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Abstract

The purpose of this document is to describe the ICT4CART evaluation methodology. The main objective of the deliverable is to provide an extended set of Key Performance Indicators (KPIs) and metrics for evaluation and analysis of the ICT4CART architecture and the corresponding use cases/ scenarios. Targeting a holistic evaluation process, the deliverable specifies KPIs aimed to guide the technical performance evaluation of the proposed solution, along with appropriate metrics to support evaluation on the fronts of impact assessment.

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
AD	Automated Driving
AT	Authorization Ticket
ADAS	Advanced Driver Assistance Systems
AMQP	Advanced Message Queuing Protocol
API	Application programming interface
CAM	Cooperative Awareness Message
CAV	Cooperative Automated Vehicle
CBA	Cost Benefit Analysis
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
DENM	Decentralised Environmental Notification Message
DL	Downlink
E2E	End-to-End
EC	European Commission
ENC	ENrolment Credential
EPM	Environment Perception Model
ETSI	European Telecommunications Standards Institute
FESTA	Field opErational teSt supporT Action
GLOSA	Green Light Optimised Optimised Speed Advisory
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Human-machine interface
HTTP	Hypertext Transfer Protocol
HW	Hardware
IAM	Identity and Access Management
IA-M	Impact Assessment Metric

ICT	Information & Communication Technology
IoT	Internet of Things
IT	Information Technology
ITS	Intelligent Transport Systems
ITS-G5	Wi-Fi (WLAN) communication standard based on IEEE 802.11a
IVIM	Infrastructure to Vehicle Information Message
I2V	Infrastructure to vehicle
L3, L4	Level 3 and level 4 driving levels of the automated driving system
LiDAR	Light Detection and Ranging
LTE	Long-Term Evolution
MAPEM	MAP (topology) Extended Message
MEC	Multi-Access Edge Computing or Mobile Edge Computing
MNO	Mobile Network Operator
NTRIP	Networked Transport of RTCM via Internet Protocol
OBU	On-board unit
OEM	Original Equipment Manufacturer
OSRM	Open Source Routing
OS	Operating System
POI	Point of Interest
PoO	Point of Observation
PoV	Proof of Value
QoL	Quality of Life
RSU	Road-Side Unit
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SCN x.y	Scenario x.y
SPATEM	Signal Phase And Timing Extended Message
SUS	System Usability Scale
SW	Software
TCP/IP	Transmission Control Protocol/Internet Protocol
TE-KPI	Technical Evaluation Key Performance Indicator
TFT	Traffic Flow Type
TLA	Traffic Light Assistance
TM Centre	Traffic Management Centre
UE	User Equipment
UC	Use Case
UDP	User Datagram Protocol
UL	Uplink
UTC	Coordinated Universal Time
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2V	Vehicle to Vehicle
V2X	Vehicle to anything
Wi-Fi	Wireless Fidelity (WLAN IEEE 802.11 Standard)
WLAN	Wireless local area network (IEEE 802.11 Standard)
WP	Work Package

Table 1: Abbreviations and Acronyms

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Executive Summary

The aim of the ICT4CART project is to design, implement and test a versatile ICT infrastructure in real-life conditions, which will enable the transition towards higher levels of automation. It focuses on four high-value use cases: Smart Parking & IoT services, dynamic adaptation of vehicle automation level based on infrastructure information, intersection crossing (urban) & lane merging (highway), and cross-border Interoperability. ICT4CART use cases have been carefully selected based on specific criteria, which are: i) alignment with EU policy and relevant forums and initiatives, ii) significant impact on connected automation, iii) the ability to generalise on the results (applicable in other scenarios and environments), and iv) interest to the consortium members and relevance to their industrial roadmaps. Moreover, these use cases are serving one of the main targets of the project, which is to show that the proposed and implemented ICT infrastructure architecture is flexible, adaptable and can serve the needs of various automated driving use cases (safety, comfort, etc.) with different requirements, across test sites with different capabilities. The ICT4CART use cases can be global or

local, can be associated with network slices or not, can use Edge Clouds/Computing or not, can use different radio technologies and can be used everywhere (roaming aspect). They also consider mechanisms for cyber-security, authentication, integrity and privacy. For this purpose, four test sites are involved in ICT4CART, namely in Austria, in Germany, in Italy and a cross-border site at the Austrian-Italian borders.

The main objective of WP8 is to evaluate the ICT4CART architecture through the proposed scenarios defined for each test site. Since ICT4CART deals with many different components, multiple use cases and novel architectural solutions, its actual evaluation becomes pivotal and inartistically multifaceted. WP8 will evaluate and validate each logical component of the proposed architecture (D3.1-D3.4) and its potential impact (impact assessment), validate the proposes use cases (D2.1) and finally evaluate the overall role of the infrastructure in enabling the transition towards road transport automation.

First, the introduction in Section 1 describes the aims of ICT4CART, i.e., the design and deployment of the ICT4CART technologies on the test sites covering all use cases. Section 2, presents the KPIs and metrics framework to be used in ICT4CART, whereas Section 3 and Section 4 present the set of the Technical KPIs and Impact assessment metrics accordingly. Section 5, presents the technical evaluation methodology to be employed in Task 8.2 “Technical Performance Evaluation” of the project, whereas Section 6 present the generalization methodology to be employed and the simulation schemes that will allow the consortium to test the ICT4CART architecture under real network and road traffic situations for a specific demanding scenario. Section 7, is devoted to the impact assessment evaluation methodology that will be employed in Task 8.3 “Impact Assessment” of the project, whereas Section 8 presents the cost analysis and market sustainability methodology to be employed in Task 8.4 “Cost Analysis and Market Sustainability” of the project. Finally, Section 9 concludes the report.

1 Introduction

1.1 Aim of the project

Today, significant and rapid advances in both telecommunication and IT industries can be accredited to fast-growing disruptive technologies. Amongst these, the ETSI ITS-G5 technology can be considered a mature and accessible technology with widely accepted norms and easily available products. Moreover, the 5G technology is evolving rapidly and features low cost and rapid deployment since it can use existing base stations. In the light of the above, several ICT challenges related to connectivity, data management, cyber-security and ICT infrastructure architectures still play a significant role and need to be addressed in order to enable road vehicle automation. Thus, it is of utmost importance for vehicle automation to work on the direction of advancing the digital and ICT infrastructure, taking also into consideration the limitations in both resources and investments in the physical transport infrastructure.

ICT4CART aims to address the gaps of the deployment by bringing together key players from automotive, telecom and IT industries, to shape the ICT landscape for Connected and Automated Road Transport, and to boost the EU competitiveness and innovation in this area.

The main goal of ICT4CART is to design, implement and test a versatile ICT infrastructure in real-life conditions, which will enable the transition towards higher levels of automation (up to L4) addressing existing gaps and working with specific key ICT elements, namely hybrid connectivity, data management, cyber-security, data privacy and accurate localisation. ICT4CART builds on high-value use cases (urban and highway), which will be demonstrated and validated in real-life conditions at the test sites in Austria, Germany and Italy. Significant effort will also be put into cross-border interoperability, setting up a separate test site at the Italian-Austrian border.

1.2 Purpose of the document

The purpose of this document is to describe the ICT4CART evaluation methodology. The main objective of the deliverable is to provide an extended set of Key Performance Indicators (KPIs) and metrics for evaluation and analysis of the ICT4CART architecture and the corresponding use cases/ scenarios. Targeting a holistic evaluation process, the deliverable specifies KPIs aimed to guide the technical performance evaluation of the proposed solution along with appropriate metrics to support evaluation on the fronts of impact assessment. KPIs/metrics are an essential part of the evaluation strategy of different technological applications and approaches. Automated driving solutions have far-reaching implications and, to understand them properly, one must address several issues. KPIs capture and detail performance measurement results, helping stakeholders to evaluate the performance of a deployment. The challenge is to select the proper set of KPIs to ensure that all the deployments and trials are using indicators aligned with their goals. It is, therefore, crucial to research and understand the KPIs that are important and specific to the ICT4CART ecosystem. To this end, the proposed KPI/metric set aims to be extensive enough to enable the thorough assessment of the involved technologies and all the use cases (UC) defined in D2.1, and spans from purely technical KPIs to impact assessment metrics.

Besides the KPIs/metrics, D8.1 defines a clear set of evaluation objectives aimed to clarify the targeting of the evaluation methodology. This includes a detailed definition of the nature of the evaluation results sought after, namely specifying the target challenges and the corresponding questions to be answered so that ICT4CART eventually derives and delivers to the community a set of conclusions regarding the transitions towards higher level of automation. On the technical evaluation front, D8.1 provides a rigorous description of the evaluation methodology by delivering a precise description of the states of the network and application components along with events taking place due to mobility.

Furthermore, the deliverable provides a generalisation methodology that will be used in order to project the experimental results from the trial sites to more complex and scalable environments through means of simulations. Although the deliverable puts particular weight on the technical performance evaluation methodology, it also establishes the evaluation methodology for the Impact Assessment activities in ICT4CART and for the Cost-Benefit Analysis (CBA) that will be employed.

1.3 Intended readership

This deliverable is addressed to any interested reader (i.e., PU dissemination level) who wishes to be informed of the evaluation framework that is used in ICT4CART project to evaluate and validate the use cases and scenarios defined in D2.1 (also PU dissemination level) and the corresponding ICT4CART reference architecture defined in D3.1 (also PU dissemination level).

2 KPIs and metrics framework

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

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

2.1 Technical evaluation KPI framework

For each selected KPI, a series of information elements are provided as described in Table 2 below.

Table 2: Technical Evaluation KPI definition template

Title	Title of the KPI: *TE-KPIx-ShortTitle* *TE*: Technical Evaluation *x*: KPI index
Description	High level description of KPI
Where to measure	Points of measurement/observation (PoO) e.g., User Equipment (UE), On-Board Units (OBUs), Application Server, etc.
How to measure	A high-level description of the measurement methodology, including (where applicable): • Detailed definition of KPI e.g., what timestamps to use for latency, which packets to consider for throughput, etc. • Key (functional) requirements for the measurements e.g., endpoint synchronization, background, traffic generation (if any), etc. • Key varying parameters e.g., background traffic, vehicle speed, video encoding, etc.
Comments	*(Optional)*

Unless otherwise stated, the identified KPIs refer to the performance perceived on an end-to-end (E2E) application level. Subject to the exact nature of each UC and the deployment scenario, the E2E application level scope may terminate at the “Edge” segment or even beyond the infrastructure edge.

2.2 Impact assessment metrics framework

The purpose of Impact Assessment is to assess the potential business and societal impacts of the systems and UCs demonstrated in the sites in the context of ICT4CART project. To this end, a series of metrics are identified for the support of a qualitative analysis on the corresponding benefits. As detailed in Section 4, the identified metrics aim to capture aspects related to the improvement of personal mobility, traffic flow efficiency, traffic safety, and business impacts. Unless otherwise stated, the identified metrics will be assessed through means of interviews with end-users and stakeholders, as well as observations of the actual demonstrations, and as such, they present a common, unified measurement methodology. Table 3, presents the Impact Assessment metric definition template including the adopted naming convention.

