ENVELOPE

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

Project deliverable D2.3

ENVELOPE availability and cooperation enablers definition and evaluation data specifications

HORIZON JU Innovation Actions | 101139048 |
ENVELOPE - HORIZON-JU-SNS-2023

Co-funded by the European Union

6GSNS

Deliverable administrative information

Dissemination level	**PU - Public**
Type of deliverable	R — Document, report
Work package	WP2
Title of the deliverable	D2.3 - ENVELOPE availability and cooperation enablers definition
Status – version, date	Draft – V1, 03/10/2024
Deliverable leader	VICOM
Contractual date of delivery	31/12/2024
Submission date	23/12/2024
Keywords	KPI, KVI, metrics

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Submission	Konstantinos Katsaros	ICCS	23/12/2024

Version History

Version	Date	Author	Summary of changes
0.1	19/09/2024	Jon Ander Iñiguez de Gordoa	ToC Proposal
0.2	09/12/2024	Gorka Vélez Jon Ander Iñiguez de Gordoa	Consolidation of contributions
0.3	17/12/2024	Gergely Kovács András Edelmayer Harilaos Koumaras	Consolidated version with reviewers' comments and suggested changes

		Vasilis Pitsilis	
0.4	20/12/2024	Jon Ander Iñiguez de Gordoa	Final revisions based on reviewers' comments

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Project executive summary

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

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

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

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

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

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Deliverable executive summary

This deliverable outlines the definition and evaluation of the availability and cooperation enablers within the ENVELOPE project, with a focus on establishing Key Performance Indicators (KPIs) and Key Value Indicators (KVIs) as metrics to assess the project's technical performance and impact on societal, environmental, and economic areas. These indicators enable assessing the success of ENVELOPE’s use cases, offering measurable data and meaningful insights into their performance and impact.

KPIs are categorized by technical metrics such as network capacity, latency, operational performance and security, ensuring a comprehensive analysis of system functionality. On the other hand, KVIs focus on the societal, environmental, and economic impact of the developed technologies. Each use case is mapped to specific indicators, addressing critical aspects of performance and impact. The methodology to define these indicators is based on established frameworks, including 5G-PPP White Papers as well as other ongoing SNS projects, ensuring reliability and alignment with industry standards. Data collection methods are also detailed, combining experimentation results, user surveys and expert evaluations, ensuring reliable and targeted insights.

This deliverable serves as a key reference for the evaluation activities planned in WP6, providing a structured approach to assess the performance and impact of the ENVELOPE project. The defined KPIs and KVIs will guide the evaluation of technical performance and societal, environmental, and economic impacts, ensuring a comprehensive understanding of the project's advancements in network capabilities and their role in enabling connected and automated mobility.

The KPIs and KVIs presented in this document are the modified and finalized version of the initial set of project objectives described in the ENVELOPE Deliverable *D1.3 Innovation management plan.*

List of abbreviations and acronyms

Acronym	Meaning
ADAS	Advanced Driver Assistance Systems
ASAP	As Soon As Possible
AV	Autonomous Vehicle
CCAM	Connected, Cooperative and Automated Mobility
E2E	End-to-end
EC	European Commission
ECU	Electronic Control Unit
GA	Grant Agreement
KPI	Key Performance Indicator
KV	Key Value
KVI	Key Value Indicator
OBU	On Board Unit
OWAMP	One-Way Active Measurement Protocol
QoS	Quality of Service
RSU	Road Side Unit
SDG	Sustainable Development Goal
SNS JU	Smart Networks and Services Joint Undertaking
UE	User Equipment
WP	Work Package

1 Introduction

1.1 Purpose of the deliverable

The present deliverable, developed as part of Task 2.3, reports on the work carried out within this task for establishing the framework for the evaluation of the components/techniques/innovations and UCs developed in ENVELOPE. Building upon the results of the first two WP2 tasks, provides the definition of suitable evaluation criteria for the technologies that will be developed within each UC and ensures their effectiveness and alignment with the overall ENVELOPE objectives.

The main concern of the deliverable is to define a robust methodology for identifying Key Performance Indicators (KPIs) and Key Value Indicators (KVIs). Based on this methodology, it provides the actual KPIs and KVIs that will serve as metrics to assess the performance of the ENVELOPE use cases. Additionally, this document describes the process for collecting evaluation data during testing activities and explains how this data will contribute to defining and producing the KPIs and KVIs, a key aspect of the overall evaluation process.

The metrics identified and outlined in this document provide a structured framework for assessing the robustness and effectiveness of the developed architecture and its alignment with the identified use case requirements. By defining and presenting KPIs and KVIs, this deliverable ensures that the evaluation process is grounded in measurable, meaningful metrics that reflect both technical performance and value-driven objectives.

This document, by providing the actual KPIs and KVIs which can ensure that WP2 outcomes are measurable and aligned with project objectives and use case requirements, will serve as a reference for the evaluation activities planned in WP6. Deliverable D6.1, titled "ENVELOPE Evaluation Methodology", will use this document as a reference framework, maintaining the defined terminology and KPI/KVI identifiers in order to ensure traceability throughout the design, development and evaluation stages.

1.2 Intended audience

This deliverable is classified as "public" (PU) and is primarily designed to serve as a reference for ENVELOPE Consortium Members throughout the evaluation phases of the project. It is also available to any interested reader who wishes to learn about ENVELOPE's evaluation methodology.

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

This document is structured as follows:

- Section 1 provides an outline of the document.
- Section 2 presents the approach of the ENVELOPE project to define KPIs and KVIs, as well as the planned method for the evaluation data collection.

- Section 3 presents the technical KPIs for each use case, categorized by use case-specific objectives.
- Section 4 defines the Key Value Indicators (KVIs) for each use case, focusing on metrics related to societal, environmental and economic outcomes.
- Section 5 concludes with key insights.
- Section 6 provides a list of references for the document.

This deliverable serves as a key input for task T6.1 “Evaluation methodology and plan”, and deliverable D6.1 “ENVELOPE evaluation methodology”. The broad set of KPIs and KVIs outlined in this document provided a comprehensive framework to evaluate the ENVELOPE use cases, covering technical performance as well as societal, environmental and economic outcomes. The KPIs and KVIs presented in this document are the modified and finalized version of the initial set of project objectives described in the ENVELOPE Deliverable *D1.3 Innovation management plan.*

2 Availability and cooperation enablers (KPIs and KVIs) definition and evaluation data specification

ENVELOPE considers connectivity and cooperation to be key enablers for CCAM. For this purpose, Key Performance Indicators (KPIs) for connectivity and cooperation (e.g. latency, reliability, data rate, security) are defined. In addition, Key Value Indicators are defined to assess the positive impact of the use cases in the society, environment and economy. This section explains ENVELOPE's approaches for KPI and KVI definition as well as the planned approach for evaluation data collection.

2.1 KPI definition methodology

2.1.1 Related work

A Key Performance Indicator (KPI) is a quantifiable metric used to evaluate the performance and success of a particular process or system in achieving its objectives. In the context of the ENVELOPE project, KPIs are essential for assessing the technical performance of the use cases, ensuring that they meet predefined goals. To ensure the KPIs are effective and relevant, they must be Specific, Measurable, Attainable, Relevant and Time-bound (SMART) [1]:

- **Specific:** The KPI must be clearly defined, focusing on a specific aspect of performance.
- **Measurable:** It must be quantifiable, allowing for objective measurement.
- **Attainable:** The KPI should be realistic and achievable within the scope of the project.
- **Relevant:** The KPI must be aligned with the objectives of the project and have meaningful implications for its success.
- **Time-bound:** The KPI should be measured over a defined period of time.

To enhance the clarity and effectiveness of the KPI analysis within the ENVELOPE project, KPIs have been classified into specific categories. These categories are useful to ensure a structured approach in the evaluation of the technical performance within the project. The following categories are used in the ENVELOPE project:

1. **Capacity KPIs** refer to metrics that are used to evaluate the amount of network resources provided to end-users.
2. **Latency KPIs** focus on the measurement of time delays within the systems.
3. **Operational KPIs** measure the overall efficiency and functionality of the system, including service reliability and packet loss rate.
4. **Compute KPIs** assess the computational efficiency and resource utilization across the network domains.
5. **Security KPIs** measure compliance with security and privacy standards or regulations, ensuring the system's robustness against threats and maintaining the security and integrity of user data.

These KPI categories are derived from the following 5G-PPP White Papers, which provide a detailed framework for the definition and measurement of KPIs in the context of 5G and 6G networks:

- The 5G-PPP White Paper: "Beyond 5G/6G KPI Measurements" [2] highlights key KPI categories relevant to 5G and beyond technologies. These categories have served as a foundation for the classification framework employed in the ENVELOPE project.
- The 5G-PPP White Paper "5G PPP Trials Results 2022 – Key Performance Indicators measured in advanced 5G Trial Sites" [3] presents detailed target values for KPIs, which have been used as a reference to set realistic and achievable performance benchmarks for the ENVELOPE project. When target values for certain KPIs in the ENVELOPE project were not available in this White Paper, ENVELOPE based these target values on other 5GAA or 3GPP documents, previous 5G-PPP or SNS JU projects, or scientific literature.
- The 5G-PPP White Paper "KPIs Measurement Tools - From KPI definition to KPI validation enablement" [4] focused on the tools and methods for KPI validation, which will be crucial when assessing the performance of the ENVELOPE system.
- The 5G-PPP White Paper "Beyond 5G/6G KPIs and Target Values" [5] establishes standardized KPI definitions for network performance.

The definition of KPI frameworks in other European projects has provided a valuable baseline in this field. Deliverables such as 5G-MOBIX's D2.5 "Initial evaluation KPIs and metrics" [2], 5G-IANA's D5.1 "Initial validation KPIs and metrics" [3], and PoDIUM's D2.3 "Availability and cooperation enablers definition and evaluation data specification" [4] have been extensively studied to inform and guide this work.

2.1.2 Proposed approach

Having reviewed existing KPI frameworks from other European projects, as mentioned in Section 2.1.1, ENVELOPE developed a KPI definition template inspired by these frameworks and introduced methodologies. The customized KPI definition template for ENVELOPE is shown in Table 1.

Table 1: Technical evaluation KPI definition template

KPI identifier	Unique identifier for each KPI: KPI_x_y-ShortTitle x: Technical Evaluation sub-category abbreviation: • Use Case x: UCx y: KPI index within sub-category Examples: KPI_UC1_3-Reliability, KPI_UC2_1-Latency.
Description	High-level description of KPI
Where to observe/measure/monitor	Network Layer/segments where this KPI refers to. Answers shall include information on: (1) Layers: Infrastructure, 3GPP network functions, Orchestration, Application, AI layer etc. (2) 5G Segments: RAN, Transport, Core, Edge, Far/ Extreme Edge, OR (3) Between Segments: e.g. From RAN to Core, From UE to Edge etc. Infrastructure Segments: Edge Cloud, Core Cloud etc.
How to observe/measure/monitor	A high-level description of the measurement method, including (where applicable): • Key (functional) requirements for the measurements e.g., endpoint synchronization, background, traffic generation (if any), etc. • Specific measurement tools planned to be used.

