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AUTOPILOT

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Abstract

The overall objective of AUTOPILOT is to bring together relevant knowledge and technology from the automotive and the IoT value chains in order to develop IoT architectures and platforms which will bring automated driving towards a new dimension.

This deliverable is part of the work carried out in task T5.4 (Cross-fertilization with IoT and Autonomous Transport Focus Areas), analyses and provides an extensive number of KPIs for autonomous vehicles and IoT pilot impact measurement, categorized into fields and mapped to the different AUTOPILOT use cases.

The document describes a methodology to evaluate autonomous vehicles and IoT ecosystems which includes the approach to define KPIs, evaluation elements, development lifecycle, and objectives and expected impacts. The main part describes the performance and KPIs regarding design, testing, validation, and impact assessment for autonomous vehicles and IoT pilot impact measurement. In the final part, the document addresses briefly the autonomous vehicles and IoT KPIs across application domains.

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
AD	Autonomous Driving
AI	Artificial intelligence
API	Application Programming Interface
CVSS	Common Vulnerability Scoring System
DoA	Description of Action
E2E	End-to-end
EC	European Commission
EV	Electric Vehicle
GDPR	General Data Protection Regulation
ICE	Internal Combustion Engine
IoT	Internet of Things
IoV	Internet of Vehicles
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
LSP	Large-Scale Pilot
MaaS	Mobility-as-a-Service
MEC	Multi-access edge computing
ML	Machine Learning
MMTC	Massive Machine Type Communication
NB-IoT	Narrow Band-IoT
OEM	Original Equipment Manufacturer
OMA NGSI	Open Mobile Alliance - Next Generation Services Interface
PF	Platform
SDO	Standards Developing Organizations
SMART	Specific, Measurable, Attainable, Relevant, and Timed
V2D	Vehicle-to-Device
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrians
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything (communication)
WP	Work Package

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Executive Summary

The state of the art vehicles today, are “connected” vehicles using telematics systems exchanging data with Original Equipment Manufacturers (OEMs) for maintenance and software updates. Connected vehicles are linked to the internet and represent a class of "things" in future automotive Internet of Things (IoT) ecosystems.

Autonomous vehicles can independently navigate the road network and connected vehicles and IoT technologies provide valuable information about the environment, and the road ahead, allowing rerouting based on new information (i.e. lane closures or obstacles on the road). Incorporating autonomous vehicles and IoT in the future Internet of Vehicles (IoV) applications provide safer, faster, and more efficient autonomous vehicle applications. Virtually all autonomous vehicles require various forms of connectivity and IoT platforms (IoT-PF) to ensure interactions with other vehicles, infrastructure, pedestrians and devices through the real-time exchange of information.

The future of autonomous vehicles and IoT is heading toward the integration of multiple domains: IoT, connected vehicles, autonomous vehicles, Vehicle to Everything (V2X) communication with a shift to make software-defined vehicles using advanced IoT enabling technologies such as deep learning, analytics, cloud, virtual reality and block chain.

This document describes the performance and Key Performance Indicators (KPIs) regarding design, testing, validation, and impact assessment for autonomous vehicles and IoT pilot impact measurement.

The document describes a methodology to evaluate autonomous vehicles and IoT ecosystems which includes the approach to define Key Performance Indicators (KPIs), evaluation elements, development lifecycle, and objectives and expected impacts. The main part describes the performance and KPIs regarding design, testing, validation, and impact assessment for autonomous vehicles and IoT pilot impact measurement. In the final part, the document addresses the autonomous vehicles and IoT KPIs across application domains.

These KPIs are potentially of interest to AUTOPILOT WP1, WP2 and WP3 and can be used during the specification, development, readiness verification and validation phases. For the AUTOPILOT WP4 and WP5, these KPIs can contribute to testing, evaluation, standardisation support and impact assessment.

For the audience external to the AUTOPILOT project this document offers both a methodological approach and technical information on KPIs for design, testing, validation and impact assessment.