Table 3: Impact Assessment metric definition template

Title	Title of the KPI: *IA-Mx-ShortTitle* IA-M: Impact Assessment-Metric x: metric index within sub-category
Description	High level description of KPI

3 Technical Evaluation KPIs

The following tables present the set of KPIs selected for the technical performance evaluation in ICT4CART.

Table 4: TE-KPI1-End-to-End Transport Latency

Title	**TE-KPI1-End-to-End Transport Latency**
Description	Elapsed time from the moment a data/C-ITS message is available at the source application instance to the moment it is received by the destination application instance(s). An application instance is a vehicle HMI, OBU, RSU, and/or application on a server.
Where to measure	UEs/OBUs and/or Application Server. The selection of the exact end-points depends on the application deployment specifics, for instance with regard to the availability/usage of a MEC solution for the deployment of the Application Server, the use of V2V communications, in which case the two application ends reside, both, on vehicles, etc.
How to measure	At the source node, a timestamp is added in the application layer to the application packet the moment the packet is delivered to the application's (data source) OS/network stack for transmission. Latency is measured the moment the packet is received at the application layer at the destination node. This requires the synchronization of the source and destination points. As different network segments, e.g., backhaul vs. core vs. access segments, contribute to the overall end-to-end latency captured by this metric, further measurements may optionally apply. For instance, focus on intermediate points in the network, e.g., measuring the latency component of the backhaul network segment. In such cases, measurements take place on the network or link layer, rather than the application layer.
Comments	This KPI aims to capture the end-to-end transport latency as perceived at the application layer. As such, the measurement values will also include delay components owing to local processing i.e., from the moment the packet is received at the link layer up until its delivery to the application layer. To arrive at a precise latency value, the systems taking timestamps need to either have synchronized clocks or the offset of the used clock to UTC needs to be specified. This KPI can be measured both for the short-range and the long range communication schemes.

Table 5: TE-KPI2-End-to-End Application Latency

Title	**TE-KPI2-End-to-End Application Latency**
Description	Elapsed time interval from the time instant at which raw data are available from sensors at the source application to the time instant the transmitted C-ITS message is processed on the vehicle-side and information is provided to the destination application instance(s). An application instance is a vehicle HMI, OBU, RSU, and/or application on a server.

Where to measure	UEs/OBUs and/or Application Server. The selection of the exact end-points depends on the application deployment specifics, for instance with regard to the availability/usage of a MEC solution for the deployment of the Application Server, the use of V2V communications, in which case the two application ends reside, both, on vehicles, etc.
How to measure	At the source node, a timestamp is logged at the moment at which the raw data are made available at the source application. This timestamp can be added in the application packet (e.g., C-ITS message) to be delivered. Latency is measured the moment the information of a packet is received by the destination application instance(s). This requires the synchronization of the source and destination points. Additional timestamps can be logged and, if needed, added to the application packet to identify the different contributions (e.g., raw data processing time, application packet coding, application packet processing at destination, etc.) of the end-to-end application latency.
Comments	This KPI aims to capture the end-to-end application latency as perceived at the application layer. This information is useful to understand the time effectiveness of a given application, i.e., if the application can provide enough fresh information to the destination application. Also, the C-ITS messages can be measured here to evaluate this KPI (how long it takes from the data entry in the road operator backend system until the message is received in the vehicle). To arrive at a precise latency value, the systems taking timestamps need to either have synchronized clocks or the offset of the used clock to UTC needs to be specified. This KPI can be measured both for the short-range and the long-range communication schemes.

Table 6: TE-KPI3- Communication Reliability

Title	**TE-KPI3- Communication Reliability**
Description	Amount of application layer packets successfully delivered to a given system node within the time constraint required by the targeted service, divided by the total number of sent network layer packets.
Where to measure	UEs/OBUs and/or Application Server
How to measure	Measurements build on the comparison between the number of packets sent and received within a certain time constraint, thus require the logging of the corresponding information on a source-destination level. The measurement will take place on an application level. Time constraints depend on the actual application context and will be defined on a per Scenario base.
Comments	The same KPI can also be measured with the C-ITS messages (the number of successfully received C-ITS messages in the vehicle is compared with the total number of disseminated messages). This KPI is the same as the packet loss ratio metric.

Table 7: TE-KPI4- Position Accuracy

Title	**TE-KPI4- Position Accuracy**
Description	Deviation between the ground truth (actual position on earth) and the measured position of a UE via RTK positioning services.
Where to measure	UE, Network
How to measure	In the corresponding UE/vehicle by comparing a well-known position (marked point on earth) to the position retrieved from a GNSS (Global Navigation Satellite System) including correction data by RTK. The measurement must be repeated and averaged. The KPI will be measured under different conditions, i.e., on different locations with either clear sky view or limited satellite visibility (rural and urban environments).

Table 8: TE-KPI5-Application Level Handover Success Rate

Title	**TE-KPI5-Application Level Handover Success Rate**
Description	Applies to scenarios where an active application level session (e.g., communication between application client at UE/OBU and the Application Server) needs to be transferred from a currently used to a new application instance (e.g., located on different MEC hosts) as a result of a cross-border mobility event. The KPI describes the ratio of successfully completed *application level handovers* i.e., where service provisioning is correctly resumed/continued at the new application instance following a network level handover.
Where to measure	UE/OBU and/or Application Server / MEC Hosts
How to measure	On the UE side, the application level components will timestamp and log all successful communication interactions with the Application Server (subject to the specificities of the corresponding scenario). Similar timestamping and logging at both the source and destination Application Servers shall complete the full picture of events prior, during and post-handover. Logged information will include the identification of Application Server instance, as well as user identifiers. Synchronization between UEs/OBUs and Application Servers is required.

Table 9: TE-KPI6-Mobility interruption time

Title	**TE-KPI6-Mobility interruption time**
Description	The time duration during which a user terminal cannot exchange packets with any base station (or other user terminal) during transitions. The mobility interruption time includes the time required to execute any radio access network procedure, radio resource control signalling protocol, or other message exchanges between the mobile station and the radio access network.
Where to measure	UE (Access points)
How to measure	Measurement shall be primarily contacted on the involved UEs, taking into account their local state with respect to their association to the network. Access point logging support can be used to cross-validate UE state transitions. This KPI requires the synchronization of UE and access points.

Table 10: TE-KPI7- Takeover/Vehicle level handover time gained

Title	**TE-KPI7- Takeover/Vehicle level handover time gained**
Description	Extra time gained for a takeover action by using ICT4CART solutions compared to available time when relying on vehicle sensors alone.
Where to measure	UE (Access points)
How to measure	Measurement shall be primarily conducted on the involved UEs with the help of external observation. Based on the scenario the measurement can be: • A vehicle user should measure the time for completing a task/ manoeuvre with and without the ICT4CART infrastructure support. • The CAV system should measure the time difference between event perception and handover of the steering wheel to the driver with and without the ICT4CART infrastructure.

Table 11: TE-KPI8-Map Matching successful ratio

Title	**TE-KPI8- Map Matching successful ratio**
Description	Successfully matched points over unsuccessfully or wrongly matched points measured at the map matching frequency.
Where to measure	OBU/Vehicle
How to measure	The vehicle should follow a fixed track into the test site. For each execution of a trial, the system should log GNSS position and map matching position output. Then, the position estimated by the map matching algorithm will be checked point-by-point and the KPI value is computed as: $MapMatch = \frac{n_{success}}{n_{success}+n_{notmatched}+n_{error}}$
Comments	The map matching could be implemented as an online and/or offline algorithm. $n_{success}$ is the total number of points that are successfully matched on the map; $n_{notmatched}$ is the total number of points the map matching algorithm cannot match to any point on the map; n_{error} is the number of points that are wrongly matched on the map.

Table 12: TE-KPI9- Driver comfort

Title	**TE-KPI9- Driver comfort**
Description	Speed profile, acceleration/deceleration profile comparison with ICT4CART infrastructure support and with vehicle sensors only.
Where to measure	UE
How to measure	Measurement shall be primarily contacted on the involved UEs. For each execution of a trial, the system should log the speed (or acceleration/ deceleration profile) for completing the given task/manoeuvre. Higher speed or less acceleration/deceleration instances compared to a benchmark profile means a higher driver comfort.
Comments	For each examined scenario a benchmark reference profile shall be defined to be used as a reference (% of time during the manoeuvre in which the vehicle deceleration/acceleration is out of the comfort zone +/- 2 m/s^2. Example: the next traffic light will become soon red and the vehicle has to stop. Using the GLOSA the vehicle could be stopped and stay in the comfort acceleration/deceleration zone for 90% of the manoeuvre time).

3.1 Use cases and target KPI values

The objective of the Technical Evaluation process is to assess the identified KPIs in the context of the targeted Use Cases (UCs) and Scenarios (SCNs) with target KPI values, i.e., values that correspond to the target performance of the network, as this adheres to the requirements of each SCN. Table 13, below presents the identified Target Values for a series of Technical Evaluation KPIs.

Table 13: TE-KPI Target Values per Use Case/Scenario (Part I)[1]

	Scenario	**TE-KPI1 (*ms*)**	**TE-KP2 (*ms*)**	**TE-KPI3 (*%*)**	**TE-KPI4 (*cm*)**	**TE-KPI5 (%)**	**TE-KPI6 (*s*)**	**TE-KPI7 (s)**	**TE-KPI8 (%)**	**TE-KPI9 (%)**
UC1–Smart Parking & IoT services	**SCN1.2: SPIoTCDV**								90	
UC2– Dynamic adaptation of vehicle automation level based on infrastructure info.	**SCN2.1: DAVAGRAZ**		3000	100				20		
	SCN2.2: DAVATRN	30 (ITS-G5), 55 (LTE)	300 (ITS-G5), 500 (LTE), **IAM** 700 **ENC** request 500 **AT** request	75% for ITS-G5 within 500 m from ITS-G5 RSU in LoS, 99% for LTE	<20 in open sky conditions with mass market RTK receiver					
	SCN2.3: DAVACDV	30 (ITS-G5), 55 (LTE)	300 (ITS-G5), 500 (LTE) **IAM** 700 **ENC** request 500 **AT** request	75% for ITS-G5 within 500m from ITS-G5 RSU in LoS, 99% for LTE	<20 in open sky conditions with mass market RTK receiver					
UC3 – Intersection crossing and	**SCN3.1a: VMULM**	25	350-400 de-pending on sensor							

[1] Note that SCN1.1:SPIoTULM will be evaluated through extended simulations described in Section 6.