How to Evaluate	Definition of comparison approach i.e., what values the measured KPI data points are compared against. This must include Target Values or results retrieved by identified alternative setups/experiments.

The proposed definition of a set of KPIs, all based on the provided template, is intended to establish a structured and consistent approach to evaluate the performance of ENVELOPE technological developments. The provisioned template ensures that all KPIs are systematically defined, with clear metrics, measurable thresholds, and also align to the specific objectives of the ENVELOPE use cases.

The adoption of this templated approach, within ENVELOPE, ensures that performance evaluation is both standardized and transparent, enabling the effective comparison and benchmarking of results across different tasks and use cases. The structured format of the KPI definitions also facilitates the clear identification of technical achievements, the quantification of results, and the validation of whether the project is meeting its performance-related objectives.

Moreover, the use of a unified template supports the traceability of KPIs throughout the lifecycle of the project. This ensures that all stakeholders, from design to evaluation stages, have a cohesive framework for assessing progress and outcomes. By providing a well-defined, performance-focused evaluation framework, the KPIs play a critical role in validating the success of the ENVELOPE's goals and offering measurable proof of its contributions to advancing 6G technologies.

2.2 KVI definition methodology

2.2.1 Related work

A **Key Value**, as defined in [6], is a selection of values agreed upon by stakeholders. This selection of values determines the set "values as criteria" (human values or principles that guide technological development goals) and "values as outcomes" (the actual results or impacts, whether benefits or detriments, that arise from the implementation of the technology), which are considered in a value analysis.

On the other hand, **Key Value Indicators** (KVIs), also as defined in [6], are quantitative or qualitative indicators used to assess the effects on values as outcomes. The purpose of KVIs is to evaluate the impact of a use case in terms of economic, social and/or ecological gains or losses. KVIs are defined within the scope of a specific use case and scenario, and can be measured on either a qualitative or, when applicable, quantitative scale. To measure KVI outcomes effectively, it is necessary to introduce the technology into the market so that both the impact on the societal value and the influence of these measures on technology can be captured. During the lifetime of a project, such as in ENVELOPE, KVI assessments can be done through expert assessments, simulations and Digital Twins.

The 6G-IA White Paper "What societal values will 6G address? Societal Key Values and Key Value Indicators analysed through 6G use cases" categorises KVIs into three main areas: environmental, societal and economic sustainability [7]. These three areas cover all the 17 Sustainability Development Goals (SDG) established by the United Nations (UN) as part of the 2030 Agenda for Sustainable Development [8]:

- **Environmental** sustainability focuses on the impact of the evaluated technologies on the environment (e.g. CO_2 emissions).
- **Societal** sustainability analyses the benefits of such technologies for society, such as improved emergency response times or increased operational efficiency in remote areas.
- **Economic** sustainability examines the economic implications of these technologies, including cost-efficiency in different sectors and the economic benefits of enabling new business models and services.

Classifying KVIs into these three categories is a common practice in several SNS projects, as confirmed in the “SNS Stream B/D Projects Workshop on KPIs and KVIs” webinar [9]. In most of these projects, KVIs are associated with use cases rather than the platform or architecture of the project, as it appears easier to identify KVIs related to specific use cases. Additionally, the SNS JU Test, Measurement and KPIs Validation Working Group has developed a common template to define KVIs, which has been adopted by other SNS projects.

2.2.2 Proposed approach

The KVI definition methodology in the ENVELOPE project addresses three KVI categories: societal, environmental and economic KVIs. These three KVI categories group the 17 SDGs goals defined by the UN. The 6G-IA White Paper suggests this categorization, which is also widely adopted by ongoing SNS projects, as noted in Section 2.2.1. Each Use Case (UC) in the ENVELOPE project addresses at least one KVI from each category, ensuring a comprehensive coverage of societal, environmental and economic aspects.

As noted in Section 2.2.1, the SNS JU Test, Measurement and KPIs Validation Working Group has created a standardized template to define KVIs in ongoing SNS projects. The ENVELOPE project has adopted this template to define its KVIs in this deliverable. The KVI definition template for ENVELOPE is presented in Table 2.

Table 2: KVI definition template

KVI identifier	Unique identifier for each KVI: KVI_x_y-ShortTitle x: Sub-category abbreviation: • Use Case x: UCx y: KVI index within sub-category Examples: KVI_UC1_3-WasteReduction, KVI_UC2_1-IncreasedAccessibility.
Key Value	The specific value or benefit that the KVI aims to assess.
Description of KVI	High-level description of KVI.
Technology enablers	The specific technologies developed in the project which enable the achievement of the KVI.
Validation method	The approach or method used to validate the KVI. This validation can be done by: • Measurements in trials, experiments or simulations • Questionnaires, user surveys or interviews • Assessment by experts
Target Value	The expected outcome for the KVI. This target value can be either qualitative or quantitative.

The definition of a set of KVIs, all based on the above provided template, is intended to establish a framework that incorporates societal value concerns into the technology development process. This approach complements the performance-based evaluation of ENVELOPE technologies with the use of a set of KPIs, as explained in section 2.1.2, with a cohesive, value-driven perspective, ensuring that societal impacts are major project concern alongside technical performance goals.

2.3 Collection of evaluation data

2.3.1 Measurements from experimentation or simulations

In order to assess every KPI defined for the ENVELOPE project, as well as some KVIs, measurements need to be conducted on each use case. These measurements can be carried out during live experimentations or through simulations when real-world data collection is not feasible. The measurements should be designed to ensure accurate and reliable data to evaluate the performance of the ENVELOPE use cases.

The measurement process follows a structured methodology, which will be detailed in deliverable D6.1 “ENVELOPE Evaluation Methodology”. While this methodology is out of scope for the current deliverable, a brief overview is provided here. The first step is to design the evaluation scenarios or tests cases for each use case. These scenarios will cover both typical and edge-case conditions to ensure a comprehensive assessment under diverse operational settings. Once the scenarios are defined, the necessary network and infrastructure components, along with measurement tools, are configured. This step might involve deploying the architecture of each use case, establishing network connections between nodes and devices, and synchronizing time across all components. Following this, the scenarios are executed, capturing relevant data across the architecture.

The measurements are conducted across different network layers and segments, including the application layer, the management layer or the orchestration layer. Data logging occurs at different levels, ranging from local logging on devices (e.g., OBUs or RSUs) to edge-level logging and cloud-based logging, depending on where the data is generated and stored.

Domain specific, widely adopted and validated, measurement tools and a systematic methodology are employed to ensure the accuracy and reliability of the data. For instance, network performance measurement tools based on a client-server model, such as iPerf, are used to measure data rates and packet loss. Latency measurements are performed using tools like One-Way Active Measurement Protocol (OWAMP), ensuring that the UE and Edge are time synchronized. For assessing service and slice setup delays, timestamps are logged from the moment a service or slice activation request is initiated to the point of completion. End-to-end application latency is measured by time-tagging data at both the source and destination applications, with synchronized clocks ensuring the accuracy of latency calculations.

This comprehensive approach ensures that the technical performance and impact of the ENVELOPE use cases are properly assessed. The methodologies and tools used are designed to capture a wide range of metrics, ensuring that the KPIs and KVIs are accurately and reliably assessed.

2.3.2 User surveys

Some KVIs, particularly those that capture subjective or societal impacts, may require the collection of data which can only be provided through user surveys, questionnaires or interviews. This method is essential when evaluating indicators of a subjective nature such as user satisfaction, perceived safety or societal acceptance.

These surveys should be designed to ensure they capture relevant and reliable data. This involves creating well-structured questionnaires or conducting interviews and focus groups adjusted to the KVI being evaluated. The questions should be concise, unbiased, and targeted to gather insightful and relevant responses. To provide a comprehensive understanding, both quantitative metrics (e.g., ratings or scores) and qualitative feedback (e.g., open-ended questions) are often employed.

The effectiveness of user surveys largely depends on engaging the right participants. Therefore, it is essential to identify and involve stakeholders affected by the technology or service being evaluated. A diverse survey sample is necessary to ensure inclusive and representative results by considering factors such as demographic differences, regional contexts, and roles in using, managing or being impacted by the evaluated technology or service.

Surveys should be deployed to maximize response rates and data quality. Depending on the evaluation context, surveys can be conducted during controlled experiments, live tests or post-simulations. Digital platforms may be useful due to their convenience and scalability, especially for remote participants, while in-person methods work well for detailed feedback and engagement. Participants should be given clear instructions on how to complete the surveys, and ethical considerations, including informed consent and data privacy, must be maintained throughout the process.

Collected data must be analysed to identify trends and understand user perceptions. Quantitative responses are aggregated in order to identify trends and patterns, while qualitative feedback provides deeper insights. Together, these findings offer a complete evaluation of the system from a user-centered perspective.

2.3.3 Expert assessment

In some cases, KVIs cannot be assessed directly through experimentation or user surveys because the technical enablers have low Technology Readiness Levels (TRL). In other cases, the solution is commercialised but the market penetration is too low to assess the impact on society, environment or economy. When a Key Value Indicator (KVI) cannot be measured directly, experts can assess it through indirect methods and informed estimations. Here are some strategies being considered in ENVELOPE:

- Delphi Method: the Delphi Method is a structured approach where experts independently provide input in multiple rounds, refining their responses based on feedback, which can lead to more reliable assessments.
- Comparison with analogous cases: by identifying technologies or projects with functions, users, or objectives similar to those of the target solution, experts can examine the performance of these "analogous" cases on comparable metrics.
- Deductive reasoning: Deductive reasoning can be valuable for assessing non-measurable Key Value Indicators (KVIs) by logically deriving conclusions based on known principles,

assumptions, and established theories. Through this process, experts can draw reasoned inferences about a KVI's performance or value, even in the absence of direct empirical data.

3 Key Performance Indicators

This section defines the Key Performance Indicators (KPIs) established for the ENVELOPE project in order to evaluate the technical performance and efficiency of the developed technologies. These indicators enable the assessment of the technical aspects of the project, ensuring that the technological solutions meet the desired standards and objectives.

The KPIs are categorized based on their relevance to different technical aspects of the project, including network capacity, latency, operational performance, security and computational efficiency. Each Use Case (UC) within the ENVELOPE project addresses specific KPIs that are critical to its success, ensuring a comprehensive evaluation of the technical performance across key areas.