1. Introduction

1.1 Purpose of the document

Several OEMs, including Tesla and BMW, already have semi-autonomous vehicles on the road today with self-driving features such as auto-pilot and self-parking. With the support of connectivity technology and platforms it is expected that, in 10 to 15 years, there may be large networks of fully-autonomous vehicles in most areas around the world.

KPIs are an essential part of the evaluation strategy of different applications and approaches. Automated Driving (AD) solutions require addressing many issues such as design, testing, validation, impact assessment, interoperability between systems, security aspects, the IoT ecosystem and applications. A KPI is a type of performance measurement that helps the stakeholders on an IoT ecosystem to understand how the deployment, pilot or experiment is performing. A good KPI acts as a compass, helping those in the ecosystem understand whether they are on the right path towards their strategic goals. To be effective, a KPI must:

- Be well-defined and quantifiable.
- Be communicated throughout the IoT ecosystem.
- Be essential to achieving the ecosystem goal.
- Be applicable to the domain and ecosystem.
- Be SMART: Specific, Measurable, Attainable, Relevant, and Timed.

The challenge is that there are thousands of KPIs to choose from and if the ecosystem selects the wrong one, then all the deployments or pilots are measuring something that doesn't align with their goals. It is, therefore, crucial to research and understand the KPIs that are important and specific to Autonomous Driving (AD) and IoT, and those that will be of no benefit.

A number of tasks in the AUTOPILOT project are dedicated to collecting KPIs or metrics to address different perspectives or objectives of the project. For instance:

- "Automated Driving performance and safety KPIs" collected in Task 4.2 and "Quality of life KPIs" collected in Task 4.4 relate to the topic of progress on benefits to the public.
- KPIs for scientific dissemination and project events organisation are collected in Task 5.2.
- Business exploitation KPIs relating to the dependability, robustness, resilience, adaptability and sustainability of the piloted technology are collected in Task 5.3 in order to validate business processes and models in relation to the AUTOPILOT's pilot sites and use cases.
- KPIs for design, testing, validation and impact assessment for autonomous vehicles and IoT pilot impact measurement are collected in Task 5.4.

The objective of this document, D5.3 "Performance and KPIs for autonomous vehicles and IoT pilot impact measurement", is to present AUTOPILOT activities performed as part of Task 5.4. Deliverable D5.3 makes recommendations to other AUTOPILOT Work Packages (WPs) about the main applicable KPIs for design, testing, validation, and impact assessment that shall be considered in the evaluation of the performance of the ecosystem.

1.2 Intended audience

D5.3 is a public deliverable. This document is addressed to project partners working in various AUTOPILOT WPs, especially those participating in design, testing, validation, impact assessment activities. It is also relevant for stakeholders and partners working on IoT European Large-Scale Pilots (LSP) Programme projects who are tackling similar issues.

For project partners working on WP1 “Requirements, Specifications and Architecture”, WP2: “Development, integration and validation” and WP3: “Large scale pilots” and T5.3 "Business models", it provides an overview of KPIs for design, testing, validation, and impact assessment that are potentially of interest and it can therefore be used for the specification, development and evaluation phases.

More generally, it offers a first indication to all partners of how the AUTOPILOT project intends to contribute to KPI evaluation in order to enhance the project results.

For people external to the project it could offer both a methodological approach and specific technical information on KPIs for design, testing, validation, and impact assessment.

2. Autonomous vehicles and IoT integration

Three major automotive areas will continue to develop during the next years: transition to electric, fully autonomous vehicles, and a higher percentage of persons relying on ride sharing services as their primary source of transportation. These areas create new market opportunities, the competitive landscape will change dramatically as more technology companies enter the space to bring these new technologies to market. Autonomous vehicles can take the form of ICE (Internal Combustion Engine) or hybrid vehicles, but it is expected that most autonomous vehicles deployed will be Electric Vehicles (EVs) because there are many synergies between the technology implemented in EVs and what will be incorporated in fully autonomous systems. Over the next 20 years, Electric Vehicles will become more affordable, using advanced sensors/actuators, onboard computing processors, multi-connectivity solutions and other components that enable fully autonomous driving capabilities.