	Scenario	TE-KPI1 (ms)	TE-KP2 (ms)	TE-KPI3 (%)	TE-KPI4 (cm)	TE-KPI5 (%)	TE-KPI6 (s)	TE-KPI7 (s)	TE-KPI8 (%)	TE-KPI9 (%)
			setup							
	SCN3.1b: VMCDV	30 (ITS-G5), 55 (LTE)	300 (ITS-G5), 500 (LTE) **IAM** 700 **ENC** request 500 **AT** request	75% for ITS-G5 within 500m from ITS-G5 RSU in LoS, 99% for LTE	<20 in open sky conditions with mass market RTK receiver					
	SCN3.2: GLOSA									90
	SCN3.3: LMBRE	30 (ITS-G5), 55 (LTE)	300 (ITS-G5), 500 ms (LTE) **IAM** 700 **ENC** request 500 **AT** request	75% for ITS-G5 within 500m from ITS-G5 RSU in LoS, 99% for LTE	<20 in open sky conditions with mass market RTK receiver					
	SCN3.4: PPRTK				4[2]					
UC4 – Cross border interoperability	**SCN4.1: DAVAXBR**		3000	100		100	*[3]	20		

[2] The reference point(s) for the location accuracy measurements are known with a location accuracy of 2cm. The TE-KPI4 value for SCN3.4 of 4cm includes the reference point(s) location inaccuracy.

[3] During the preparation of the deliverable and due to the extended lockdown, the initial integration and testing has been delayed and the consortium was not able to define a target value for TE-KPI6 for SCN4.1. This will take place along T8.2 and the actual evaluation of the corresponding UC.

4 Impact Assessment metrics

In the ICT4CART context, it is intended to sketch a Proof-of-Value (PoV) based on the outcomes of the test sites operation. The impact assessment will first focus on the validation of the proposed UCs, hence, it will assess the value of the ICT4CART solutions, paying particular attention to the end-user. As such, the impact analysis focuses on Quality of Life (QoL), Business impacts and Cost Benefit Analysis. The objective of the impact assessment, and in particular, the cost analysis and market sustainability is to assess the potential business and societal impacts of the systems and applications demonstrated in the involved sites. In the course of the project, and in T8.3 in particular, impact assessment will be mostly realized as a qualitative analysis. Input will be collected mainly through interviews and questionnaires to end-users and stakeholders as well as an extensive literature search. Additionally, T8.4 will perform an assessment of the costs and the benefits for the different stakeholders.

Table 14: Impact Assessment metrics

IA-M1- Increase/decrease of traffic (transport) flow: speed
Traffic efficiency increases when utilizing ICT4CART solution compared to existing traffic, as speed increases and as standard deviation of speed decreases. This metric shall be assessed through GPS and accelerometer data generated by trials, where applicable (apart from questionnaire). Additionally, expert interviews will enhance view on the traffic flow improvement. Traffic flow speed will be turned to percentage improvement values.
IA-M2- Manoeuvre completion time
The total time it takes from when the examined manoeuvre is initiated until it has been completed. E.g., a lane merging manoeuvre can be completed within “x” seconds given certain car velocities, weather conditions, comfort aspects and safety requirements. This metric shall be assessed through data from the OBU and or Application Server. Manoeuvre completion time will be compared to traditional driving and findings are turned to percentage values of time savings.
IA-M3-Decrease of automation level (False positives)
This metric aims to capture the cases where the driver took back control of the vehicle because of an unexpected safety issue monitored by the system (existing or falsely triggered). This is related to the comfort feeling of the driver. Objective aspects will be investigated e.g., automated driving Application Server/ OBU log data, in an effort to cross-validate the driver decision (where applicable). The expert interviews will be used to count the number of cases where the driver took back control of the vehicle. This metric can also capture false positives in the sense that action have been triggered due to a false interpretation of traffic/road status by the ICT4CART infrastructure.
IA-M4 - Costs of infrastructure deployment
Whole-life infrastructure costs to operators (road and telecom) of implementation of the ICT4CART systems will be estimated. Infrastructure costs will be analysed as a part of cost-benefit studies in T8.4. This metric will be used for the analysis of Cost-Benefit-Analysis of ICT4CART technologies implementation.
IA-M5- Revenue potential for operators

There may be multiple operators, including infrastructure and service operators; each will want to know the impact on themselves (financial). Revenue for main stakeholders will be estimated in the context of T8.4.
IA-M6 - Business cases maturity
Based on the rest of the business-related metrics, the maturity of the business cases will be analysed by interviewing trial site experts and business experts in the consortium. Here, the maturity of the business will be estimated. It is critical to identify commercialization roles around the business model.
IA-M7 – Market sustainability
The likelihood that the costs associated with deploying ICT4CART solutions will be affordable, cost-effective and lead to long-term commercially sustainable propositions. Market sustainability will be measured using three different metrics, depending on the outcomes of the cost analysis: • Cost/benefit ratio – Will the investment provide purchasers with an acceptable level of return over a defined timescale? • Benchmarking – Does the level investment required broadly align with costs associated with established comparable investments? • Alternative solution comparison – How does the level of investment compare with what purchasers would need to spend to gain equivalent benefits through different means? Operators (road network and telco) within ICT4CART will help set suitable metrics for each based on established investment decision making practices.

5 Technical Evaluation Methodology

This section describes the technical performance evaluation methodology and the information to be "logged" during the trials to enable offline validation of the KPIs as defined in Section 3. In order to compute the technical KPIs, a number of measurements at relevant points (the "points of observation" PoO) need to be taken. Here, we also describe the concept of PoO and identify possible locations within the ICT4CART architectural structure, i.e., the deployment of all components (mobile network, ITS infrastructure, UEs/OBUs and application) required to validate a SCN.

A Point of Observation (PoO), in the context of the project test methodology, is a specific point within the architecture of the system, at which either an observation (measurement) is recorded or data is injected. A PoO should combine all the technical solutions needed to gather the data (measurements) that have to be collected to later process and calculate the KPIs. At specific cases, a PoO should also provide the capability of injecting traffic packets in the system under test to be able to set the adequate scenario so that the relevant KPI can be computed out of the measurements taken.

After performing the measurements, an Extract, Transform and Load series of actions take place to convert the data into a suitable data format (Task 7.7 of WP7). The formatted data will be processed accordingly and the output will be the calculated KPIs.

Finally, the data processing step consists of taking the formatted data and applying a set of filtering and processing calculations to finally obtain the KPIs' values. This will be done using data processing tools and scripting languages.

There are two basic layers/options where the capturing of the evaluation measurements (introduction of a PoO) can take place: The **ITS stations** (vehicles-OBU, RSUs, connected sensors, connected traffic lights, etc.) and the **ITS application centre/server** (OEM Backend, Service provider, MEC server[4], etc.).

The PoOs will be located at relevant communication interfaces. In terms of communications, there are two relevant communication channels where interfaces to be observed and/or data injected can be located:

- ITS station to ITS app communication channel, and/or
- ITS station to ITS station communication channel.

For the purpose of the ICT4CART evaluation process, every type of ITS message (i.e., CAM, DENM, CPM, SPATEM, MAPEM, etc.) sent or received via V2X shall be appropriately logged to enable the Extract, Transform and Load series of actions mentioned above.
The minimum data to be collected is:

- **Timestamp**: It shall be set to a precise absolute time obtained by the GNSS component of ITS station or the network. If the precise absolute time is not available a method to compensate the drift shall be investigated.
- **Precise location**: Provided by reference navigation systems, ITS messages (from messages that contain location information), or any other method.
- **Identity of the ITS station**: log of the StationID field used in C-ITS messages.
- **Direction of communication:** Uplink (UL) or Downlink (DL).
- **C-ITS message type**: type of the logged C-ITS message (i.e., CAM, DENM, CPM, SPATEM, MAPEM, IVIM, etc.).

[4] The MEC Server is located behind the mobile network, connected to it via the GSi interface to the PGW and can be considered as one instance of an application server.

5.1 SCN-based technical KPIs evaluation

The evaluation process of each ICT4CART SCN (presented in D2.1) heavily depends on the characteristics of the SCN primarily demonstrated by the different traffic flow types involved, i.e., each SCN may be composed of multiple traffic flow types with different requirements and characteristics. We shed light on these aspects by employing the following two template tables.

Table 15, is used for the definition of the various traffic flow types (TFT) identified in each of the SCNs (fields self-explanatory). Based on the traffic flow type definition, we present the data collection specificities identified for each selected KPI on a per SCN and per traffic flow type basis. Table 16, provides an explanation of the selected data collection methodology aspects.

Table 15: SCN Traffic Flow Type - Template

SCN	***TFT name***	***Description***	***UL/DL***

Table 16: Per SCN TE-KPI Traffic Flow Type - Template

TE-KPI	*Selected KPI, as defined in Section 3.*
Traffic Flow	*The traffic flow type at hand, as previously identified. Subject to SCN specificities, not all flow types may be subject to the corresponding KPI evaluation.*
PoO	*The selected Point of Observation for this KPI and flow e.g., OBU, gNB, MEC, Application Server, etc.*
Protocol/Layer	*Protocol employed at the selected PoO, MPEG-DASH, and actual network layer* • *Transport: TCP, UDP, etc* • *Network: IP, etc* • *Application:* CAM, DENM, CPM, SPATEM, MAPEM, etc.
Logging Frequency	*The frequency of data logging: can follow the application message rate by logging all exchanged traffic, or indicate a lower sampling rate.*
Logging Information	*Describe here the logging information you use for the measurement of the KPI. Indicative examples can be found in Section 5.*

For some KPIs (e.g., TE-KPI4- Position Accuracy), there are no specific traffic flows to be measured. For those KPIs where the metric is only a punctual measurement of, e.g., the position provided by two different positioning systems, there will be no flows to be defined (i.e., the Traffic flow entry should be "N/A—Static/Punctual measurement") and the corresponding PoO will be a singular point (e.g., an ITS station).

Table 17: ICT4CART SCN Traffic Flow Types

SCN[5]	**TFT name**	**Description**	**UL/DL**
1.2	Smart Parking Traffic Flow	The Smart Parking traffic flow starts with information for availability of free slots which are sent to the cloud infrastructure. From the cloud infrastructure, a specific point of interest ITS message is created and sent to the vehicle through an AMQP Broker. The vehicle receives the messages	UL/DL

[5] SCN1.1:SPIoTULM will be only evaluated through simulations.