The following subsections provide detailed definitions and descriptions of the KPIs associated with each Use Case. A summary of all the KPIs, categorized by Use Case and technical category, is presented in Section 3.7.

3.1 It-UC1 Advanced In-Service Reporting for Automated Driving Vehicles

3.1.1 Capacity KPIs

Table 3: Technical evaluation KPI – End User Peak Data Rate for It-UC1

KPI identifier	KPI_It-UC1_1-EndUserPeakDataRate
Description	The peak data rate KPI is the maximum achievable data rate at the highest theoretical speed under ideal conditions that an end user (i.e., UE) can experience considering downstream and upstream traffic
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge (upstream) and from Edge to UE (downstream)
How to observe/measure/monitor	This KPI will be measured using a network performance measurement tool based on a client-server model such as iPerf. The tool needs to be configured with settings that ensure the highest possible throughput.
How to Evaluate	Up to 200 Mbps both in upstream and downstream

Table 4: Technical evaluation KPI – Average User Experienced Data Rate for It-UC1

KPI identifier	KPI_It-UC1_2-AverageUserExperiencedDataRate
Description	The user experienced data rate KPI is the average data rate that is experienced by end users (i.e., UEs) considering downstream and upstream traffic

Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge (upstream) and from Edge to UE (downstream)
How to observe/measure/monitor	This KPI will be measured using a network performance measurement tool based on a client-server model such as iPerf. The measurement of this KPI will be done involving several UEs and in different time intervals. The average throughput obtained will provide an estimate of the KPI.
How to Evaluate	Up to 100 Mbps both in upstream and downstream

Table 5: Technical evaluation KPI – Area Traffic Capacity for It-UC1

KPI identifier	KPI_It-UC1_3-AreaTrafficCapacity
Description	The area traffic capacity KPI is the total traffic throughput served per geographic area (in Mbit/s/m^2) considering the UEs in the selected area and downstream and upstream traffic
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from multiple UEs to Edge and from Edge to multiple UEs
How to observe/measure/monitor	This KPI will be measured using a network performance measurement tool based on a client-server model such as iPerf. Several UEs will be involved in measuring this KPI. The aggregate throughput of the UEs will be used to compute the KPI.
How to Evaluate	Up to 5 kbit/s/m^2

3.1.2 Latency KPIs

Table 6: Technical evaluation KPI – User Plane Latency for It-UC1

KPI identifier	KPI_It-UC1_4-UserPlaneLatency
Description	The user plane latency KPI is the time employed by a packet to travel from the UE to the edge server that represents the Data Network instance.
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge
How to observe/measure/monitor	This KPI can be measured using a network performance measurement tool based on a client-server model such as One-Way Ping (OWAMP). UE and edge must be time synchronized.

How to Evaluate	< 30 ms < 15 ms (URLLC)

Table 7: Technical evaluation KPI – Service Setup Delay for It-UC1

KPI identifier	KPI_It-UC1_5-ServiceSetupDelay
Description	The required time to setup a new service. It is measured as the time difference between when a new service is initiated, and the service setup is complete.
Where to observe/measure/monitor	This KPI will be measured: - At the Management and Orchestration Layer
How to observe/measure/monitor	The KPI can be measured using a log collection and processing system by calculating the time elapsed between when the Service Orchestrator receives a request to instantiate a service and when it is notified by the computing infrastructure that the service has been instantiated
How to Evaluate	< 120s

Table 8: Technical evaluation KPI – Slice Setup Delay for It-UC1

KPI identifier	KPI_It-UC1_6-SliceSetupDelay
Description	Time elapsed between the request for a new 5G slice activation with traffic redirection and the actual moment in which the targeted users' traffic flows over the new slice.
Where to observe/measure/monitor	The KPI will be measured: - at the orchestrator (or corresponding AF) and in the Data Network.
How to observe/measure/monitor	This KPI will be measured by reading the time at which the orchestrator (or corresponding AF) sends to the 5GC a request for a new slice activation and the moment in which the first user-plane packet is forwarded to the data network (N6 interface of the 5G system) over the newly activated slice.
How to Evaluate	Targeted delay in the most constraining scenario (in which slice activation includes VM boot): < 180s

Table 9: Technical evaluation KPI – E2E Application Latency for It-UC1

KPI identifier	KPI_It-UC1_7-E2EApplicationLatency
Description	Calculation of the time difference between data transmission at the application sender (e.g., client) and reception by the receiver (e.g., service)
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge or from Edge to UE

How to observe/measure/monitor	Data sent by the source application at the UE or at the Edge are time tagged. The application at the destination node retrieves the timestamp associated with the data and it computes the latency. UE and edge must be time synchronized.
How to Evaluate	Up to 200 ms

3.1.3 Operational KPIs

Table 10: Technical evaluation KPI – Packet Loss Rate for It-UC1

KPI identifier	KPI_It-UC1_8-PacketLossRate
Description	The ratio of packets dropped to packets transmitted between two endpoints over a period of time.
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge and from Edge to UE
How to observe/measure/monitor	This KPI can be measured using a network performance measurement tool based on a client-server model such as iPerf.
How to Evaluate	< 1%

3.1.4 Security KPIs

Table 11: Technical evaluation KPI – Security & privacy standards compliance for It-UC1

KPI identifier	KPI_It-UC1_9-ComplianceWithSecurity&PrivacyStandards
Description	The percentage of the system that complies with security and privacy standards or regulations (e.g., GDPR, Data Act, etc).
Where to observe/measure/monitor	This KPI will be measured considering all layers
How to observe/measure/monitor	This KPI can be measured as follows: - Identify and list the security and privacy requirements that the system should meet. - Verify which requirements in the list are met by the system. - Compute the percentage of the requirements met over the total number of requirements identified.
How to Evaluate	> 90%

3.2 It-UC2 Dynamic Collaborative Mapping for Automated Driving

3.2.1 Capacity KPIs

Table 12: Technical evaluation KPI – End User Peak Data Rate for It-UC2

KPI identifier	KPI_It-UC2_1-EndUserPeakDataRate
Description	The peak data rate KPI is the maximum achievable data rate at the highest theoretical speed under ideal conditions that an end user (i.e., UE) can experience considering downstream and upstream traffic
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge (upstream) and from Edge to UE (downstream)
How to observe/measure/monitor	This KPI will be measured using a network performance measurement tool based on a client-server model such as iPerf. The tool needs to be configured with settings that ensure the highest possible throughput.
How to Evaluate	Up to 200 Mbps both in upstream and downstream

Table 13: Technical evaluation KPI - Average User Experienced Data Rate for It-UC2

KPI identifier	KPI_It-UC2_2-AverageUserExperiencedDataRate
Description	The user experienced data rate KPI is the average data rate that is experienced by end users (i.e., UEs) considering downstream and upstream traffic
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge (upstream) and from Edge to UE (downstream)
How to observe/measure/monitor	This KPI will be measured using a network performance measurement tool based on a client-server model such as iPerf. The measurement of this KPI will be done involving several UEs and in different time intervals. The average throughput obtained will provide an estimate of the KPI.
How to Evaluate	Up to 100 Mbps both in upstream and downstream

Table 14: Technical evaluation KPI – Area Traffic Capacity for It-UC2

KPI identifier	KPI_It-UC2_3-AreaTrafficCapacity
Description	The area traffic capacity KPI is the total traffic throughput served per geographic area (in Mbit/s/m^2) considering the UEs in the selected area and downstream and upstream traffic
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from multiple UEs to Edge and from Edge to multiple UEs

How to observe/measure/monitor	This KPI will be measured using a network performance measurement tool based on a client-server model such as iPerf. Several UEs will be involved in measuring this KPI. The aggregate throughput of the UEs will be used to compute the KPI.
How to Evaluate	Up to 5 kbit/s/m²

3.2.2 Latency KPIs

Table 15: Technical evaluation KPI - User Plane Latency for It-UC2

KPI identifier	KPI_It-UC2_4-UserPlaneLatency
Description	The user plane latency KPI is the time employed by a packet to travel from the UE to the edge server that represents the Data Network instance.
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge
How to observe/measure/monitor	This KPI can be measured using a network performance measurement tool based on a client-server model such as One-Way Ping (OWAMP). UE and edge must be time synchronized.
How to Evaluate	< 30 ms < 15 ms (URLLC)

Table 16: Technical evaluation KPI - Service Setup Delay for It-UC2

KPI identifier	KPI_It-UC2_5-ServiceSetupDelay
Description	The required time to setup a new service. It is measured as the time difference between a new service is initiated and the service setup is complete.
Where to observe/measure/monitor	This KPI will be measured: - At the Management and Orchestration Layer
How to observe/measure/monitor	The KPI can be measured using a log collection and processing system by calculating the time elapsed between when the Service Orchestrator receives a request to instantiate a service and when it is notified by the computing infrastructure that the service has been instantiated
How to Evaluate	< 120s

Table 17: Technical evaluation KPI - Slice Setup Delay for It-UC2

KPI identifier	KPI_It-UC2_6-SliceSetupDelay
Description	Time elapsed between the request for a new 5G slice activation with traffic redirection and the actual moment in which the targeted users' traffic flows over the new slice.
Where to observe/measure/monitor	The KPI will be measured: - at the orchestrator (or corresponding AF) and in the Data Network.
How to observe/measure/monitor	This KPI will be measured by reading the time at which the orchestrator (or corresponding AF) sends to the 5GC a request for a new slice activation and the moment in which the first user-plane packet is forwarded to the data network (N6 interface of the 5G system) over the newly activated slice.
How to Evaluate	Targeted delay in the most constraining scenario (in which slice activation includes VM boot): < 180s

Table 18: Technical evaluation KPI - E2E Application Latency for It-UC2

KPI identifier	KPI_It-UC2_7-E2EApplicationLatency
Description	Calculation of the time difference between data transmission at the application sender (e.g., client) and reception by the receiver (e.g., service)
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge or from Edge to UE
How to observe/measure/monitor	Data sent by the source application at the UE or at the Edge are time tagged. The application at the destination node retrieves the timestamp associated with the data and it computes the latency. UE and edge must be time synchronized.
How to Evaluate	Up to 200 ms

3.2.3 Operational KPIs

Table 19: Technical evaluation KPI - Packet Loss Rate for It-UC2

KPI identifier	KPI_It-UC2_8-PacketLossRate
Description	The ratio of packets dropped to packets transmitted between two endpoints over a period of time.
Where to observe/measure/monitor	This KPI will be measured: - at the Application layer - from UE to Edge and from Edge to UE

How to observe/measure/monitor	This KPI can be measured using a network performance measurement tool based on a client-server model such as iPerf.
How to Evaluate	< 1%

