solution are expected to lead to an energy consumption decrease. Additionally, trial site experts will be interviewed for enriching views. Additional evaluations may be performed via means of simulation<sup>9</sup>.</p>

## 4.5. Business metrics

This section presents the metrics that are relevant to the assessment of business impact of the 5G-MOBIX project. Business metrics aim to view the business ecosystem view on 5G-MOBIX, how different businesses are being developed and how different stakeholders are doing business together in the future.

**Table 21: Impact Assessment: Business metrics**

IA-M5.1 - Cost benefits in mobility
<p>Cost benefits to road users, mainly related to time savings, operating cost savings and reliability gains that 5G based cross-border operations can bring. Cost savings are estimated in each trial / use case. Savings in time of the travel (IA-M1.1) can contribute to generated cost benefits, which will be analysed based on this metric. Metric values will be further elaborated in the context of WP5.</p>
IA-M5.2 - Costs to government building infrastructure
<p>Costs to operators and government infrastructure investments will be estimated, in implementation of 5G cross-border mobility systems. 5G connectivity infrastructure in roads should be developed before practical 5G-MOBIX realization. Infrastructure costs will be analysed as a part of cost-benefit studies in T5.3. KPI values will be further elaborated by trial site experts, and consortium partners in the context of WP5. This KPI will be used for the analysis of Cost-Benefit-Analysis of 5G-MOBIX technologies implementation.</p>

<sup>9</sup> Details on simulation-based investigations will be provided in "D5.1 – Evaluation methodology and plan" (M16)

#### **IA-M5.3- Revenue to operators**

There may be multiple operators, including infrastructure and service operators; each will want to know the impact on themselves (financial), although for the social CBA these revenues may be aggregated. Revenue for main stakeholders will be estimated in the context of WP6. WP6 business models and cost structures will give input to this analysis of potential new revenue models.

#### **IA-M5.4- Environmental cost benefits**

Estimation of environmental cost benefits, that 5G cross border operations can bring. Cost benefits can include costs related to climate change, regional and local air quality effects; noise; and other impacts, where developed solutions will have implications.

#### **IA-M5.5 -Amount of new solutions, technologies and products to be entering the market**

This KPI measures the amount of developed technologies in 5G-MOBIX, which can be entering the market. In other words, this KPI identifies the amount of mature technologies that can be commercialized during or right after the project. WP6 will provide information for the assessment of this KPI.

#### **IA-M5.6-Adoption of new business models**

5G-MOBIX is demonstrating different technologies for cross-border mobility and several technologies are aimed to enter the market (see previous KPI). This KPI is for identifying how many new business models will be defined and adopted for automated mobility. This KPI will be assessed though the work to be delivered in the context of T6.2.

#### **IA-M5.7- Business cases maturity**

Based on the previous KPI, the maturity of the business cases will be analysed by interviewing trial site experts and business experts in consortium. Here, the maturity of the business will be estimated. It is critical to identify commercialization roles around the business model.

## 5. USER ACCEPTANCE RELATED METRICS

In the scope of the user acceptance evaluation activities, we consider as end-users the stakeholders that have direct interaction with the HMI systems, either as a vehicle occupant or as an operator at one end of the system – such as it is the case of border patrol (in the Greek-Turkish corridor) or vehicle remote operators (in the Spanish-Portuguese corridor).

The metrics presented in this section are divided into four different categories. The first one refers to metrics of technology acceptability and is based mostly on the work of Venkatesh and colleagues [23]. The second one refers to measures of trust and perceived safety, which are of an essence when referring to use-cases of Connected and Automated Vehicles. The third refers to the system usability as measured by observation of the interaction, which is an indicator of acceptability. The last one refers to the ability of the system to deal with user error and misuse.

### 5.1. General Technology Acceptability metrics

Table 22: User Acceptance: General Technology Acceptability metrics

UA-M1.1: Acceptance (Intention statement of interest)
A psychometric scale rating of the acceptance intention (acceptability) regarding the evaluated use-case. Acceptability is defined as the “prospective judgment” made by the potential users regarding their adoption of the system or technology [22].
UA-M1.2: Perceived Technology Usefulness
A psychometric scale rating of the perceived technology usefulness regarding the evaluated use-case. The <i>perceived technology usefulness</i> is defined as the extent to which the respondent believes that the service/technology will facilitate his/her achievement of a task/goal at hand [25].
UA-M1.3: Perceived Technology Ease-of-use
A psychometric scale rating of the perceived ease-of-use regarding the evaluated use-case. The <i>perceived ease-of-use</i> is defined as the extent to which the respondent believes that the service/technology is easy to use [23].
UA-M1.4: Affinity for Technology Interaction

A psychometric scale rating of the user's general ability for interacting with technological artefacts. Several researchers point this factor as relevant in understanding user acceptance. This metric will employ the *Affinity for Technology Interaction (ATI) Scale* [12].