		containing the digital map of the area and map match itself on the digital map using the GNSS data.	
2.1, 4.1	Infrastructure Automation Level Guidance Traffic Flow	This traffic flow starts with the storage of the data set in the backend system of the road operator, for the corresponding road section; this information is then provided to the C-ITS system which creates an IVI message; the IVI message is published on the AMQP broker and broadcasted by the relevant RSUs; the OBU receives the message (via ITS-G5 and/or AMQP) and provides the Automation Level Guidance to the ADAS module.	DL
2.1, 4.1	Infrastructure Hazardous Location Notification Traffic Flow	This traffic flow starts with the storage of the data set in the backend system of the road operator, for the corresponding traffic event; this information is then provided to the C-ITS system which creates a DEN message; the DENM is published on the AMQP broker and broadcasted by the relevant RSUs; the OBU receives the message (via ITS-G5 and/or AMQP) and provides the Hazardous Location Notification to the ADAS module.	DL
2.2, 2.3, 3.1b, 3.3	Collective Perception Traffic Flow	This traffic flow starts with data from camera and LiDAR sensors, attached to the Perception Processing Platform that processes the raw data for extracting perception information; this processed information is then provided to the Collective Perception Service for building the Collective Perception Messages (CPM) that are transmitted to the OBU of the Connected and Automated Vehicles; the OBU extracts relevant information from CPM and it provides this data to the ADAS module.	DL
2.2, 2.3, 3.1b, 3.3	Collision Warning Traffic Flow	This traffic flow starts with data from camera and LiDAR sensors attached to the Perception Processing Platform that processes the raw data for extracting perception information; this information is then provided to the Anti-Collision service that, if required, sends a DENM to the OBU of the Connected and Automated Vehicles; the OBU extracts the warning information from the DENM and it provides the collision risk warning to the ADAS module.	DL
2.2, 2.3, 3.1b, 3.3	Identity and Access Management (IAM) Traffic Flow	This traffic flow starts with the request of a certificate from OBU/RSU to the Identity and Access Management center that processes the request and replies to the OBU/RSU with the content corresponding to the request.	UL/DL
3.1a	Collective Perception Traffic Flow in Ulm test site	This traffic flow starts with data from camera and LiDAR sensors, which is then processed by attached Sensor Processing Units in order to generate object detections. These detections are sent via cellular network to a MEC server, on which a Collective Perception Service calculates a fused Environment Perception Model (EPM) via object	DL

		tracking. Additionally, predictions of this EPM are calculated. The EPM and its predictions can then be encoded in Collective Perception Messages (CPM) or extensions of that standard. These messages are transmitted either directly via LTE/5G network to the OBU of the Connected and Automated Vehicles, or indirectly, in which case the messages are first sent via cellular network to RSUs which then forward them via ITS-G5 to the vehicle OBUs.	
3.2	Green Light Optimized Speed Advice (GLOSA) Traffic Flow	This traffic flow starts with feedback from the controllers about the state of the traffic light and the position of the vehicle. Then TM Center sends the SPAT and MAP messages to the TLA application server, installed on MEC, to provide the optimized speed and send it to the vehicle (TLA application client) via the LTE/5G mobile network. Then the anonymized GPS traces are recorded and sent to the center to provide the acceleration graph.	UL/DL

Table 18: SCN1.2 TE-KPI8 smart parking traffic flow details

TE-KPI	TE-KPI8
Traffic Flow	Smart parking traffic flow of SCN 1.2
PoO	OBU for the source application and OBU for the destination application
Protocol/Layer	Protocol employed • Network and Transport: ITS-G5 stack (BTP and GeoNetworkng) - LTE/5G and AMQP for MEC-based solution • Application: ETSI POI (Point of Interest)
Logging Frequency	Logging each message received, depending on the periodicity of the source application, maximum frequency 10 Hz.
Logging Information	At the source application: • ETSI POI messages sent At the destination application: • ETSI POI messages received

Table 19: SCN2.1 & SCN4.1 TE-KPI2 infrastructure automation level guidance and infrastructure hazardous location notification flow details

TE-KPI	TE-KPI2
Traffic Flow	Infrastructure Automation Level Guidance Traffic Flow of SCNs 2.1, 4.1 Infrastructure Hazardous Location Notification Traffic Flow of SCNs 2.1, 4.1
PoO	Road operator back-end server for the source application and OBU for the destination application
Protocol/Layer	Protocols employed: • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) for RSU-based solution - LTE/5G and AMQP for MEC-based solution. • Application: IVIM, DENM.
Logging Frequency	Logging is done for every unique message IDs for the first reception (message repetitions by ITS-G5 design are ignored).
Logging Information	At the source application: • Timestamp at the source application when the data is persisted

	At the destination application: • Timestamp at the destination application when the C-ITS message is processed

Table 20: SCN2.1 & SCN4.1 TE-KPI3 infrastructure automation level guidance and infrastructure hazardous location notification flow details

TE-KPI	TE-KPI3
Traffic Flow	Infrastructure Automation Level Guidance Traffic Flow of SCNs 2.1, 4.1 Infrastructure Hazardous Location Notification Traffic Flow of SCNs 2.1, 4.1
PoO	Road operator back-end server for the source application and OBU for the destination application
Protocol/Layer	Protocols employed: • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) for RSU-based solution - LTE/5G and AMQP for MEC-based solution • Application: IVIM, DENM
Logging Frequency	Logging is done for every unique message IDs for the first reception (message repetitions by ITS-G5 design are ignored).
Logging Information	At the source application: • Timestamp at the source application when the data is persisted At the destination application: • Timestamp at the destination application when the C-ITS message is processed

Table 21: SCN2.1 & SCN4.1 TE-KPI5 infrastructure hazardous location notification flow details

TE-KPI	TE-KPI5
Traffic Flow	Infrastructure Hazardous Location Notification Traffic Flow of SCNs 2.1, 4.1
PoO	Road operator back-end server for the source application and OBU for the destination application
Protocol/Layer	Protocols employed: • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) for RSU-based solution - LTE/5G and AMQP for MEC-based solution • Application: DENM
Logging Frequency	Logging is done for every unique message IDs for the first reception (message repetitions by ITS-G5 design are ignored). Several tests will be done to capture the handover scenarios • LTE/5G to LTE/5G (ITS-G5 receiver disabled) • ITS-G5 to ITS-G5 (cellular receiver disabled) • LTE/5G to ITS-G5 or vice versa (roaming disabled) • LTE/5G and ITS-G5 or vice versa with roaming
Logging Information	At the source application: • Timestamp at the source application when the data is persisted At the destination application: • Timestamp and precise location at the destination application when the C-ITS message is processed

Table 22: SCN2.1 & SCN4.1 TE-KPI6 infrastructure hazardous location notification flow details

TE-KPI	TE-KPI6
Traffic Flow	Infrastructure Hazardous Location Notification Traffic Flow of SCNs 2.1, 4.1
PoO	Road operator back-end server for the source application and OBU for the destination application
Protocol/Layer	Protocols employed: • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) for RSU-based solution - LTE/5G and AMQP for MEC-based solution • Application: DENM
Logging Frequency	Logging is done for every unique message ID for the first reception (message repetitions by ITS-G5 design are ignored). Several tests will be done to capture the mobility interruption time in different communication channel combinations: • LTE/5G only (ITS-G5 receiver disabled) • ITS-G5 only (cellular receiver disabled) • LTE/5G and ITS-G5 without roaming • LTE/5G and ITS-G5 with roaming
Logging Information	At the source application: • Timestamp at the source application when the data is persisted. At the destination application: • Timestamp and precise location at the destination application when the C-ITS message is processed. WIND-TRE (the telecom operator at the Italian side of the cross-border test site) can also offer the ERAB (E-UTRAN Radio Access Bearer) correlated to the registration errors and the average number of ERAB users active in a given cell. It will also be possible to use the information about "critical zone" as far as the signal level is concerned; which allows an indirect evaluation of the Mobility Interruption Time.

Table 23: SCN2.1 & SCN4.1 TE-KPI7 infrastructure hazardous location notification flow details

TE-KPI	TE-KPI7
Traffic Flow	Infrastructure Hazardous Location Notification Traffic Flow of SCNs 2.1, 4.1
PoO	Road operator back-end server for the source application and OBU for the destination application
Protocol/Layer	Protocol employed: • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) for RSU-based solution - LTE/5G and AMQP for MEC-based solution • Application: DENM • Video and Radar Signals and computing • UI-Interface
Logging Frequency	Every event on the test track. Logging is done for every unique message ID for the first reception (message repetitions by ITS-G5 design are ignored). Which contains relevant information for each scenario. The internal notification from the Radar or Video for the scenarios has to be logged. Calculate the time difference between the detections or

	notifications for each event.
Logging Information	Length of time elapsed: • Time between event reception and driver notification (only CAV perception) • Time between event reception and driver notification (with ICT4CART)

Table 24: SCN2.2, SCN2.3, SCN3.1b & SCN3.3 TE-KPI1, TE-KPI2 & TE-KPI3 collective perception flow details

TE-KPI	TE-KPI1, TE-KPI2, TE-KPI3
Traffic Flow	Collective Perception Traffic Flow of SCNs 2.2, 2.3, 3.1b, 3.3
PoO	RSU/MEC for the source application and OBU for the destination application
Protocol/Layer	Protocol employed • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) for RSU-based solution - LTE/5G and AMQP for MEC-based solution • Application: CPM
Logging Frequency	Logging at each CPM received, maximum frequency 10 Hz.
Logging Information	At the source application: • Timestamp at the source application when data are made available; • CPM message sent; At the destination application: • timestamp at the destination application when C-ITS messages are processed; • CPM message received; In both PoOs mandatory logging information defined in Section 5.

Table 25: SCN2.2, SCN2.3, SCN3.1b & SCN3.3 TE-KPI1, TE-KPI2 & TE-KPI3 collision warning flow details

TE-KPI	TE-KPI1, TE-KPI2, TE-KPI3
Traffic Flow	Collision Warning Traffic Flow of SCNs 2.2, 2.3, 3.1b, 3.3
PoO	RSU/MEC for the source application and OBU for the destination application
Protocol/Layer	Protocol employed • Network and Transport: ITS-G5 stack (BTP and GeoNetworkng) for RSU-based solution - LTE/5G and AMQP for MEC-based solution • Application: DENM
Logging Frequency	Logging at each DENM received, depending on the periodicity of the source application, maximum frequency 10 Hz.
Logging Information	At the source application: • Timestamp at the source application when data are made available; • DENM message sent; At the destination application: • timestamp at the destination application when C-ITS messages are processed;

	• DENM message received; In both PoOs mandatory logging information defined in Section 5.

Table 26: SCN2.2, SCN2.3, SCN3.1b & SCN3.3 TE-KPI2 identity and access management flow details

TE-KPI	TE-KPI2
Traffic Flow	Identity and Access Management Traffic Flow of SCNs 2.2, 2.3, 3.1b, 3.3
PoO	Identity and Access Management (IAM) service for the source application and at the OBU/RSU side.
Protocol/Layer	• Transport: TCP • Network: IP • Application: HTTP
Logging Frequency	Logging at each certificate request performed by the OBU/RSU.
Logging Information	At the source application (i.e., the Identity and Access Management service): • Timestamps at the source application when the certificate request (from an OBU/RSU) is received and delivery of the response is performed; • Type of the certificate requested; At the OBU/RSU side: • Timestamps at the destination application when certificate is received; • Type of the certificate requested; In both OBU/RSU PoOs mandatory logging information defined in Section 5.

Table 27: SCN3.1a TE-KPI1 collective perception traffic flow in Ulm test site details

TE-KPI	TE-KPI1
Traffic Flow	Collective Perception Traffic Flow in Ulm test site for SCN 3.1a (RSU/MEC-Server to OBU)
PoO	OBU
Protocol/Layer	Protocols employed for LTE/5G: • Network and Transport: TCP/IP • Application: CPM + possible extensions, maybe SPATEM/MAPTEM Protocols employed for ITS-G5: • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) • Application: CPM + possible extensions, maybe SPATEM/MAPTEM
Logging Frequency	Same frequency as messages are received (10Hz)
Logging Information	Latency of communication from MEC server/RSU to automated vehicle’s OBU via LTE/5G or ITS-G5.