3.2.4 Security KPIs

Table 20: Technical evaluation KPI – Security and privacy standards compliance for It-UC2

KPI identifier	KPI_It-UC2_9-ComplianceWithSecurity&PrivacyStandards
Description	The percentage of the system that complies with security and privacy standards or regulations (e.g., GDPR, Data Act, etc).
Where to observe/measure/monitor	This KPI will be measured considering all layers
How to observe/measure/monitor	This KPI can be measured as follows: - Identify and list the security and privacy requirements that the system should meet. - Verify which requirements in the list are met by the system. - Compute the percentage of the requirements met over the total number of requirements identified.
How to Evaluate	> 90%

3.3 Dt-UC3 Periodic vehicle data collection for improving digital twin

3.3.1 Capacity KPIs

Table 21: Technical evaluation KPI – User experienced data rate at UPF for Dt-UC3

KPI identifier	KPI_Dt-UC3_1-UserExperiencedDataRateAtUPF
Description	User experienced data rate defined as the network layer throughput for the user plane traffic measured at the User Plane Function (UPF) of the B5G core.
Where to observe/measure/monitor	At the User Plane Function (UPF) (B5G core)
How to observe/measure/monitor	Uplink and downlink data rates for one or more defined UEs at the UPF. This is done by monitoring the data volume per second for the combined traffic of one or more PDU sessions of each UE as observed at the user plane. <u>Measurement tools used</u>:

	Performance metrics (i.e., throughput) exposed via service Open APIs. Subscribers receive periodic uplink and downlink throughput values over time for a defined UE. Network layer measurement: 1. Traffic is generated (e.g., via iperf or from use case services) from one or more UEs connected to the B5G core (uplink and/or downlink). 2. Throughput measurements for each UE are collected periodically at the egress interface of the UPF for a defined duration time.
How to Evaluate	Target value (uplink): >= 16 Mbit/s

3.3.2 Latency KPIs

Table 22: Technical evaluation KPI – User plane latency for Dt-UC3

KPI identifier	KPI_Dt-UC3_2-UserPlaneLatency
Description	User plane latency is the contribution of the overall B5G system (radio + core) to the time from when the source sends a packet to when the destination receives it (in ms). It is defined as the one-way time it takes to successfully deliver a user plane packet between the UE and the egress port of the User Plane Function (UPF) of the B5G core.
Where to observe/measure/monitor	Between the UE's network interface corresponding to the 5G modem and at the egress port of the User Plane Function (UPF) (B5G core)
How to observe/measure/monitor	Measurement tools used: Ping and pcap (packet capture) analysis tools. Network layer measurement: 1. Ping (ICMP) echo-request packets are generated with different packet sizes and generation rates from one UE. The packets are sent to the UPF egress port IP address of the B5G core. Echo reply packets are collected and the round-trip time is calculated. The one-way latency is estimated as half of the round-trip time for each packet. 2. Pcap traces are started at both the UEs and at the UPF egress port of the UPF at the B5G core. By using pcap analysis tools, packets are matched between traces recorded at UE and UPF sides. The one-way latency is then calculated as the difference between the transmission and reception times. Time synchronization between UE and B5G core is required.
How to Evaluate	Target value: <= 150ms

Table 23: Technical evaluation KPI – One-way delay (OWD) for Dt-UC3

KPI identifier	KPI_Dt-UC3_3-OneWayDelay

Description	End-to-end delay or one-way delay (OWD) refers to the time taken for a packet to be transmitted across a network from source to destination. It is a common term in IP network monitoring and differs from round-trip time (RTT) in that only path in the one direction from source to destination is measured.
Where to observe/measure/monitor	In the case of the remote monitoring use-case this end-to-end latency is measured between the message sent by the publisher - by the sensors mounted on the vehicle - and the message received (subscriber) by the Digital Twin service.
How to observe/measure/monitor	Both the publisher and subscriber are time synchronized using a central clock. The message when is sent and when is received is timestamped. The one-way delay is calculating by subtracting the two timestamps as follows: timestamp_received – timestamp_published.
How to Evaluate	Target value: <= 150ms

3.3.3 Operational KPIs

Table 24: Technical evaluation KPI – Service reliability for Dt-UC3

KPI identifier	KPI_Dt-UC3_4-ServiceReliability

Description	Service reliability refers to the probability that the implemented system/services will maintain performance standards for a specific period. Since the terminology has a broad meaning, the reliability metrics must be defined on a use-case basis considering the service components involved in the monitoring of the selected KPI aspects. The measurement period can be the duration of an experimentation performed using the service components. The services involved in the remote monitoring process are 1) the remote monitoring service (Digital Twin - DT) initiating the remote monitoring, 2) the in-vehicle component of the remote monitoring (DT) service sending the data obtained from the vehicle sensors, 3) the V2N connectivity services between the vehicle and remote monitoring (DT) service, 4) the B5G system. The metrics for measuring remote monitoring (DT) service reliability are:
	• Sustaining guaranteed B5G QoS performance during the experimentation period (4) (as guaranteed by ENVELOPE APIs)
	  ○ latency (1, 2, 3, 4)
	  ○ Packet loss rate (1, 2, 3, 4)
	  ○ Throughput
	• Sustaining guaranteed E2E QoS performance during the experimentation period (4)
	  ○ E2E-latency (1, 2, 3, 4)
	  ○ Packet loss rate (1, 2, 3, 4)
	  ○ E2E throughput
	Service reliability refers to uplink-heavy service(s).

Where to observe/measure/monitor	• The sustainment of the guaranteed B5G QoS performance can be measured at different 5G network components (e.g., between the gNodeB serving the UE and the UPF performing gateway functionality toward the backend application services) ○ Latency in the B5G system can be measured between the two points of the B5G system where packets enter and leave.

	○ Packet loss rate in the B5G system can be measured at the two points of the B5G system where packets enter and leave. ○ The throughput of the B5G system can be measured at the two points of the B5G system where packets enter and leave. • The sustainment of the guaranteed E2E QoS performance can be measured at the two endpoints of the communication. In this case, these are the vehicle UE producing the data (2) and the remote monitoring (DT) service consuming the data (1). ○ E2E latency can be measured by comparing packet/message timestamps in the producing vehicle UE (2) and the consuming remote monitoring (DT) service (1). ○ Packet loss rate can be measured by comparing the number of packets sent by the producing vehicle UE (2) and received by the consuming remote monitoring (DT) service (1). ○ E2E throughput can be measured by checking the total data (e.g., in bytes) produced and sent by the vehicle UE (2) and consumed by the remote monitoring (DT) service (1) during a fixed period. ○ Additional granularity of mapping the above sub-indicators can be achieved if the V2N connectivity components (3) and the B5G system components (4) (see B5G QoS performance above) also measure said sub-indicators.
How to observe/measure/monitor	• Latency can be measured by synchronizing the different system components to a central clock and checking differences in the timestamp values of a packet at each component from the producing vehicle UE to the consuming remote monitoring (DT) service. • Packet loss rate can be measured by counting and comparing the outbound/inbound packets at the two endpoints of the transmission (producing vehicle UE & consuming monitoring [DT] service). For additional granularity, the components between the two endpoints (e.g., V2N message broker, B5G UPF) can also count inbound/outbound packets. • The throughput can be measured by checking the total data (e.g., in bytes) processed/forwarded by a certain component during a fixed period. E2E throughput is measured between the producing vehicle UE (2) and the consuming remote monitoring (DT) service (1). • The sustainment of the guaranteed QoS performance can be measured by combining the sub-indicators involved in the guaranteed QoS level (e.g., throughput, latency) and checking if the actual performance measured is within the guaranteed limits.
How to Evaluate	Target values: • E2E latency target value <= max threshold value (e.g., 150 ms) • Packet loss rate <= max threshold ratio (e.g., 0.05%) • Throughput >= min threshold value (e.g., 16 Mbit/s) • Sustainment of guaranteed QoS performance (per experimentation) == yes/no ○ Optionally track which of the guaranteed performance metrics were not met

3.3.4 Security KPIs

Table 25: Technical evaluation KPI – Security and privacy audit compliance for Dt-UC3

KPI identifier	KPI_Dt-UC3_5-SecurityPrivacyAuditCompliance
Description	Dutch trial site may record and process the following categories of raw sensor data (vehicle GPS, camera, radar and LiDAR). However, only the data recorded by the camera, called video recordings are subject to GDPR. The collected data will only be used to develop and enhance products and for scientific research aimed at improving automated driving and all related technologies.
Where to observe/measure/monitor	The legal basis for the collection and processing of these video recordings of the surroundings of the test vehicles (including the recording of personal data such as video recordings of pedestrians, drivers) is in the legitimate interest of consortium according to Art. 6 (f) General Data Protection Regulation).
How to observe/measure/monitor	The consortium will transfer and disclose personal data only if it is legally permitted, e.g.: transfer personal data to courts, law enforcement authorities, regulators or attorneys if necessary to comply with the law or for the establishment, exercise or defense of legal claims. Data retention & deletion: The data collected while using the test vehicle is kept as long as it is needed for testing and trial purposes. Once these objectives have been achieved the data is erased. In some cases, it is necessary to keep the data for longer periods for quality assurance purposes, such as long-term monitoring and development (product documentation and evidence preservation). Additionally, the data is stored if is legally obligated to do so, if further processing is necessary to assert, exercise or defend legal claims, or if it is necessary for scientific research purposes. Pedestrians and drivers, recorded during the data collection have the right to request the consortium immediately to erase any personal data stored if the legal requirements are met. During data recording – on public roads - a sticker is placed on the vehicle, which informs that data recording is ongoing and people who do not want to be recorded, could access a website, where they can request that their data is deleted from the recording.
How to Evaluate	Target value: Each consortium partner involved in data collection, data storage and data sharing shall have a in their organization a Data Privacy Officer to provide support with any data privacy related questions, comments, concerns or complaints related to data privacy. At Siemens the data privacy team may be contacted at: dataprotection@siemens.com.

3.4 Dt-UC4 Vehicle testing with mixed reality

3.4.1 Capacity KPIs

Table 26: Technical evaluation KPI – User experienced data rate at UPF for Dt-UC4

KPI identifier	KPI_Dt-UC4_1-UserExperiencedDataRateAtUPF
Description	User experienced data rate defined as the network layer throughput for the user plane traffic measured at the User Plane Function (UPF) of the B5G core.