#### **UA-M 1.5: Acceptability difference between prior and post-contact with technology**

For the test subjects that interact with the technology, the variation in terms of acceptance intention, perceived usefulness and perceived ease-of-use between before (prospective evaluation) and after (retrospective evaluation) contact with the technology. The evaluation of this metric will focus on the comparison of the scores of metrics UA-M1.1, UA-M1.2 and UA-M1.3 prior and after contact with the technology.

## **5.2. Trust on the System metrics**

**Table 23: User Acceptance: Trust on the System metrics**

#### **UA-M2.1: Perceived Safety**

A psychometric scale rating of the perceived safety of the system evaluated in the user-story. Perceived safety is a construct defined as the extent to which an individual believes using the system will carry some risk to his safety [18].

#### **UA-M2.2: Perceived Trust**

A psychometric scale rating of the perceived trust on the system evaluated in the user-story. Perceived trust is a construct that defines the extent to which the individual believes that the system/technology will assist him in achieving a goal even in uncertain and vulnerable situations [18].

## **5.3. Systems Usability metrics**

The metrics in this Section are correlated with the metrics in Section 4.3. While in the latter the metrics are the focus, here we focus on the user acceptance point of view.



**Table 24: User Acceptance: Systems Usability metrics**

UA-M <sub>3.1</sub> : General usability metric
<p>For the test subjects that interact with the technology, a psychometric scale score of the system's perceived usability. This metric will employ the System Usability Scale (SUS) [8]. This is ten items scale with questions such as:</p> <ul style="list-style-type: none"> <li>• "I think that I would like to use this system frequently".</li> <li>• "I found the system unnecessarily complex".</li> </ul>
UA-M <sub>3.2</sub> : Effectiveness
<p>For the test subjects that interact with the technology, a score of the system's effectiveness (level of success) in handling the human-machine interaction. This metric will be assessed based on:</p> <ul style="list-style-type: none"> <li>(i) Percentage of sub-tasks (within each task) achieved.</li> <li>(ii) Percentage of users successfully completing task.</li> </ul> <p>This metric shall be assessed through means of Observation (Video) and System's event log data, where applicable (apart from questionnaire). The goals will be defined per use case, based on the human-machine interactions that are expected to be conducted. The contribution of each metric to the final overall score will be determined based on system analysis by experts.</p>
UA-M <sub>3.3</sub> : Efficiency
<p>For the test subjects that interact with the technology, a score of the system's performance level in handling the human-machine interaction will be assessed on the basis of the following (second-level) metrics:</p> <ul style="list-style-type: none"> <li>(i) Time to complete task.</li> <li>(ii) Number of instances where the driver must take manual control / 1000 km or miles[13]<sup>10</sup>.</li> <li>(iii) Psychometric scale for Mental Workload – using the Nasa TLX questionnaire[13].</li> </ul> <p>Values shall be assessed through means of Observation (Video) / System's event log data, where applicable (apart from questionnaire). The contribution of each metric to the final overall score will be determined based on system analysis by experts.</p>

<sup>10</sup> This aspect will be captured by IA-M<sub>3.1</sub> (see Section 4.3).

#### UA-M3.4: Satisfaction

For the test subjects that interact with the technology, a score of their satisfaction in their interaction with the technology. This will be assessed on the basis of the following (second-level) metrics:

- (i) Psychometric scale for satisfaction – using the After-Scenario Questionnaire (ASQ) [19].
- (ii) Frequency of complaints (10% or less dissatisfaction).
- (iii) Number of instances where the car did not do what the driver expected the car to do based on the L3 system.
- (iv) Psychometric scale for the feeling of frustration using NASA\_TLX [13].

Values shall be assessed through means of Observation (Video) / System's event log data, where applicable (apart from questionnaire). The contribution of each metric to the final overall score will be determined based on system analysis by experts.

### 5.4. Error tolerance metrics

This section lists KPIs to evaluate the system's ability to deal with user error and misuse. These will be applicable for user-stories that imply interaction between users and HMI.

**Table 25: User Acceptance: Trust on the System metrics**

#### UA-M4.1: Error dealing effectiveness

For the test subjects that interact with the technology, a score of the system's effectiveness to deal with user errors. This will be assessed on the basis of the following (second-level) metrics:

- (i) Percentage of errors corrected or reported by the system.
- (ii) Percentage of user errors tolerated.

This metric shall be assessed through means of Observation (Video) / System's event log data, where applicable (apart from questionnaire). The contribution of each metric to the final overall score will be determined based on system analysis by experts.

#### UA-M4.2: Error dealing efficiency

For the test subjects that interact with the technology, the percentage of time spent on correcting interaction errors. This metric shall be assessed through means of Observation (Video), where applicable.

#### UA-M4.3: Error dealing satisfaction

For the test subjects that interact with the technology, a psychometric scale rating of their satisfaction with the system's ability in dealing with user errors [15].