Table 28: SCN3.1a TE-KPI2 collective perception traffic flow in Ulm test site details

TE-KPI	TE-KPI2
Traffic Flow	Collective Perception Traffic Flow in Ulm test site for SCN 3.1a
PoO	OBU
Protocol/Layer	Protocols employed for LTE/5G: • Network and Transport: TCP/IP • Application:

	○ Sensors to MEC-Server: proprietary ○ MEC-Server to RSU/OBU: CPM + possible extensions, maybe SPATEM/MAPTEM Protocols employed for ITS-G5: • Network and Transport: ITS-G5 stack (BTP and GeoNetworking) • Application: CPM + possible extensions, maybe SPATEM/MAPTEM
Logging Frequency	Same frequency as messages are received (10Hz)
Logging Information	Total application latency, measured from timestamp of oldest corresponding sensor measurement to time of retrieval in automated vehicle's OBU. This delay includes time for sensor data processing, transmission via cellular network to MEC server, synchronization delays at the MEC server, time for calculation of the EPM on the MEC server and finally the network delay (cellular and ITS-G5).

Table 29: SCN3.2 TE-KPI9 GLOSA traffic flow details

TE-KPI	TE-KPI9
Traffic Flow	GLOSA Traffic Flow SCN 3.2
PoO	TLA application for the source application and TM Centre for the destination application
Protocol/Layer	Protocol employed • Network:IP • Transport: TCP • Application: SPATEM/MAPEM
Logging Frequency	Logging at each speed recorded, maximum frequency 1 Hz
Logging Information	At the source application: • Timestamp at the source application when vehicle speed is processed • GPS traces • Messages sent to the TM Centre At the destination application: • Messages received from TM Centre

Table 30: SCN3.4 TE-KPI4 details

TE-KPI	TE-KPI4
Traffic Flow	N/A – no traffic flow is evaluated
PoO	MEC for the source application to distribute RTK correction information and OBU for the destination application to use RTK correction information
Protocol/Layer	• Protocol employed: Ntrip (RTCM 3.2) Network and Transport: from MEC Server (Ntrip-Caster) to GNSS-Receiver • Protocol employed: NMEA-0183 Network and Transport: from GNSS-Receiver to application
Logging Frequency	Single measurements in different times of the year.
Logging	A well-known position *P* (marked point on earth) is given. A position *P* is identified

Information	by its North/South coordinate NS_P, its East/West coordinate EW_P, and height over sea-level H_P. At the well-known position P, the coordinates P_{RTK} are measured with RTK, and TE-KPI4 is the deviation of P_{RTK} from P is determined. Note that the measurements will be conducted at different times over the year as weather conditions, ionospheric activity, and satellite positions determine the measurement accuracy.

6 Generalization methodology

Due to the size of the demonstrations and the nature of the majority of the KPIs presented in this document, some of them cannot be directly obtained from actual SCN demos at the different involved sites. As such, additional methods need to be implemented to obtain a deep evaluation of the performance of the ITS SCNs involved in ICT4CART. Three alternatives are proposed to cope with this objective: i) stress the network by traffic injection to obtain the maximum performance the network is able to offer: ii) inject traffic in the network to set the network in traffic conditions equivalent to the real conditions expected in the SCNs developed (i.e., with a realistic number of users, etc.) and iii) perform simulations (outside of the network) to analyse the behaviour of the network under different mobility and data transfer scenarios.

To test and measure the performance of the ICT4CART architecture instances at each site with just a few vehicles and traffic sessions using few OBU/RSUs/mobile terminals do not represent a significant result, because these tests are more realistic when more terminal nodes stress the network and when these mobile terminals perform multiple sessions. Aiming to simulate real traffic by achieving a massive traffic test, and, therefore, getting statistical relevance out of these tests, ICT4CART will implement traffic generation schemes where applicable.

The first step in network traffic generation is understanding the network traffic behaviour, such as packet frequency, packet size, or any other features. The identification of relevant parameters enables the traffic source modelling characterization, and the creation of procedures capable to replicate the previously observed and modelled real traffic.

This approach allows, in a second step, the development of an OBU/RSU that mimics the observed traffic (that can be modelled), such CAM or CPM messages, for example. These OBUs can stress the network by injecting other synthetic vehicles' data traffic that can access the network in parallel. This approach provides a more realistic test, since other vehicles/OBUs are competing for the same network resources. One more advantage of using this approach is the process governance capability, since it is dedicated to testing proposes. The process can be better controlled according to a given test plan, since it can be controlled manually, geographic or timely. Another important advantage is being able to easily increase the number of OBUs, enabling, or getting close to, the massive test approach.

The main idea of this concept is to push each network component to the physical limits enabling multiple traffic session flows, aiming to drive the network to "massive", test conditions. This approach allows the evaluation of the network performance on some SCNs without the need of using a real fleet of vehicles.

A crucial parameter in ICT4CART is the potential behaviour of the network once a large number of vehicles employs the corresponding SCN applications considered in the project. Given the lack of such a large vehicle population, the project foresees a generalization methodology based on simulations. The purpose of this effort is to yield a fully controlled environment able to investigate the impact of larger vehicle populations on the application and network behaviour. This is expected to provide several benefits in what concerns the completeness of the evaluation process, namely:

- The total traffic generated within the simulation environment can be controlled, which will enable the investigation of the network behavior in variable load conditions without physically repeating the demo.
- The completeness of the evaluation, in terms of covered scenarios/events, can be substantially improved, covering aspects such as vehicle density, possible different weather conditions, etc.

In ICT4CART a Ride-Hailing Simulator developed by BMW will be used for the performance evaluation of SCN1.1 SPIoTULM and other simulation platforms will be used if needed for the evaluation of the rest of the SCNs. The technical details of the simulator can be found in Annex 4.

7 Impact Assessment Methodology

In this section, we shortly introduce the methodology for the Quality of Life (QoL) – User acceptance of the ICT4CART that will be conducted in the course of T8.3 of the project. The procedure and recommendations of FESTA[6] handbook will be a starting point for the methodologies but the approach is adapted based on the scope and scale of the planned demos/trials.

The aim of the QoL assessment is to identify potential impact mechanisms leading to the different areas related to (societal) QoL. Due to the scope of the trials and the focus on technical evaluation, the impact assessment will be carried out on a high level, and will focus on qualitative results regarding metrics IA-M1 to IA-M4 presented in Section 4. The work will be carried out as expert assessments by the consortium partners. Data from the trials and technical evaluation will be used if available and feasible. Other data sources include stakeholder interviews and literature.

The main objective of the QoL evaluation is to study the impacts of the examined use cases on traffic flow, efficiency, environment, etc. In addition, the impacts on traffic safety are also of high interest, although not as a main topic.

All the impacts are mediated through changes in behaviour, mostly either driving behaviour or traveling behaviour. In order to assess the impacts of the examined use cases behavioural data need to be collected to some extent. Here, we describe typical study designs on how to collect such data in a suitable way for impact assessment. Upscaling of available data is also used in order to assess the impacts in e.g., EC level.

An overview of the state of the art of the impacts of the examined use cases will be made to start with. In this review, special attention will be paid to the results of the ongoing and finished EU-wide large-scale trials on ITS that incorporate hybrid communication systems. Hence, the impact assessment will be strongly built on this existing knowledge, since no large-scale demos and trials are to be conducted in the scope of ICT4CART.

More specifically, carefully selected subsets of the exact measures used in the earlier trials will be applied to scale up the impacts of ICT4CART use cases with the most recent existing knowledge. Consequently, limited and carefully selected datasets – such as small-scale user data and expert assessments – are to be collected during the testing at each test site, and will be efficiently utilised in impact assessment.

To complete the impact assessment data from the earlier studies, the ICT4CART use cases impacts on efficiency and environment will be mainly assessed with help of existing simulation models. The safety impact evaluation will be strongly built on existing data, existing scaling up tools, such as ERIC-tool (European Risk Calculation tool) to scale up the safety impacts, and the selected user behaviour data collected during the tests. All other impacts are mediated through changes in behaviour (see Figure 1). All three categories or hierarchical levels of driver decision making and behaviour: strategic decisions, tactical decisions and operational decisions are to be taken into account when relevant.

[6] https://connectedautomateddriving.eu/wp-content/uploads/2019/01/FESTA-Handbook-Version-7.pdf

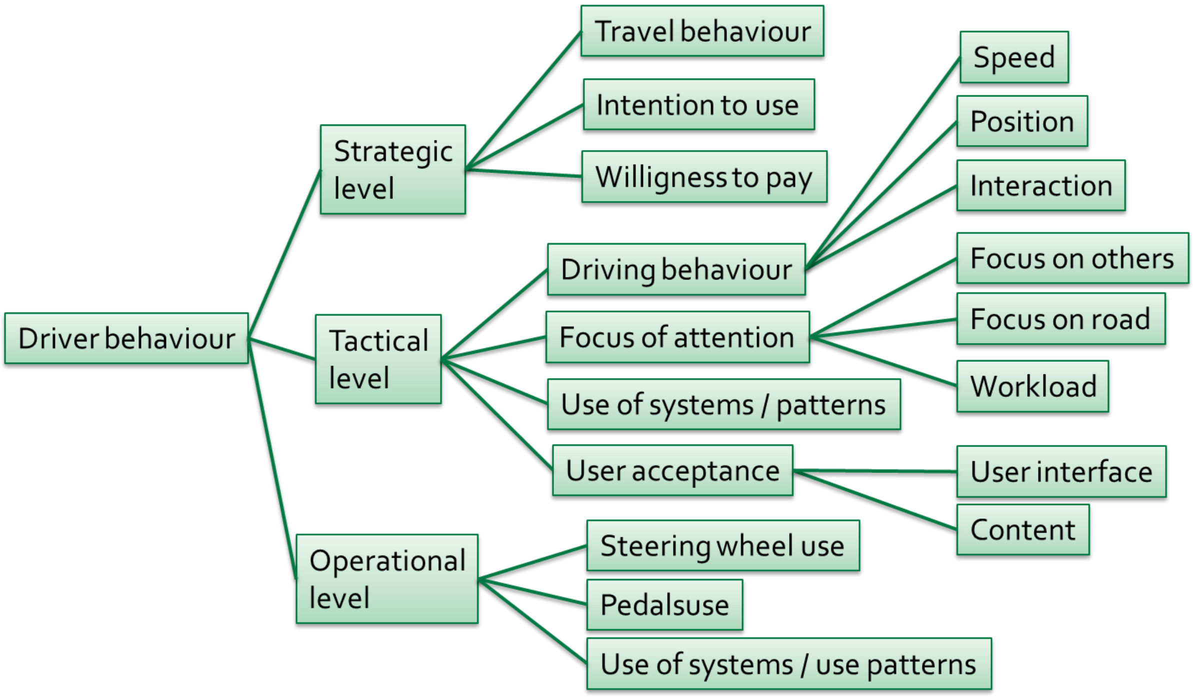

Figure 1: Impacts are mediated through changes in driver, or traveller behaviour

Since ICT4CART is not conducting any long term naturalistic experiments, the behavioural changes of individual users will be mainly collected by using subjective measures, i.e. users (drivers and travellers) reporting themselves how they have (or would be willing) to change their behaviour due to implementation of the examined use cases in their own travelling context. When possible, the FESTA methodology will be utilised, but not anyhow in the extent it is utilised in real Field Operational Tests.