Where to observe/measure/monitor	At the User Plane Function (UPF) (B5G core)
How to observe/measure/monitor	Uplink and downlink data rates for one or more defined UEs at the UPF. This is done by monitoring the data volume per second for the combined traffic of one or more PDU sessions of each UE as observed at the user plane. Measurement tools used: Performance metrics (i.e., throughput) exposed via service Open APIs. Subscribers receive periodic uplink and downlink throughput values over time for a defined UE. Network layer measurement: 3. Traffic is generated (e.g., via iperf or from use case services) from one or more UEs connected to the B5G core (uplink and/or downlink). 4. Throughput measurements for each UE are collected periodically at the egress interface of the UPF for a defined duration time.
How to Evaluate	Target value (uplink): >= 16 Mbit/s

3.4.2 Latency KPIs

Table 27: Technical evaluation KPI – User plane latency for Dt-UC4

KPI identifier	KPI_Dt-UC4_2-UserPlaneLatency
Description	User plane latency is the contribution of the overall B5G system (radio + core) to the time from when the source sends a packet to when the destination receives it (in ms). It is defined as the one-way time it takes to successfully deliver a user plane packet between the UE and the egress port of the User Plane Function (UPF) of the B5G core.
Where to observe/measure/monitor	Between the UE's network interface corresponding to the 5G modem and at the egress port of the User Plane Function (UPF) (B5G core)
How to observe/measure/monitor	Measurement tools used: Ping and pcap (packet capture) analysis tools. Network layer measurement: 3. Ping (ICMP) echo-request packets are generated with different packet sizes and generation rates from one UE. The packets are sent to the UPF egress port IP address of the B5G core. Echo reply packets are collected and the round-trip time is calculated. The one-way latency is estimated as the half of the round-trip time for each packet. 4. Pcap traces are started at both the UEs and at the UPF egress port of the UPF at the B5G core. By using pcap analysis tools, packets are matched between traces recorded at UE and UPF sides. The one-way latency is then calculated as the difference between the transmission and reception times. Time synchronization between UE and B5G core is required.

How to Evaluate	Target value: <= 100ms

Table 28: Technical evaluation KPI – One-way delay (OWD) for Dt-UC4

KPI identifier	KPI_Dt-UC4_3-OneWayDelay
Description	End-to-end delay or one-way delay (OWD) refers to the time taken for a packet to be transmitted across a network from source to destination. It is a common term in IP network monitoring and differs from round-trip time (RTT) in that only path in the one direction from source to destination is measured.
Where to observe/measure/monitor	In the case of the mixed reality testing use-case this end-to-end latency is measured between the message sent by the publisher the Digital Twin or the intelligent infrastructure and the message received (subscriber) by the vehicle.
How to observe/measure/monitor	Both the publisher and subscriber are time synchronized using a central clock. The message when is sent and when is received is timestamped. The one-way delay is calculating by subtracting the two timestamps as follows: timestamp_received – timestamp_published.
How to Evaluate	Target value: <= 100ms

3.4.3 Operational KPIs

Table 29: Technical evaluation KPI – Service reliability for Dt-UC4

KPI identifier	KPI_Dt-UC4_4-ServiceReliability

Description	Service reliability refers to the probability that the implemented system/services will maintain performance standards for a specific period. Since the terminology has a broad meaning, the reliability metrics must be defined on a use-case basis considering the service components involved in the monitoring of the selected KPI aspects. The measurement period can be the duration of an experimentation performed using the service components. The services involved in the mixed reality testing process are 1) the Digital Twin service initiating the injection of virtual objects, 2) the in-vehicle components receiving the object data and injecting it to the autonomous vehicle control systems, 3) the V2N connectivity services between the vehicle and remote monitoring service, 4) the B5G system. The metrics for measuring remote monitoring service reliability are:
	• Sustaining guaranteed B5G QoS performance during the experimentation period (4) (as guaranteed by ENVELOPE APIs)
	  ○ latency (1, 2, 3, 4)
	  ○ Packet loss rate (1, 2, 3, 4)
	  ○ Throughput
	• Sustaining guaranteed E2E QoS performance during the experimentation period (4)
	  ○ E2E-latency (1, 2, 3, 4)
	  ○ Packet loss rate (1, 2, 3, 4)
	  ○ E2E throughput
	Service reliability refers to downlink-heavy service.

Where to observe/measure/monitor	• The sustainment of the guaranteed B5G QoS performance can be measured at different 5G network components (e.g., between the gNodeB serving the UE and the UPF performing gateway functionality toward the backend application services)
	  ○ Latency in the B5G system can be measured between the two points of the B5G system where packets enter and leave.
	  ○ Packet loss rate in the B5G system can be measured at the two points of the B5G system where packets enter and leave.
	  ○ The throughput of the B5G system can be measured at the two points of the B5G system where packets enter and leave.
	• The sustainment of the guaranteed E2E QoS performance can be measured at the two endpoints of the communication. In this case, these are the vehicle UE consuming the data (2) and the Digital Twin service sending the data (1).
	  ○ E2E latency can be measured by comparing packet/message timestamps in the consuming vehicle UE (2) and the producing Digital Twin service (1).
	  ○ Packet loss rate can be measured by comparing the number of packets sent by the consuming vehicle UE (2) and received by the producing Digital Twin service (1).
	  ○ E2E throughput can be measured by checking the total data (e.g., in bytes) received by the vehicle UE (2) and sent by the Digital Twin service (1) during a fixed period.

	Additional granularity of mapping the above sub-indicators can be achieved if the V2N connectivity components (3) and the B5G system components (4) (see B5G QoS performance above) also measure said sub-indicators.
How to observe/measure/monitor	• Latency can be measured by synchronizing the different system components to a central clock and checking differences in the timestamp values of a packet at each component from the Digital Twin service to the vehicle. • Packet loss rate can be measured by counting and comparing the outbound/inbound packets at the two endpoints of the transmission (vehicle UE & Digital Twin service). For additional granularity, the components between the two endpoints (e.g., V2N message broker, B5G UPF) can also count inbound/outbound packets. • The throughput can be measured by checking the total data (e.g., in bytes) processed/forwarded by a certain component during a fixed period. E2E throughput is measured between the vehicle UE (2) and the Digital Twin service (1). The sustainment of the guaranteed QoS performance can be measured by combining the sub-indicators involved in the guaranteed QoS level (e.g., throughput, latency) and checking if the actual performance measured is within the guaranteed limits.
How to Evaluate	Target values: • E2E latency target value <= max threshold value (e.g., 100 ms) • Packet loss rate <= max threshold ratio (e.g., 0.05%) • Throughput >= min threshold value (e.g., 16 Mbit/s) • Sustainment of guaranteed QoS performance (per experimentation) == yes/no Optionally track which of the guaranteed performance metrics were not met

3.5 Dt-UC5 Tele-operated driving aided by DT

3.5.1 Capacity KPIs

Table 30: Technical evaluation KPI – User experienced data rate at UPF for Dt-UC5

KPI identifier	KPI_Dt-UC5_1-UserExperiencedDataRateAtUPF
Description	User experienced data rate defined as the network layer throughput for the user plane traffic measured at the User Plane Function (UPF) of the B5G core.
Where to observe/measure/monitor	At the User Plane Function (UPF) (B5G core)
How to observe/measure/monitor	Uplink and downlink data rates for one or more defined UEs at the UPF. This is done by monitoring the data volume per second for the combined traffic of one or more PDU sessions of each UE as observed at the user plane. Measurement tools used: Performance metrics (i.e., throughput) exposed via service Open APIs. Subscribers receive periodic uplink and downlink throughput values over time for a defined UE. Network layer measurement: 5. Traffic is generated (e.g., via iperf or from use case services) from one or more UEs connected to the B5G core (uplink and/or downlink). 6. Throughput measurements for each UE are collected periodically at the egress interface of the UPF for a defined duration time.
How to Evaluate	Target value (uplink): >= 16 Mbit/s

3.5.2 Latency KPIs

Table 31: Technical evaluation KPI – User plane latency for Dt-UC5

KPI identifier	KPI_Dt-UC5_2-UserPlaneLatency
Description	User plane latency is the contribution of the overall B5G system (radio + core) to the time from when the source sends a packet to when the destination receives it (in ms). It is defined as the one-way time it takes to successfully deliver a user plane packet between the UE and the egress port of the User Plane Function (UPF) of the B5G core.
Where to observe/measure/monitor	Between the UE's network interface corresponding to the 5G modem and at the egress port of the User Plane Function (UPF) (B5G core)
How to observe/measure/monitor	Measurement tools used: Ping and pcap (packet capture) analysis tools. Network layer measurement: 5. Ping (ICMP) echo-request packets are generated with different packet sizes and generation rates from one UE. The packets are sent to the UPF egress port IP address of the B5G core. Echo reply packets are

	collected and the round-trip time is calculated. The one-way latency is estimated as the half of the round-trip time for each packet. 6. Pcap traces are started at both the UEs and at the UPF egress port of the UPF at the B5G core. By using pcap analysis tools, packets are matched between traces recorded at UE and UPF sides. The one-way latency is then calculated as the difference between the transmission and reception times. Time synchronization between UE and B5G core is required.
How to Evaluate	Target value: <= 75ms

Table 32: Technical evaluation KPI – One-way delay (OWD) for Dt-UC5

KPI identifier	KPI_Dt-UC5_3-OneWayDelay
Description	End-to-end delay or one-way delay (OWD) refers to the time taken for a packet to be transmitted across a network from source to destination. It is a common term in IP network monitoring and differs from round-trip time (RTT) in that only path in the one direction from source to destination is measured.
Where to observe/measure/monitor	Since safe tele-operated driving is performed in closed loop there are two end-to-end delays, which have to be considered. The first end-to-end latency is measured between the message sent by the publisher - by the sensors mounted on the vehicle - and the message received (subscriber) by the Digital Twin service and remote driver. The second end-to-end delay is measured between the message sent by the remote driver actuators (publisher) and the message received by the vehicle (subscriber). In this use-case the round-trip time is a better KPI than the end-to-end delay. However, to keep the discussion simple, we will approximate the RTT as RTT = 2*E2E
How to observe/measure/monitor	Both the publisher and subscriber are time synchronized using a central clock. The message when is sent and when is received is timestamped. The one-way delay is calculating by substracting the two timestamps as follows: timestamp_received – timestamp_published. This procedure is repeated for both trips, so finally the round-trip time is calculated.
How to Evaluate	Target value: E2E <= 37.5ms; RTT <= 75ms

3.5.3 Operational KPIs

Table 33: Technical evaluation KPI – Service reliability for Dt-UC5

KPI identifier	KPI_Dt-UC5_4-ServiceReliability
Description	Service reliability refers to the probability that the implemented system/services will maintain performance standards for a specific period. Since the terminology has a broad meaning, the reliability metrics must be defined on a use-case basis considering the service components involved in the monitoring of the selected KPI aspects. The services involved in the teleoperation are a combination of the remote monitoring and mixed reality testing use cases with some additional components: 1) the Digital Twin service initiating the remote

	monitoring and the injection of virtual objects, 2) the in-vehicle components sending sensor data, and receiving the object data and teleoperation commands and injecting them into the autonomous vehicle control systems, 3) the V2N connectivity services between the vehicle and remote monitoring service, 4) the B5G system, 5) the teleoperation service. The metrics for measuring remote monitoring service reliability are:
	• Sustaining guaranteed B5G QoS performance during the experimentation period (4) (as guaranteed by ENVELOPE APIs)
	    o latency (1, 2, 3, 4)
	    o Packet loss rate (1, 2, 3, 4)
	    o Throughput
	• Sustaining guaranteed E2E QoS performance during the experimentation period (4)
	    o E2E-latency (1, 2, 3, 4)
	    o Packet loss rate (1, 2, 3, 4)
	    o E2E throughput
	Service reliability refers to a combination of uplink-heavy and downlink-heavy sub-services.