Fully autonomous vehicles do not require a human driver, rather they are computer and connectivity-driven systems, where the vehicle drives itself from departure to destination, and the human is completely removed from the process. Autonomous vehicles assure the full-time performance by an AD system in all aspects of the dynamic driving task under all roadway and environment conditions that can be managed by a human driver. They require connectivity and IoT functionalities to ensure software and data sets are updated in real-time, and rely on knowing the roadway they are travelling on. Changes to the driving environment such as new development or construction, require the type of real-time exchange of information that IoT technology provides in real time through various platforms.

2.1 IoT infrastructure

Autonomous vehicles and IoT technologies are evolving in ways that have a major impact on infrastructure, vehicle ownership, and the automotive industry. Thanks to V2X and cellular communication technology, it is expected that large networks of fully-autonomous vehicles will be available in most major cities around the world in the future. These “things” will be part of a large ecosystem and should follow the rules of the IoT world to support the AD functions.

From the connectivity point of view, V2X and cellular communications are evolving to increase support for a large number of devices. In the evolution of 4G, NB-IoT (Narrow Band-IoT) has already been defined to support many low-throughput objects. In the framework of 5G specifications, Massive Machine Type Communication (MMTC) will be defined to address the challenge of communicating with thousands of things per square meter.

Communication among vehicles also requires delay-sensitive performances. For which standardization bodies are working to ensure the best solutions. The current standard concerns Wi-Fi specifically. This standard, which describes the functions and services of wireless access in vehicular environments (WAVE), was initially defined under the IEEE 802.11p but is included today in the mainstream IEEE 802.11 definition.

4G and 5G are also working to cover this communication market segment thanks to the LTE-V2X specifications. For 5G, the requirement in terms of delay, targets a value of less than 1 ms. This will be achieved not only with the increase of data speeds but also with new technologies such as Multi-Access Edge Computing (MEC) and, obviously, with direct communications among vehicles. This topic is addressed in more detail in the deliverable D1.7 - “Initial specification of communication system for IoT enhanced AD" [16].

The IoT infrastructure is made up not only by the communication channel but also by a series of functions, required by all IoT applications. These requirements have been described in the Deliverable D1.5 - "Initial Open IoT Vehicle Platform Specification" (chapter 2.1) and are summarized here [17]:

- Interoperability
- Service-based
- Context-awareness
- Data management
- Remote management
- Security and privacy
- Based on open standards
- Defined APIs
- Event management, analytics and user interface (UI)

The most relevant aspects are addressed by the KPIs described in the following paragraphs. For a more detailed description, please refer to D1.5 [17].

The IoT world helps the decision algorithm of the vehicle in the decision-taking procedure increasing the safety, the comfort and the effectiveness of the AD functions. Moreover, the IoT paradigm permits the collection and the processing of a large amount of data that have a twofold validity. On the one hand, they can give feedback to the AD function, providing even more useful information than the raw data, typically not in real-time. On the other hand, they allow the creation of new applications with big value for the stakeholders of AD vehicles such us users, OEM, Tier 1, generic developer, etc.

2.2 Cyber security

Public acceptance of autonomous vehicles, IoT technologies and the safety and security of the vehicles rely on secure cyber systems. Data and information must be protected from external and internal attacks that could occur. Security-by-design is essential to prevent loss of control of vehicle functions while privacy-by-design prevents the exposure of information that could be used to the detriment of the vehicle owner, automaker or service provider.

New challenges for IoT-AD must be addressed:

- Secure channels to cloud services.
- Over-the-Air-Updates delivering new functions or security updates/patches.
- Compliance to regulation on personal data protection.

Cyber security features in the IoT augmented AD context can be grouped into two main functional areas:

1. Prevent an attacker from compromising the vehicle (safety, availability, confidentiality, integrity)
2. Allow law enforcement to block a vehicle even while in manual driving mode to prevent it from causing damage, such as in case of terrorism or the driver losing control.