Several study designs can be applied to collect the data on use cases' impacts on traveller behaviour and hence safety, efficiency, environment, etc. Subjective data can be collected by methods such as travel diaries, interviews, questionnaires, expert assessment and workshops. Objective data can be collected by e.g., travel time measures, driving behaviour related measures (logging vehicle data). To study the impacts, test persons from the test sites will be recruited to use the functions/components in a real context when possible. In practice, several types of user data will be collected from small scale behaviour monitoring to subjective user data.

Based on the detailed research question, and related hypotheses, the actual impact evaluation data collection is done before, during and after any kind of experience the user had with the application and the use case. The experience can be from the lightest to the most extensive experience, depending on the deployment of the system in each site:

- A description of the system;
- A demonstration of the system, e.g., a real prototype;
- Testing the system in a pre-selected task/route;
- Obtain the system for permanent use over a certain period (not very possible regarding the ICT4CART Use Cases).

Anyhow, it is important to collect and compare the data with and without the system in order to be able to see what the real impacts are.

Especially in safety impact assessment, it is important that the impacts are considered not only to the user of a system, but in the larger scale, taking into account all the impact mechanisms of ITS[7]. The list of mechanisms is as follows:

- Direct in-car modification of the driving task;
- Direct influence by roadside systems;
- Indirect modification of user behaviour;
- Indirect modification of non-user behaviour;
- Modification of interaction between users and non-user;
- Modification of road user exposure;
- Modification of modal choice;
- Modification of route choice;
- Modification of accident consequences.

The first five bullet points deal with accident risk. The related measures are: Speed, Proximity, Position, Interaction, Use of signals, Driver condition, Attention. The following assumptions were made:

- ✓ Safety increases as speed decreases;
- ✓ Safety increases as standard deviation of speed decreases;
- ✓ Safety increases as number of jerks decreases;
- ✓ Safety increases as lateral position is more stable;
- ✓ Safety increases as vulnerable road users are taken into consideration;
- ✓ Safety increases as signals are used correctly;
- ✓ Safety increases as driver condition is not deteriorated;
- ✓ Safety increases as focus of attention is allocated correctly.

The next three bullet points are related to exposure. Accordingly, the related research questions are (1) Time spent on road; (2) Mode chosen for the journey; (3) Timing of the journey; and (4) Road type used. Finally, the last bullet point deals with accident consequences. It was assumed that the consequences would be more severe as speed increases.

Impact assessment tools

Impact evaluation is carried out with two kinds of data. On the one hand, objective data is collected from testing demonstrations. The tools for collecting such data are the same like the tools used for technical evaluation and are described in the respective chapters above. On the other hand, impact evaluation is carried out based on subjective data collected, where a specific focus will be on the questionnaires and interviews on impact related questions.

In order to assess user acceptance and impact, a well-established set of scales and questionnaires are presented in Annex 1, Annex 2 and Annex 3.

[7] Kulmala (2010). Ex-ante assessment of the safety effects of intelligent transport systems. Accident Analysis and Prevention 42 (2010), p. 1359 -1369

8 Cost analysis and market sustainability methodology

This section presents the methodology for the cost analysis and market sustainability assessment that will be conducted in T8.4.

Alongside ICT4CART's technical solution – both its technical components and the overall architecture – it is important to assess the commercial implications and viability of what is being proposed. This will help the consortium reach a conclusion on the market likelihood and sustainability of ICT4CART solutions.

The main objectives of T8.4 are:

- To estimate the costs of deploying the ICT4CART technical solution(s) at scale;
- To determine the likelihood that the ICT4CART solution(s) will be commercially viable and sustainable.

8.1 Approach

The approach to T8.4 has been divided into two sub-tasks aligned to the two stated objectives.

Sub-task 8.4.1 Cost Analysis steps are:

1. Define boundary of ICT4CART solution(s)
2. Develop initial cost model
3. Refine cost model through engagement with technology partners
4. Populate cost model
5. Apply cost model to scenarios
6. Analyse costs, e.g. main variables, likely variations across the suppliers and geographies

Sub-task 8.4.2 Market Sustainability Assessment steps are:

1. Determine measures of sustainability, selecting one or more of the following, depending on the outcomes of the cost analysis:
    - Cost/benefit ratio – Will the investment provide purchasers with an acceptable level of return over a defined timescale? (dependent on Task 8.3 Impact Assessment)
    - Benchmarking – Does the level investment required broadly align with costs associated with established comparable investments?
    - Alternative solution comparison – How does the level of investment compare with what purchasers would need to spend to gain equivalent benefits through different means?
2. Outline potential service models to sustain deployment costs (from Task 9.5 Innovative Business Models)
3. Evaluate service models
4. Assess market sustainability of ICT4CART solutions
5. Write report

The approach to Task 8.4 and the nature of the final deliverables are significantly dependent on the extent and accuracy of the cost information input that project partners are able and willing to provide, which will determine whether the modelling can:

- Be undertaken at a component level or based on aggregated costs of deployment
- Be based on pilot deployments, scenarios more generally or broader deployment scenarios
- Address supporting CAV service and vehicle technology costs as well as those for the infrastructure costs

- Address end-to-end deployments of generic, joined up CAV solutions or be limited to specific ICT4CART and/or proprietary supplier solutions.

9 Conclusions

This document (D8.1) sets the ground for the ICT4CART evaluation activities by defining the corresponding methodologies involved in all considered evaluation fronts, namely, the Technical Evaluation, Impact Assessment, and Cost Analysis and Market Sustainability. In doing so, the deliverable specifies the evaluation KPIs and metrics, and the corresponding technical means to achieve them. This includes the identification of the required evaluation data and the related methodologies for their collection and processing. The technical performance evaluation thought actual demos on the ICT4CART test sites will take place in T8.2 and will be reported gradually in D8.2 and D8.3 ("Technical evaluation" first and final version), whereas the Impact Assessment and the Cost analysis will be part of the work that will take place in T8.3 and T8.4 and will be reported in D8.4 "Impact assessment" and D8.5 "Cost Analysis" accordingly.

Annex 1 : User Acceptance Scale Example

The user acceptance is a crucial requirement for any new system. Acceptance as defined for the User Acceptance Scale is a concept based on the perception on usefulness and satisfaction.

Proposed tool
Subjects are instructed to tick a box on each of the scales below of the following questionnaire indicating the extent to which the stated attributes are applicable with respect to the system under evaluation.

User Acceptance Scale Indicative Example:

My judgements of the system are ... (tick one box in every line)

1	Useful	☐☐☐☐☐	Useless
2	Pleasant	☐☐☐☐☐	Unpleasant
3	Bad	☐☐☐☐☐	Good
4	Nice	☐☐☐☐☐	Annoying
5	Effective	☐☐☐☐☐	Superfluous
6	Irritating	☐☐☐☐☐	Likeable
7	Assisting	☐☐☐☐☐	Worthless
8	Undesirable	☐☐☐☐☐	Desirable
9	Raising alertness	☐☐☐☐☐	Sleep-inducing

Figure 2: User acceptance scale example

Using the User Acceptance scale is easy:

- The test leader should describe the system to be evaluated in terms of 'what is your judgement about a system that would…?' (short & clear explanation of the system functioning) and present the nine items (before-measurement).
- After experiences with the system under evaluation the nine items are presented again: 'What is your judgement about the system…(name)?', 'you just finished driving with…' (after-measurement).
- The results of those two judgements will be compared.

Annex 2 : User Experience Questionnaire Example

Method of investigation:
AttrakDiff™ is an instrument for measuring the attractiveness of interactive products. With the help of pairs of opposite adjectives, users (or potential users) can indicate their perception of the product. These adjective-pairs make a collation of the evaluation dimensions possible.

The following product dimensions are evaluated:

Pragmatic Quality (PQ):
Describes the usability of a product and indicates how successfully users are in achieving their goals using the product.

Hedonic quality - Stimulation (HQ-S):
Mankind has an inherent need to develop and move forward. This dimension indicates to what extent the product can support those needs in terms of novel, interesting, and stimulating functions, contents, and interaction- and presentation-styles.

Hedonic Quality - Identity (HQ-I):
Indicates to what extent the product allows the user to identify with it.

Attractiveness (ATT):
Describes a global value of the product based on the quality perception.
For more detailed information refer to the website: http://attrakdiff.de/index-en.html

The AttrakDiff semantic differential example:

human	○	○	○	○	○	○	○	technical
isolating	○	○	○	○	○	○	○	connective
pleasant	○	○	○	○	○	○	○	unpleasant
inventive	○	○	○	○	○	○	○	conventional
simple	○	○	○	○	○	○	○	complicated
professional	○	○	○	○	○	○	○	unprofessional
ugly	○	○	○	○	○	○	○	attractive
practical	○	○	○	○	○	○	○	impractical
likeable	○	○	○	○	○	○	○	disagreeable
cumbersome	○	○	○	○	○	○	○	straightforward
stylish	○	○	○	○	○	○	○	tacky
predictable	○	○	○	○	○	○	○	unpredictable
cheap	○	○	○	○	○	○	○	premium
alienating	○	○	○	○	○	○	○	integrating
brings me closer to people	○	○	○	○	○	○	○	separates me from people
unpresentable	○	○	○	○	○	○	○	presentable
rejecting	○	○	○	○	○	○	○	inviting
unimaginative	○	○	○	○	○	○	○	creative
good	○	○	○	○	○	○	○	bad
confusing	○	○	○	○	○	○	○	clearly structured
repelling	○	○	○	○	○	○	○	appealing
bold	○	○	○	○	○	○	○	cautious
innovative	○	○	○	○	○	○	○	conservative
dull	○	○	○	○	○	○	○	captivating
undemanding	○	○	○	○	○	○	○	challenging

Figure 3: AttrakDiff scale for joy of use evaluation example

Annex 3 : Testing Usability Questionnaire Example

In order to test the usability of the applications and HMI it is recommended to use a standardised questionnaire. Usability tests should be seen also as a valid source for optimisation of the product in following development cycles.

Definition of concept
Usability is defined as *"the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO 9241-11, 1998).

The terms effectiveness, efficiency and satisfaction are defined as follows:

- **Effectiveness**: Accuracy and completeness with which users achieve specified goals.
- **Efficiency**: resources expended in relation to the accuracy and completeness with which users achieve goals.
- **Satisfaction**: Freedom from discomfort and positive attitudes towards the use of the product.

Proposed tool

It is proposed to assess usability with the System Usability Scale (SUS)[8], which provides a reliable, low-cost tool that can be used for global assessments of systems' usability. For further reading https://www.usability.gov/ is recommended. The SUS is applied after a user has used a system, but before any discussion and debriefing. Subjects are asked to respond immediately, rather than thinking for long. The figure below presents a System Usability Scale indicative example.