Where to observe/measure/monitor	• The sustainment of the guaranteed B5G QoS performance can be measured at different 5G network components (e.g., between the gNodeB serving the UE and the UPF performing gateway functionality toward the backend application services)
	    o Latency in the B5G system can be measured between the two points of the B5G system where packets enter and leave.
	    o Packet loss rate in the B5G system can be measured at the two points of the B5G system where packets enter and leave.
	    o The throughput of the B5G system can be measured at the two points of the B5G system where packets enter and leave.
	• The sustainment of the guaranteed E2E QoS performance can be measured at the two endpoints of the communication. In one case, these are the vehicle UE (2) and the Digital Twin service (1), in another case it is the vehicle UE (2) and the teleoperation service (5).
	    o E2E latency can be measured by comparing packet/message timestamps in the vehicle UE (2) and the Digital Twin service (1) or teleoperation service (5).
	    o The packet loss rate between the vehicle and the Digital Twin can be measured by comparing the number of packets sent/received by the vehicle UE (2) and sent/received by the Digital Twin service (1). The packet loss rate between the vehicle and the teleoperation service can be measured by comparing the number of packets sent/received by the vehicle UE (2) and sent/received by the teleoperation service (1).
	    o E2E throughput between the vehicle UE and the Digital Twin service can be measured by checking the total data (e.g., in bytes) sent/received by the vehicle UE (2) and received/sent by the Digital Twin service (1) during a fixed period. E2E throughput between the vehicle UE and the teleoperation service can be measured by checking the total data (e.g., in bytes) sent/received by the vehicle UE (2) and received/sent by the teleoperation service (5) during a fixed period.
	Additional granularity of mapping the above sub-indicators can be achieved if the V2N connectivity components (3) and the B5G system components (4) (see B5G QoS performance above) also measure said sub-indicators.

How to observe/measure/monitor	• Latency can be measured by synchronizing the different system components to a central clock and checking differences in the timestamp values of a packet at each component between the vehicle UE and the Digital Twin service, or the vehicle UE and the teleoperation service. • Packet loss rate can be measured by counting and comparing the outbound/inbound packets at the two endpoints of the transmission (producing vehicle UE & Digital Twin or teleoperation service). For additional granularity, the components between the two endpoints (e.g., V2N message broker, B5G UPF) can also count inbound/outbound packets. • The throughput can be measured by checking the total data (e.g., in bytes) processed/forwarded by a certain component during a fixed period. E2E throughput is measured between the vehicle UE (2) and the Digital Twin or teleoperation service (1 or 5). The sustainment of the guaranteed QoS performance can be measured by combining the sub-indicators involved in the guaranteed QoS level (e.g., throughput, latency) and checking if the actual performance measured is within the guaranteed limits.
How to Evaluate	Target values: • E2E latency target value <= max threshold value (e.g., 40 ms) • Packet loss rate <= max threshold ratio (e.g., 0.05%) • Throughput >= min threshold value (e.g., 20 Mbit/s) • Sustainment of guaranteed QoS performance (per experimentation) == yes/no Optionally track which of the guaranteed performance metrics were not met

3.5.4 Security KPIs

Table 34: Technical evaluation KPI – Security and privacy audit compliance for Dt-UC5

KPI identifier	KPI_Dt-UC5_5-SecurityPrivacyAuditCompliance
Description	Dutch trial site may record and process the following categories of raw sensor data (vehicle GPS, camera, radar and LiDAR). However, only the data recorded by the camera, called video recordings are subject to GDPR. The collected data will only be used to develop and enhance products and for scientific research aimed at improving automated driving and all related technologies.
Where to observe/measure/monitor	The legal basis for the collection and processing of these video recordings of the surroundings of the test vehicles (including the recording of personal data such as video recordings of pedestrians, drivers) is in the legitimate interest of consortium according to Art. 6 (f) General Data Protection Regulation).
How to observe/measure/monitor	The consortium will transfer and disclose personal data only if it is legally permitted, e.g.: transfer personal data to courts, law enforcement authorities, regulators or attorneys if necessary to comply with the law or for the establishment, exercise or defense of legal claims. Data retention & deletion: The data collected while using the test vehicle is kept as long as it is needed for testing and trial purposes. Once these objectives have been achieved the data is erased. In some cases, it is necessary to keep the data for longer periods for quality assurance purposes, such as long-term monitoring and development (product

	documentation and evidence preservation). Additionally, the data is stored if is legally obligated to do so, if further processing is necessary to assert, exercise or defend legal claims, or if it is necessary for scientific research purposes. Pedestrians and drivers, recorded during the data collection have the right to request the consortium immediately to erase any personal data stored if the legal requirements are met. During data recording – on public roads - a sticker is placed on the vehicle, which informs that data recording is ongoing and people who do not want to be recorded, could access a website, where they can request that their data is deleted from the recording.
How to Evaluate	Target value: Each consortium partner involved in data collection, data storage and data sharing shall have a in their organization a Data Privacy Officer to provide support with any data privacy related questions, comments, concerns or complaints related to data privacy. At Siemens the data privacy team may be contacted at: dataprotection@siemens.com.

3.6 Gr-UC6 MEC service handover between multiple MNOs

3.6.1 Capacity KPIs

Table 35: Technical evaluation KPI – Network peak data rate for Gr-UC6

KPI identifier	KPI_Gr-UC6_1-NetworkPeakDataRate
Description	This KPI measures the maximum data transfer rate achieved by the mobile network which is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e. excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times). It is a critical metric for evaluating the network's capacity and performance under peak load, ideal conditions
Where to observe/measure/monitor	Application Layer: Measure at the application layer to determine the end-to-end data transfer rates experienced by applications running on the network.
How to observe/measure/monitor	Background Traffic Generation: Generate background traffic to simulate real-world network conditions. Measurement tools: Iperf tool that will be running on the UE and in various domains (cloud, edge) generating traffic in the downlink and uplink directions Monitoring Software: The measurement result could be stored in a timeseries database and acquired through API.
How to Evaluate	The target value should depend on the radio configurations and compared to the numerical value as defined in 3GPP TS 38.306 throughput equation and/or the maximum target value provided by mobile vendor.

Table 36: Technical evaluation KPI – User experienced data rate for Gr-UC6

KPI identifier	KPI_Gr-UC6_2-UserExperiencedDataRate
Description	User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time.
Where to observe/measure/monitor	Application Layer: Measure at the application layer to determine the end-to-end data transfer rates experienced by applications running on the network.
How to observe/measure/monitor	Background Traffic Generation: Generate background traffic to simulate real-world network conditions. Since the major difference between peak data rate and user experienced data rate is the difference between ideal peak performance and more realistic performance which can be achieved by 95 percent of users, it is important to choose appropriate measurement points in the testing environment Measurement tools: Iperf tool that will be running on the UE and in various domains (cloud, edge) generating traffic in the downlink and uplink directions Monitoring Software: The measurement result could be stored in a timeseries database and acquired through API.
How to Evaluate	Target values in a Dense Urban eMBB test environment are: Downlink: 100 Mbit/s Uplink: 50 Mbit/s

Table 37: Technical evaluation KPI – Area traffic capacity for Gr-UC6

KPI identifier	KPI_Gr-UC6_3-AreaTrafficCapacity
Description	The area traffic capacity KPI is the total traffic throughput served per geographic area (in Mbit/s/m^2) considering the UEs in the selected area and downstream and upstream traffic
Where to observe/measure/monitor	Application Layer: Measure at the application layer to determine the end-to-end data transfer rates experienced by applications running on the network.
How to observe/measure/monitor	Background Traffic Generation: Generate background traffic to simulate real-world network conditions for multiple UEs in a specific geographic area. The aggregate throughput of the UEs will be used to compute the KPI Measurement tools: Iperf tool that will be running on each UE and in various domains (cloud, edge) generating traffic in the downlink and uplink directions Monitoring Software: The measurement result could be stored in a timeseries database and acquired through API.

How to Evaluate	Definition of comparison approach i.e., what values the measured KPI data points are compared against. This must include Target Values or results retrieved by identified alternative setups/experiments.

3.6.2 Latency KPIs

Table 38: Technical evaluation KPI – Service setup delay for Gr-UC6

KPI identifier	KPI_Gr-UC6_4-ServiceSetupDelay
Description	The required time to setup a new service. It is measured as the time difference between a new service is initiated and the service setup is complete.
Where to observe/measure/monitor	The KPI will be measured at the UE side (i.e., OBU) and/or the Edge server.
How to observe/measure/monitor	Triggering Events: Define clear triggering events for the start and end of the service setup process to measure the delay accurately at both UE (i.e., OBU) and Edge server. Service Deployment Request (start): When a new service (e.g., a pod) is initiated, capture the timestamp of the deployment request. Service Setup Completion (end): Capture the timestamp when the service is marked as ready (i.e., when the pod status is "Running" and the readiness probes are successful). Monitoring: Prometheus and Grafana could be used as monitoring tools to collect and visualize metrics. Prometheus can scrape metrics, for instance from Kubernetes, and Grafana can display these metrics in dashboards. Application and K8 management APIs shall be leveraged to calculate accurately the service deployment time.
How to Evaluate	The service setup delay measurements, calculated as defined above, are expected to be in the order of seconds.

Table 39: Technical evaluation KPI – E2E application latency for Gr-UC6

KPI identifier	KPI_Gr-UC6_5-E2EApplicationLatency
Description	Calculation of time difference between data transmission at the application sender (e.g., client) and reception by the receiver (e.g., service)
Where to observe/measure/monitor	Application Layer: Measure at the application layer to determine the end-to-end delay experienced by applications running on the network.