## 6. CONCLUSIONS

This document (D2.5) provides an extended set of KPIs and metrics that will be considered for evaluation and analysis of the 5G-MOBIX solutions and corresponding UCC/US. The proposed KPI/metric set is extensive enough to facilitate the involved 5G technology and all the UCC/US defined in D2.1. D2.5 pays particular attention to mobility related aspects, further identifying application agnostic KPIs aimed to capture the effects of (cross-border) mobility on user perceived performance. While it puts emphasis on purely technical KPIs, the deliverable also includes metrics for the support of user acceptance and impact assessment related evaluation activities. The deliverable further identifies key aspects in KPI assessment, including the importance of system events, states and transitions, as well as network dimensioning. The KPI/metric set that will be considered for the actual evaluation stage of the project (as well as their target values) will be finalized by the corresponding partners based on the implementation plans at each test site and will be reported in *D5.1 "Evaluation methodology and plan"*, including a fine grained description of the overall performance evaluation methodology.

## REFERENCES

- [1] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Scenarios and Requirements for Next Generation Access Technologies;(Release 15), 3GPP TR 38.913 V15.0.0 (2018-06)
- [2] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration; 5G end to end Key Performance Indicators (KPI) (Release 16), 3GPP TS 28.554 V16.1.0 (2019-06)
- [3] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration;5G performance measurements (Release 15), 3GPP TS 28.552 V15.1.0 (2018-12)
- [4] 5GAA P-180092: V2X Functional and Performance Test Procedures – Selected Assessment of Device to Device Communication Aspects (2018-05)
- [5] 5G PPP Architecture Working Group, "View on 5G Architecture," Version 3.0, June 2019
- [6] 5G PPP Phase II KPIs – Annex to Programme Management Report
- [7] 5G-PPP White Paper on Automotive Vertical Sector, October 2015
- [8] Brooke, John. "SUS-A quick and dirty usability scale." Usability evaluation in industry 189.194 (1996): 4-7.
- [9] ETSI TR 102 638 V1.1.1 (2009-06) Technical Report Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions
- [10] ETSI TS 101 539-1 V1.1.1 (2013-08) Intelligent Transport Systems (ITS); V2X Applications; Part 1: Road Hazard Signalling (RHS) application requirements specification
- [11] Euro-5g – Supporting the European 5G Initiative, D2.6 Final report on programme progress and KPIs, 2017
- [12] Franke, Thomas; Attig, Christiane; Wessel, Daniel (2019): A Personal Resource for Technology Interaction: Development and Validation of the Affinity for Technology Interaction (ATI) Scale. In International Journal of Human–Computer Interaction 35 (6), pp. 456–467. DOI: 10.1080/10447318.2018.1456150.
- [13] Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In Advances in psychology (Vol. 52, pp. 139-183). North-Holland.
- [14] Innamaa, Satu; Salla, Kuisma (2018): Key performance indicators for assessing the impacts of automation in road transportation: Results of the Trilateral key performance indicator survey. VTT.
- [15] I. O. for Standardization, "Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems," 2010.
- [16] ITU-R, Minimum requirements related to technical performance for IMT-2020 radio interface(s), M Series Mobile, radio determination, amateur and related satellite services, Report ITU-R M.2410-0 (11/2017)
- [17] Kline, P. (2000). Handbook of psychological testing (2nd ed.). London, England: Routledge

- [18] Lee, J.D., See, K.A., 2004. Trust in automation: designing for appropriate reliance. *Hum. Factors* 46 (1), 50
- [19] Lewis, James R. "Psychometric evaluation of an after-scenario questionnaire for computer usability studies: the ASQ." *ACM Sigchi Bulletin* 23.1 (1991): 78-81.
- [20] Mahmud, S. M. S., Ferreira, L., Hoque, S., & Tavassoli, A. (2017). Application of proximal surrogate indicators for safety evaluation: A review of recent developments and research needs. *IATSS Research*, 41(4), 153–163.
- [21] Sauro, J., & Kindlund, E. (2005, April). A method to standardize usability metrics into a single score. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 2005.
- [22] Schade, J., and Schlag, B. (2003). Acceptability of urban transport pricing strategies. *Transportation Research Part F: Traffic Psychology and Behaviour*, 6(1), 45-61.
- [23] Venkatesh, Viswanath; Bala, Hillol (2008): Technology Acceptance Model 3 and a Research Agenda on Interventions. In *Decision Sciences* 39 (2), pp. 273–315. DOI: 10.1111/j.1540-5915.2008.00192.x
- [24] Venkatesh; Morris; Davis (2003): User Acceptance of Information Technology: Toward a Unified View. In *MIS Quarterly* 27 (3), p. 425. DOI: 10.2307/30036540.
- [25] Young, K. L., Regan, M. A., Misopoulos, E., & Haworth, N. (2003). Acceptability of in-vehicle intelligent transport systems to young novice drivers in New South Wales. Victoria: Monash University.