[8] Brooke, J. (1996) SUS: a "quick and dirty" usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester & A. L. McClelland (eds.) Usability Evaluation in Industry. London: Taylor and Francis

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine that most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I needed to learn a lot of things before I could get going with this system					

Figure 4: System usability scale (SUS) example

Annex 4 : BMW's Ride-Hailing Simulator

This is a BMW proprietary simulator developed to simulate ride-hailing scenarios. It is not based in any know traffic simulations. The architecture of the simulator as well as the technologies used for its development can be seen in the following figures.

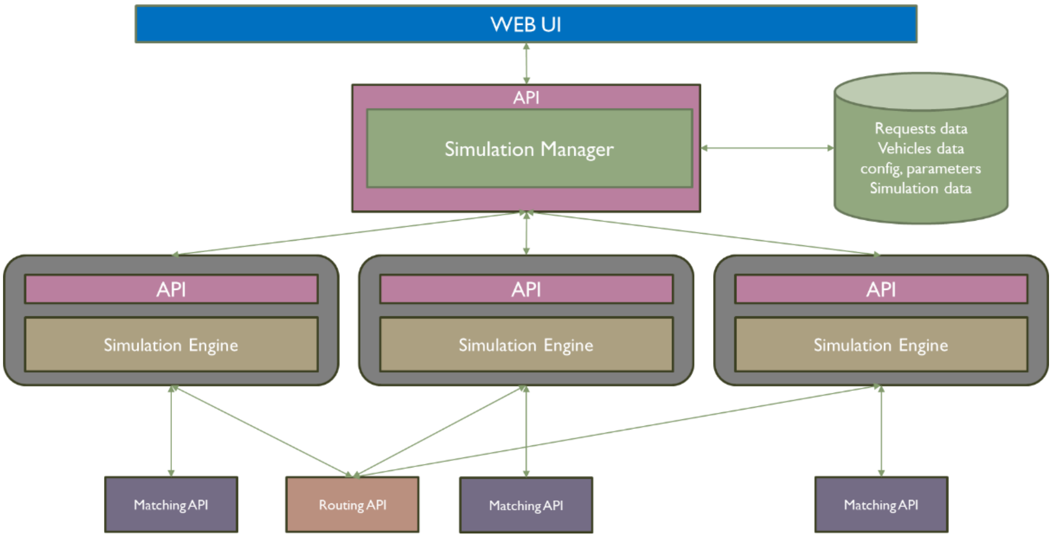

Figure 5: Architecture of Ride-Hailing Simulator in SCN1.1

Architecture of the Ride-Hailing-Simulator

The simulation environment comprises several individual components or services respectively. The Simulation Engine as the main component is responsible for running the actual simulation. The logic for matching customer requests to fleet vehicles is separated into an individual service, the Matching API. The Routing API is used for the calculation of vehicle routes based on OpenStreetMap data. In addition, there is a so-called Simulation Manager that allows the compilation and configuration of multiple simulation instances running in parallel. Furthermore, it receives the input data necessary for the simulation and stores this data plus all simulation statistics in a MongoDB database. Built on top is a web user interface which makes the compilation and configuration available to the user on a frontend. Along with that, the Web UI visualizes the simulation in real time on a map and displays all corresponding statistics.

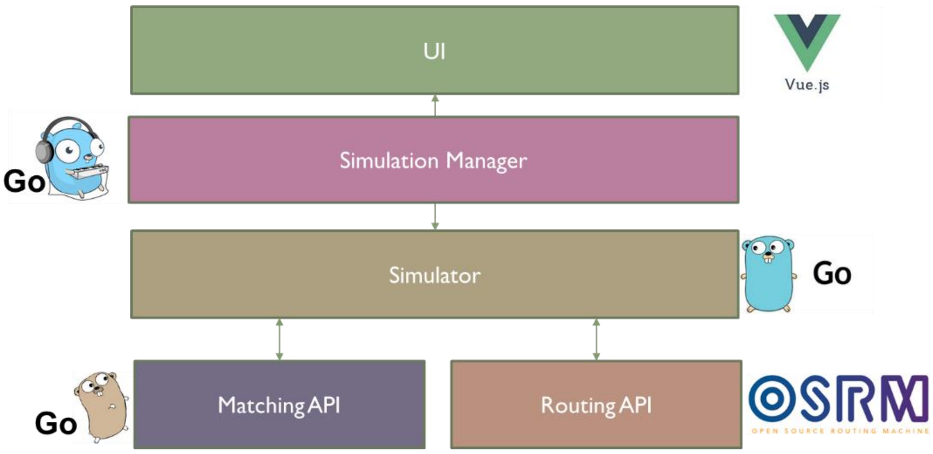

Figure 6: Technologies Used in the Ride-Hailing Simulator

Technologies

For the implementation of the Ride-Hailing-Simulator, four main technologies were used. The graphical user interface for the creation, configuration and visualization of simulations is realized as a website utilizing the frontend framework Vue.js. The actual simulation components including the Simulator (Simulation Engine), the Simulation Manager and the Matching API are completely written in Google's open source programming language Go. As for the Routing API, the "Open Source Routing Machine (OSRM)" is utilized. It is a high-performance routing engine written in C++14 designed to run on OpenStreetMap data. It is available on Docker Hub (https://hub.docker.com/r/osrm/osrm-backend). For storing all input data and simulation statistics a MongoDB database is used.

Functionality of simulator

The Simulation Engine comprises several internal components. An internal clock keeps track of time and publishes every "tick" to all other internal components. In a real-time simulation one tick would be one second. A simulation has as many vehicle entities as fleet vehicles are defined in the input data. A vehicle entity contains all vehicle attributes and provides methods to update those attributes. A Vehicle Manager is responsible for managing all vehicle entities which includes assigning requests to a vehicle's request queue as well as updating its statistics. The Request Manager parsed the input data containing all customer requests. With every tick it looks for a request in the list. If there is a request, it gets added to the current batch. The batch size is parameterizable but in most cases amounts to 60 seconds. When, in this case, 60 seconds have passed, the batch of requests is sent to the Matching API. This is where the requests will be matched to vehicles based on an arbitrary algorithm. The matches are returned to the Request Manager which subsequently will tell the Vehicle Manager to effectively assign the requests to the individual vehicles. As soon as a vehicle has an assigned request, it will start moving and traverse through the vehicle lifecycle states as long as it has requests in its queue. When all requests have been served the simulation will stop. During the whole simulation, the Stats Manager component keeps track of the simulation statistics and exposes these data to the Simulation Manager which stores the information in a database.

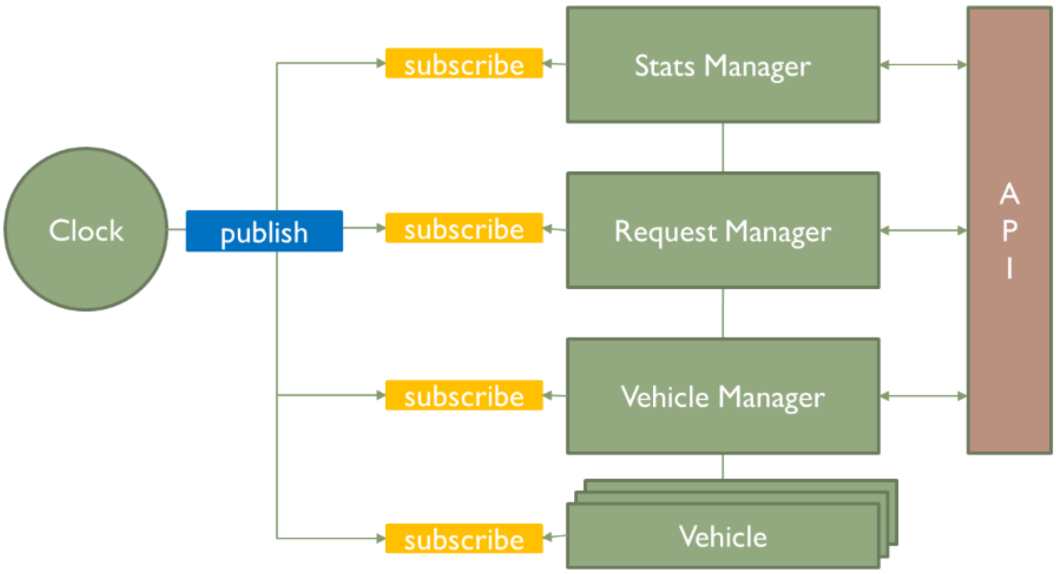

Figure 7: Simulator components

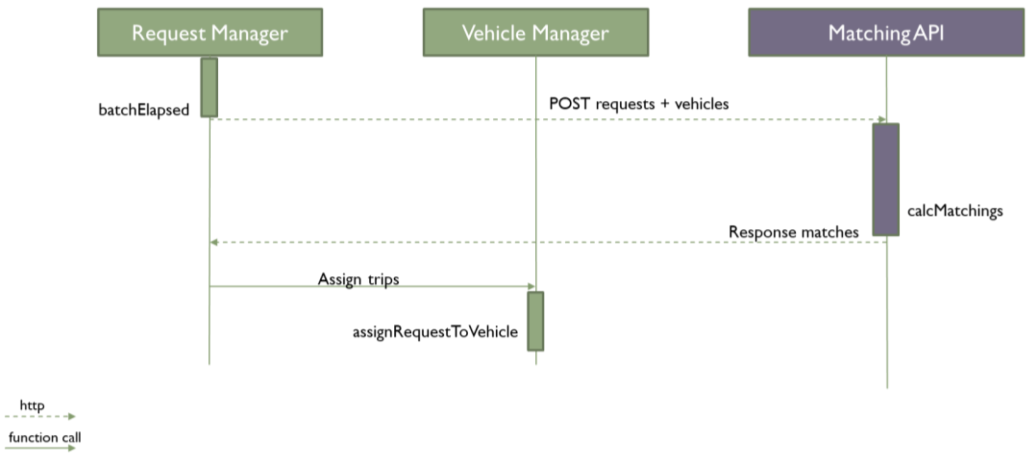

Figure 8: Communication sequence - Simulator and Matching API

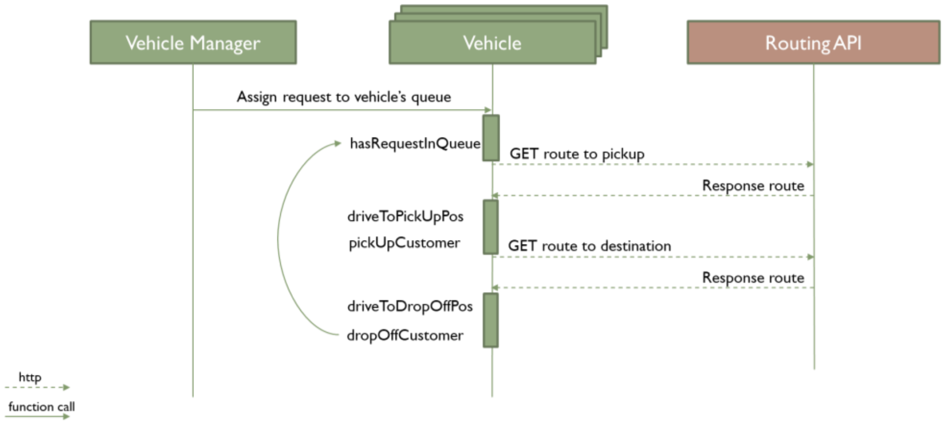

Figure 9: Communication sequence - Simulator and Routing API

Simulation states and data required for simulation

- Requests data
- Vehicles data
- Config data
  - Simulator API URL
  - Matching API URL
  - Routing API URL