How to observe/measure/monitor	Measurement tools: Utilizing ping probes echo-request packets are generated with different packet sizes and generation rates from one UE. The packets are sent to the application server. Echo reply packets are collected and the round-trip time is calculated. The one-way latency is estimated as the half of the round-trip time for each packet. Monitoring Software: The measurement result could be stored in a timeseries database and acquired through API.
How to Evaluate	Target value for Data Sharing for Real-time Situation Awareness should be between 100-2000ms

3.6.3 Operational KPIs

Table 40: Technical evaluation KPI – Service availability for Gr-UC6

KPI identifier	KPI_Gr-UC6_6-ServiceAvailability
Description	Measured as a ratio between up-time and down-time.
Where to observe/measure/monitor	Logging/monitoring of services is necessary to know where the services are down and for how long. A set of acceptable causes of outages might be necessary, such as power outage, maintenance windows, etc. Monitoring might be done externally to services and every service is evaluated individually.
How to observe/measure/monitor	• sum up of all the unacceptable outage time in logs • obtain the elapsed working time (during experiments or demos) • calculate the ratio and outage percentage.
How to Evaluate	Target value: > 95%

Table 41: Technical evaluation KPI – Application service reliability for Gr-UC6

KPI identifier	KPI_Gr-UC6_7-ApplicationServiceReliability
Description	Reliability is maximum tolerable packet loss rate at the application layer within the maximum tolerable end-to-end latency for that application.
Where to observe/measure/monitor	Application Layer: Measure the packet loss rate at the two endpoints (UE and application server)
How to observe/measure/monitor	Packet loss rate can be measured by counting and comparing the outbound/inbound packets at the two endpoints of the transmission (vehicle UE & vertical application server). For additional granularity, the components between the two endpoints (e.g., UPF) can also count inbound/outbound packets.

How to Evaluate	The target values depend on the particular UC, since different reliability times are required for certain critical or non-critical situations. Target value for Data Sharing for Real-time Situation Awareness should be 99%.

3.7 Summary

ENVELOPE has defined KPIs categorized into various technical aspects, such as network capacity, latency, operational performance and security. These KPIs are distributed among the different Use Cases within the project, ensuring that each UC addresses specific KPIs critical to its success. This comprehensive approach ensures a balanced and thorough evaluation of the technical performance and efficiency of each UC. A summary of the defined KPIs per Use Case and technical category is shown in Table 42.

Table 42: Classification of ENVELOPE KPIs

	Capacity KPIs	Latency KPIs	Operational KPIs	Security KPIs
It-UC1	KPI_It-UC1_1-EndUserPeakDataRate KPI_It-UC1_2-AverageUserExperienceddDataRate KPI_It-UC1_3-Area Traffic Capacity	KPI_It-UC1_4-UserPlaneLatency KPI_It-UC1_5-ServiceSetupDelay KPI_It-UC1_6-SliceSetupDelay KPI_It-UC1_7-E2EApplicationLatency	KPI_It-UC1_8-PacketLossRate	KPI_It-UC1_9-ComplianceWithSecurity&PrivacyStandards
It-UC2	KPI_It-UC2_1-EndUserPeakDataRate KPI_It-UC2_2-AverageUserExperienceddDataRate KPI_It-UC2_3-Area Traffic Capacity	KPI_It-UC2_4-UserPlaneLatency KPI_It-UC2_5-ServiceSetupDelay KPI_It-UC2_6-SliceSetupDelay KPI_It-UC2_7-E2EApplicationLatency	KPI_It-UC2_8-PacketLossRate	KPI_It-UC2_9-ComplianceWithSecurity&PrivacyStandards
Dt-UC3	KPI_Dt-UC3_1-UserExperiencedDataRateAtUPF	KPI_Dt-UC3_2-UserPlaneLatency KPI_Dt-UC3_3-OneWayDelay	KPI_Dt-UC3_4-ServiceReliability	KPI_Dt-UC3_5-SecurityPrivacyAuditCompliance
Dt-UC4	KPI_Dt-UC4_1-UserExperiencedDataRateAtUPF	KPI_Dt-UC4_2-UserPlaneLatency KPI_Dt-UC4_3-OneWayDelay	KPI_Dt-UC4_4-ServiceReliability	N/A
Dt-UC5	KPI_Dt-UC5_1-UserExperiencedDataRateAtUPF	KPI_Dt-UC5_2-UserPlaneLatency KPI_Dt-UC5_3-OneWayDelay	KPI_Dt-UC5_4-ServiceReliability	KPI_Dt-UC5_5-SecurityPrivacyAuditCompliance

Gr-UC6	KPI_Gr-UC6_1-NetworkPeakDataRate KPI_Gr-UC6_2-UserExperiencedDataRate KPI_Gr-UC6_3-AreaTrafficCapacity	KPI_Gr-UC6_4-ServiceSetupDelay KPI_Gr-UC6_5-E2EApplicationLatency	KPI_Gr-UC6_6-Service_Availability KPI_Gr-UC6_7-ApplicationService Reliability	N/A

4 Key Value Indicators

This section defines the Key Value Indicators (KVIs) for the ENVELOPE project, in order to evaluate the impact of the developed technologies across various dimensions. These indicators are categorized into three main areas: societal, environmental, and economic. Each Use Case within the ENVELOPE project addresses at least one KVI from each category, ensuring a comprehensive assessment of ENVELOPE's impact on these critical areas.

The following subsections provide detailed definitions and descriptions of the KVIs for each Use Case within the ENVELOPE project. Section 4.7 summarizes all the defined KVIs classified by ENVELOPE Use Case and KVI category.

4.1 It-UC1 Advanced In-Service Reporting for Automated Driving Vehicles

4.1.1 Societal KVIs

Table 43: KVI – Reduction in accident rates for It-UC1

KVI identifier	KVI_It-UC1-1-AccidentRateReduction
Key Value	Good health and well-being
Description of KVI	This KVI assesses the effectiveness of ENVELOPE solutions in preventing accidents.
Technology enablers	Vertical service for Advanced In-Service Reporting for Automated Driving Vehicles.
Validation method	Assessment by expert.
Target Value	50% reduction in accidents compared to not using the driver assistance system implemented in ENVELOPE.

Table 44: KVI - Reduction in emergency response time for It-UC1

KVI identifier	KVI_It-UC1-2-EmergencyResponseTime
Key Value	Good health and well-being
Description of KVI	This KVI assesses the decrease in response time for emergencies.
Technology enablers	Vertical service for Advanced In-Service Reporting for Automated Driving Vehicles.
Validation method	Assessment by expert.
Target Value	30% reduction of time spent than baseline.

4.1.2 Environmental KVIs

Table 45: Resource usage optimization for It-UC1

KVI identifier	KVI_It-UC1-3-ResourceUsageOptimization
Key Value	Environmental sustainability
Description of KVI	Efficiency in resource allocation in cloud and edge computing environments to minimize idle processing power and unnecessary storage. Measurement unit: resource utilization percentage or efficiency rate.
Technology enablers	Dynamic management and orchestration of network and computing resources.
Validation method	Measurements in trials/experiments/simulations.
Target Value	Less energy consumption than baseline.

4.1.3 Economical KVIs

Table 46: Operational cost savings for It-UC1

KVI identifier	KVI_It-UC1-4-OperationalCostSavings
Key Value	Economical sustainability and innovation
Description of KVI	This KVI assesses the savings in vehicle operation and maintenance due to optimized routes, reduced idling, and real-time information sharing.
Technology enablers	Vertical service for Advanced In-Service Reporting for Automated Driving Vehicles.
Validation method	Assessment by expert.
Target Value	Operational costs less than baseline.

4.2 It-UC2 Dynamic Collaborative Mapping for Automated Driving

4.2.1 Societal KVIs

Table 47: KVI - Reduction in accident rates for It-UC2

KVI identifier	KVI_It-UC2-1-AccidentRateReduction
Key Value	Good health and well-being
Description of KVI	This KVI assesses the effectiveness of ENVELOPE solutions in preventing accidents.
Technology enablers	Vertical service for Advanced In-Service Reporting for Automated Driving Vehicles.
Validation method	Assessment by expert.
Target Value	Reduction in accidents compared to not using the driver assistance system implemented in ENVELOPE.

4.2.2 Environmental KVIs

Table 48: KVI - Resource usage optimization for It-UC2

KVI identifier	KVI_It-UC2-2-ResourceUsageOptimization
Key Value	Environmental sustainability
Description of KVI	Efficiency in resource allocation in cloud and edge computing environments to minimize idle processing power and unnecessary storage. Measurement unit: resource utilization percentage or efficiency rate.
Technology enablers	Dynamic management and orchestration of network and computing resources.
Validation method	Measurements in trials/experiments/simulations.
Target Value	Less energy consumption than baseline.

4.2.3 Economical KVIs

Table 49: KVI - CapEx reduction for It-UC2

KVI identifier	KVI_It-UC2-3-CapExReduction
Key Value	Economical sustainability and innovation
Description of KVI	Cost reduction in acquiring, upgrading, and maintaining physical assets in comparison to baseline.
Technology enablers	Vertical service for Dynamic Collaborative Mapping for Automated Driving.
Validation method	Assessment by expert.
Target Value	CapEx costs less than baseline.

Table 50: KVI - Operational cost savings for It-UC2

KVI identifier	KVI_It-UC2-4-OperationalCostSavings
Key Value	Economical sustainability and innovation
Description of KVI	This KVI assesses savings in vehicle operation and maintenance due to optimized routes, reduced idling, and real-time information sharing.
Technology enablers	Vertical service for Dynamic Collaborative Mapping for Automated Driving.
Validation method	Assessment by expert.
Target Value	Operational costs less than baseline.

4.3 Dt-UC3 Periodic vehicle data collection for improving digital twin

4.3.1 Societal KVIs

Table 51: KVI - Less stressful mobility for citizens for Dt-UC3

KVI identifier	KVI_Dt-UC3-1-LessStressfulMobility
Key Value	Good health and well-being
Description of KVI	This KVI assesses the decrease in stress levels of citizens when using ENVELOPE mobility solutions compared to baseline.
Technology enablers	Autonomous vehicles (AVs) can decrease stress levels as users do not need to drive and can relax during travel.
Validation method	Assessment by expert.
Target Value	Less stress than baseline, since the vehicle operation is remotely monitored during operation. In some countries for driverless vehicles, remote monitoring is already required by the local regulation.

4.3.2 Environmental KVIs

Table 52: KVI - Waste reduction (e-waste) for Dt-UC3

KVI identifier	KVI_Dt-UC3-2-WasteReduction
Key Value	Environmental sustainability
Description of KVI	The amount of electronic waste generated due to hardware upgrades or obsolescence by the ENVELOPE use case compared to baseline. A reduction in hardware devices required by the ENVELOPE use case compared to baseline (for instance having a more efficient architecture with less hardware nodes) would mean a reduction in hardware waste.
Technology enablers	More efficient/lightweight architecture with less HW on the vehicle and with more software functionalities in the cloud, in line with the software defined vehicle concept.
Validation method	Assessment by expert.
Target Value	Less waste than baseline.

4.3.3 Economical KVIs

Table 53: KVI - Time to market reduction for Dt-UC3

KVI identifier	KVI_Dt-UC3-3-TimeToMarketReduction
Key Value	Economical sustainability and innovation
Description of KVI	This KVI tracks the time taken to develop and launch new solutions or technologies.
Technology enablers	Monitoring and diagnostics software running in the cloud, much easier to update and maintain compared with the baseline situation, running on ECU, installed in the vehicle.
Validation method	Assessment by expert.

Target Value	Efficient and more economical software update related to advanced diagnostic features.

4.4 Dt-UC4 Vehicle testing with mixed reality

4.4.1 Societal KVIs

Table 54: KVI - User trust in CCAM for Dt-UC4

KVI identifier	KVI_Dt-UC4-1-TrustInCCAM
Key Value	Simplified life
Description of KVI	This KVI evaluates the level of public trust and willingness to adopt CCAM technologies.
Technology enablers	Innovative features that increase system reliability and performance by using advanced and efficient testing methodologies like mixed-reality testing, applicable for CCAM, ADAS, and AV.
Validation method	Assessment by expert.
Target Value	A more efficient and safer approach to testing the CCAM, ADAS, and AV system, which leads to a certifiable system and higher user trust in the new technology.

4.4.2 Environmental KVIs

Table 55: KVI - Carbon footprint reduction for Dt-UC4

KVI identifier	KVI_Dt-UC4-2-CarbonFootprintReduction
Key Value	Environmental sustainability
Description of KVI	The total CO_2 emissions generated by the operation of the ENVELOPE use case compared with state of the art or baseline.
Technology enablers	Tests and validation of new features and functionalities in the virtual environment. Reduction of the testing time on the test track as well as in the real world.
Validation method	Measurements in trials/experiments/simulations.
Target Value	Less footprint than baseline.

4.4.3 Economical KVIs

Table 56: KVI - Time to market reduction for Dt-UC4

KVI identifier	KVI_Dt-UC4-3-TimeToMarketReduction
Key Value	Economical sustainability and innovation
Description of KVI	This KVI tracks the time taken to develop and launch new solutions or technologies.
Technology enablers	Virtualization of the tests, which reduces the resources needed during test track and real-world testing.
Validation method	Assessment by expert.
Target Value	Reduction with 20% of test track and real-world testing, by test virtualization.

4.5 Dt-UC5 Tele-operated driving aided by DT

4.5.1 Societal KVIs

Table 57: KVI - User trust in CCAM for Dt-UC5

KVI identifier	KVI_Dt-UC5-1-TrustInCCAM
Key Value	Simplified life
Description of KVI	This KVI evaluates the level of public trust and willingness to adopt CCAM technologies.
Technology enablers	Advanced remote monitoring, predictive maintenance and safe teleoperation are innovative features that increase system reliability, and user trust in CCAM.
Validation method	Assessment by expert.
Target Value	More trust than baseline.

Table 58: KVI - Reduction in emergency response time for Dt-UC5

KVI identifier	KVI_Dt-UC5-2-EmergencyResponseTime
Key Value	Good health and well-being
Description of KVI	This KVI assesses the decrease in response time for emergencies.
Technology enablers	Advanced remote monitoring and safe teleoperation reduce significantly the response time in case of emergencies and allow the execution of certain emergency maneuvers via safe teleoperation.
Validation method	Measurements in trials/experiments/simulations
Target Value	Less time spent than baseline.

4.5.2 Environmental KVIs

Table 59: KVI - Energy consumption reduction for Dt-UC5

KVI identifier	KVI_Dt-UC5-3-EnergyConsumption
Key Value	Environmental sustainability
Description of KVI	The amount of energy consumed (kWh) by the ENVELOPE use case compared with the baseline.
Technology enablers	Safe teleoperation of the automated driving systems could reduce the deployment of safety drivers in case of emergency situations.
Validation method	Measurements in trials/experiments/simulations.
Target Value	Less energy consumption than baseline.

4.5.3 Economical KVIs

Table 60: KVI - OpEx reduction for Dt-UC5

KVI identifier	KVI_Dt-UC5-4-OpExReduction
Key Value	Economical sustainability and innovation
Description of KVI	Cost reduction for running the ENVELOPE system/service in comparison to baseline. These are the day-to-day expenses required to keep the business operational.
Technology enablers	Implementing advanced remote monitoring, predictive maintenance using IoT sensors and analytics can prevent costly downtime and repairs.
Validation method	Assessment by expert.
Target Value	OpEx costs less than baseline.

4.6 Gr-UC6 MEC service handover between multiple MNOs

4.6.1 Societal KVIs

Table 61: KVI - Increase in users for Gr-UC6

KVI identifier	KVI_Gr-UC6-1-IncreaseUsers
Key Value	Digital inclusion
Description of KVI	More users can be served with the ENVELOPE use case compared with the baseline: UC6 achieves accurate local situation awareness and provides traffic information notifications to a wide range of users. The current baseline is zero.
Technology enablers	Ubiquitous and resilient 5G service, network slicing for network KPIs assurance.
Validation method	Questionnaires, interviews or focus groups.
Target Value	Successful pilot demonstration, positive feedback in the majority of questionnaire responses.

Table 62: KVI - User trust in CCAM for Gr-UC6

KVI identifier	KVI_Gr-UC6-2-TrustInCCAM
Key Value	Simplified life
Description of KVI	This KVI evaluates the level of public trust and willingness to adopt CCAM technologies: User trust in CAM increased due to information sharing and the establishment of accurate situation awareness that can justify automated decisions.
Technology enablers	Quality on Demand, Traffic Influence, service continuity in cross-domains.
Validation method	Questionnaires, interviews or focus groups.
Target Value	Successful pilot demonstration, positive feedback in the majority of questionnaire responses.

Table 63: KVI - Reduction in accident rates for Gr-UC6

KVI identifier	KVI_Gr-UC6-3-AccidentRateReduction
Key Value	Good health and well-being
Description of KVI	This KVI assesses the effectiveness of ENVELOPE solutions in preventing accidents through early hazardous information notification.
Technology enablers	Driver assistance system that helps reducing safety risks, predictive QoS.
Validation method	Assessment by expert.
Target Value	Reduction of accidents due to early notification of hazards ahead, compared with baseline.

4.6.2 Environmental KVIs

Table 64: KVI - Reduction of travel time and associated emissions for Gr-UC6

KVI identifier	KVI_Gr-UC6-4-TravelTimeEmissions
Key Value	Environmental sustainability
Description of KVI	This KVI assesses the reduction of average travel time spent by citizens. Rerouting with more optimal paths can be achieved due to the information sharing
Technology enablers	Highly available and resilient service.
Validation method	Assessment by expert.
Target Value	Less average travel time due to reduction of waiting times in traffic lights.

4.6.3 Economical KVIs

Table 65: KVI - Increase in productivity for Gr-UC6

KVI identifier	KVI_Gr-UC6-5-IncreaseProductivity

Key Value	Economical sustainability and innovation
Description of KVI	This KVI measures the improvement in productivity due to automation and optimization compared to baseline.
Technology enablers	Zero-touch automation, Predictive QoS.
Validation method	Assessment by expert.
Target Value	Less time spent by fleet supervisors for each vehicle compared to baseline.

Table 66: KVI - Operational cost savings for Gr-UC6

KVI identifier	KVI_Gr-UC6-6-OperationalCostSavings
Key Value	Economical sustainability and innovation
Description of KVI	This KVI assesses savings in vehicle operation and maintenance due to optimized routes, reduced idling, and real-time information sharing.
Technology enablers	Zero-touch automation, Predictive QoS.
Validation method	Assessment by expert.
Target Value	Less operational costs than baseline.

4.7 Summary

ENVELOPE has defined KVIs that are classified into three main categories: societal, environmental and economic. These KVIs are distributed among the different Use Cases within the project, ensuring that each UC addresses at least one KVI from each category. This comprehensive approach ensures a balanced and thorough evaluation of the project and each UC in terms of societal, environmental and economic impact. A summary of the defined KVI per Use Case and KVI category is shown in Table 67.

Table 67: Classification of ENVELOPE KVIs

	Societal KVIs	**Environmental KVIs**	**Economical KVIs**
It-UC1	KVI_It-UC1-1-AccidentRateReduction KVI_It-UC1-2-EmergencyResponseTime	KVI_It-UC1-3-ResourceUsageOptimization	KVI_It-UC1-4-OperationalCostSavings
It-UC2	KVI_It-UC2-1-AccidentRateReduction	KVI_It-UC2-2-ResourceUsageOptimization	KVI_It-UC2-3-CapExReduction KVI_It-UC2-4-OperationalCostSavings
Dt-UC3	KVI_Dt-UC3-1-LessStressfulMobility	KVI_Dt-UC3-2-WasteReduction	KVI_Dt-UC3-3-TimeToMarketReduction
Dt-UC4	KVI_Dt-UC4-1-TrustInCCAM	KVI_Dt-UC4-2-CarbonFootprintReduction	KVI_Dt-UC4-3-TimeToMarketReduction

Dt-UC5	KVI_Dt-UC5-1-TrustInCCAM KVI_Dt-UC5-2-EmergencyResponseTime	KVI_Dt-UC5-3-EnergyConsumption	KVI_Dt-UC5-4-OpExReduction
Gr-UC6	KVI_Gr-UC6-1-IncreaseUsers KVI_Gr-UC6-2-TrustInCCAM KVI_Gr-UC6-3-AccidentRateReduction	KVI_Gr-UC6-4-TravelTimeEmissions	KVI_Gr-UC6-5-IncreaseProductivity KVI_Gr-UC6-6-OperationalCostSavings

5 Conclusions

This document has established the Key Performance Indicators (KPIs) and Key Value Indicators (KVIs) for the ENVELOPE project, providing a framework to evaluate the technical performance and impact of the developed technologies across various dimensions, respectively. For each ENVELOPE UC, specific KPIs have been defined across categories such as network capacity, latency, operational performance, and security. Additionally, each use case includes at least one societal, environmental and economic KVI, ensuring a comprehensive evaluation that encompasses both technical metrics and the project's key values.

This comprehensive framework enables a detailed assessment of each use case's contributions to ENVELOPE's objectives, addressing both technical achievements and their societal relevance. This framework leverages established methodologies from 5G-PPP and other SNS projects.

The defined KPIs and KVIs will guide upcoming evaluation activities in WP6, providing a structured approach to monitor and assess the project's performance and impact. They will also serve as input for the deliverable "D6.1 – ENVELOPE Evaluation Methodology".

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