Simulation parameters

- Batching period
- Request service time (announcement time)
- Request max wait time
- Vehicle waiting time pick up (simulates pick up delay)
- Vehicle waiting time drop off (simulates drop off delay)
- Simulation speed
- Snapshot interval (e.g. saves simulation state every 5 mins)

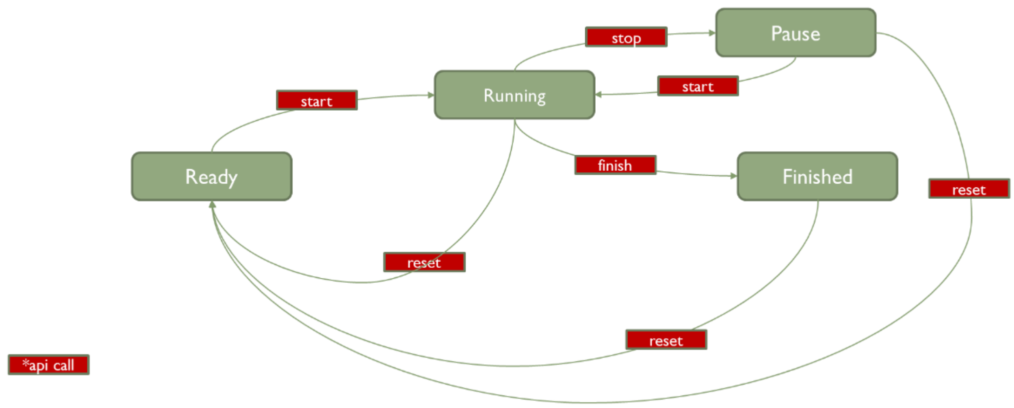

Figure 10: Simulation states

The BMW Simulator has two types of basic entities: vehicles and requests. Vehicles are entities that include information typically associated with cars, like position, and also other information that are described in the table below. Requests are entities that represent a request of a client to be picked up for a ride. Requests are matched to vehicles. A description of its attributes can be seen in the table below. For the simulation to start properly we need a set of parameters (which all have default values) and a list of vehicles and requests with initial positions. As the simulation starts running, requests are matched to vehicles and vehicles start moving. Both vehicles and requests go through different statuses. Transitions from one status to another are triggered when a vehicle reaches a position, for example pickup location, drop off location or vehicle service location. In the future BMW will probably also have events triggered by other parameters, like level of fuel or battery. Information about vehicles and requests are stored and can be exported from the simulation anytime as a snapshot of the simulation.

Data Diagram

This section provides an overview of the data model used in the fleet management application in combination with the data depicted in **Error! Reference source not found.**.

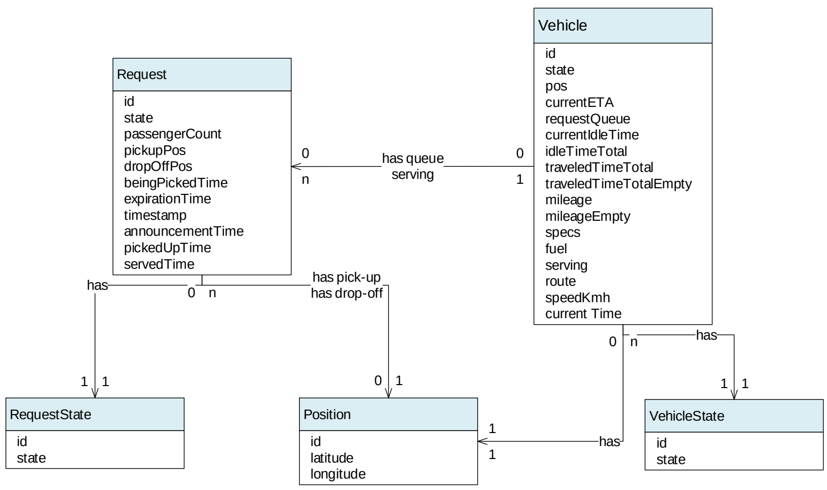

Figure 11. Fleet Management Data Model

This section describes basic types defined in the data model.

Position

Position data type represents a single location in geographic WGS 84 coordinates.

Attribute	Description
Latitude	Latitude of the location
Longitude	Longitude of the location

State

State (request or vehicle) data type represents the state of a request or a vehicle. The values are different for requests and vehicles.

Attribute	Description
state	State of request/vehicle

Advanced Types

This section describes advanced types defined in the data model.

Request

Requests are entities that represent a request of a client to be picked up for a ride. Requests are matched to vehicles.

Attribute	Description
state	State of the request.
passengerCount	Count of passengers.
pickupPos	Coordinates of the pick-up position.
dropOffPos	Coordinates of the drop-off position.
beingPickedTime	Estimation date and time when the request will be picked up.
expirationTime	Date and time when the request expires, That means that if the request is not picked up until then, then the request is no longer valid.
announcementTime	Date and time when the request was inserted in the system.
pickedUpTime	Date and time when the request is actually picked up.
servedTime	Date and time when the request is actually served. Will be 0 if the request has not been served yet.

Vehicle

Vehicles are entities that include information typically associated with cars, like position and speed.

Attribute	Description
state	State of the vehicle.
pos	Coordinates of the vehicle position.
currentETA	Date and time of estimated time of arrival.
requestQueue	List of request ids matched to this vehicle.
currentIdleTime	Current idle time. How much time has the vehicle been idle until now in minutes.
idleTimeTotal	Total time while in idle state in minutes.
traveledTimeTotal	Total time the vehicle was moving in minutes.
traveledTimeTotalEmpty	Total time the vehicle has been moving while not having a customer in minutes.
mileage	Total distance the vehicle has been moving in km.
mileageEmpty	Total distance the vehicle has been moving while not having a customer in km.
specs	Specification of the vehicle, like how many seats are available, etc. This field is for future reference. Empty at the moment.
Fuel	Percentage of fuel tank or battery remaining. This field is for future reference. Empty at the moment.

serving	Request being served. Request id with all attributes of the request.
route	Route of the vehicle. When vehicle on route to pick up the customer, the route is up to the pick-up point. When vehicle is serving a request, the route is to the destination.
speedKmh	Vehicle speed.
currentTime	Date and time of the simulator.

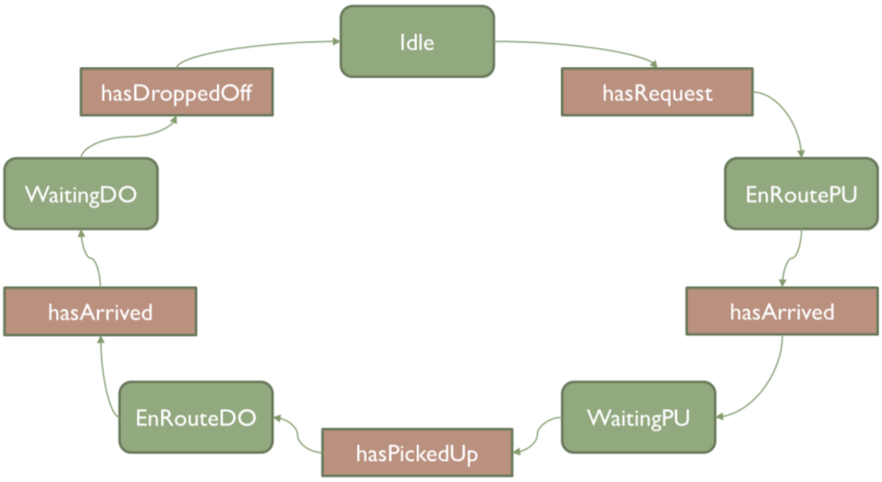

Figure 12: Vehicle lifecycle states

Vehicle lifecycle

- Idle: Vehicle is parked and ready to serve requests.
- EnRoutePU: Vehicle is on its way to the pickup location.
- WaitingPU: Vehicle waits at pickup location until customer has entered the vehicle.
- EnRouteDO: Vehicle is on its way to the drop-off location.
- WaitingDO: Vehicle waits at drop-off location for customer to exit the vehicle.

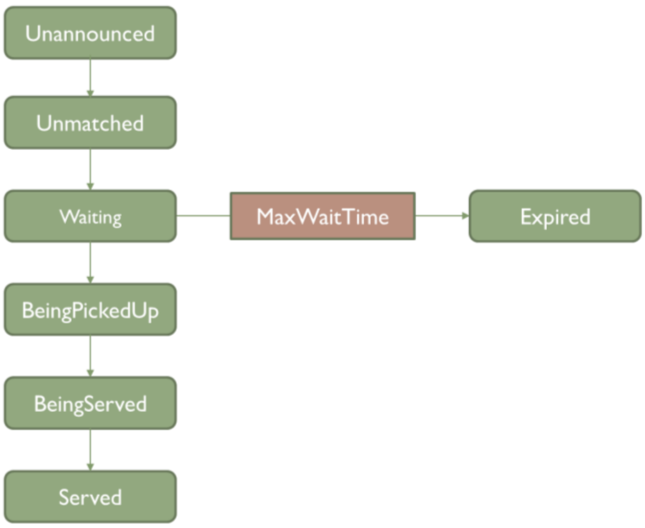

Figure 13: Request lifecycle

Request lifecycle

- Unannounced: Request i^{st} not active yet.
- Unmatched: Request is announced/active. Customer has sent request.
- Waiting: Waiting time of customer at pickup location.

- BeingPickedUp: Customer enters vehicle.
- BeingServed: Customer is in vehicle and on the way to the drop-off location.
- Served: The ride has ended/The request is fulfilled.

The following API calls have been implemented so far:
- Request list of vehicles.
- Request list of requests.
- Request simulation statistics

Simulation statistics

InitTime:	Start time of simulation
CurrentTime:	Current time
Running:	State of simulation (Ready, Running, Paused, Finished)
Progress:	Progress of simulation in percent
ClockSpeed:	Speed of simulation (e.g. real time or time lapse)
EstimatedFinishTime:	Estimated finish time of simulation
RequestsTotal:	Total number requests in simulation
RequestsBatched:	Number of requests that are currently batched
RequestsWaiting:	Number of requests currently in state "waiting"
RequestsBeingPickedUp	Number of requests currently in state "being picked up"
RequestsBeingServed:	Number of requests currently being in state "being served"
RequestsServed:	Number of fulfilled requests
RequestsExpired:	Number of requests that expired due exceeding pickup time
VehiclesTotal:	Number of vehicles available
VehiclesIdle:	Number of vehicles currently available to serve requests
VehiclesActive:	Number of vehicles that are not in state "idle"

Cost measurement

To assess fleet operations costs that occur with and without the accessibility to real time parking data and predictions a so-called Cost API will be implemented. This service will provide a parametrizable cost model. Based on this cost model and the statistics delivered by the Simulator fleet operations costs will be calculated and taken as input for KPI measurement.