While features in the first category are in principle shared by conventional AD and even human driving, features in the second group can be greatly improved by the vehicles IoT connection. For this reason, even if public acceptance can be facilitated by both feature categories, only the second one has a competitive advantage of IoT+AD compared to human driving.

The possible negative impact of security features on the AD user experience is a big factor standing in the way of public acceptance. An important AUTOPILOT task is to define how to quantitatively or semi-quantitatively measure the impact of security features on users and what level of protection the AUTOPILOT vehicles, devices and IoT cloud can offer against malicious usage of the system. An in-depth security risk analysis is available in AUTOPILOT Deliverable D1.9 [13], which uses the ISA/IEC 62443-3-3 [14] as a guideline to derive AUTOPILOT's security requirements. It is possible to derive a standard quantitative measure of the designed Security Level (see Security level vectors in the standard). In order to verify the correct implementation of security features and requirements, penetration tests can be performed and the vulnerabilities found can be evaluated and scored by the Common Vulnerability Scoring System v3.0 (CVSSv3) [15].

3. Methodology to evaluate autonomous vehicles and IoT ecosystems

3.1 Approach to define key performance indicators

The AUTOPILOT approach from use cases, through KPIs to autonomous vehicles integration is illustrated in the pyramid in Figure 1. We start with the project's use cases that need to be achieved to define the performance goals. To achieve success, KPIs are defined through common metric indicators and metrics used by the use cases. The idea is to focus on the domains, areas, fields and critical factors, and to address the elements that are needed to complete the evaluation and identification of results to assess design, validation and testing to achieve the autonomous vehicle integration goal.

Figure 1 – The approach from use cases to autonomous vehicles integration

The different steps in the pyramid can be summarized as follows:

- **Use cases:** Use cases that need to achieve the defined performance goals.
- **Key performance indicators:** The common metric indicators and the metrics used by the project's use cases for defining success.
- **Critical success factors:** The domains, areas, fields and the critical factors to focus in order to achieve the goal.
- **Objectives:** Elements to address to complete the evaluation and identification of results to assess design, validation and testing.
- **Strategy:** Actions defined by the projects' use cases to accomplish the goal.
- **Goal:** Autonomous vehicles integrated with IoV ecosystems.

The approach and methods adopted in this report establish a suitable short list of recommended KPIs for design, testing, validation and impact assessment of autonomous vehicles and IoT pilots. These are addressed based on a State of the Art review of:

- Current KPIs used, based upon publicly available data sources.
- Overview of opinions of industry experts to ascertain existing levels of KPI use and views on the issues surrounding development of appropriate autonomous vehicles.
- IoT KPIs, i.e., list of KPIs developed by EC H2020 CREATE-IoT [6] and the views of stakeholders on the emerging KPIs by providing additional qualitative detail around the key trends identified.

The analysis process determined a recommended list of KPIs that can allow for their composition, implementation and assessment.

3.2 KPI evaluation elements

In order to realize performance optimizations in AUTOPILOT, KPIs for autonomous vehicles and IoT pilot impact measurements are developed showing how the use cases are performing and are able to achieve improved results, when taking technical and organizational decisions into account. The KPI metrics are driven by the project objectives, use case goals and the impact requirements for the IoT European Large-Scale Pilots Programme. The KPIs are applicable to different AUTOPILOT domains and to all IoT architectural layers. Furthermore, the identified KPIs should be Specific, Measurable, Attainable, Relevant, Timed (SMART), and simple to understand.

- **Specific:** Target a specific domain or field.
- **Measurable:** Quantifiable evaluation metric.
- **Attainable:** Achievable with the resources, technology and the time available.
- **Relevant:** Evaluation and success relevant.
- **Timed:** The value and outcomes for a period.

Different types of indicators are considered in the initial phase, including the lagging indicators that focus on the past (and the alignment with the legacy systems), and leading indicators that focus on the future. Result indicators provide information of what was done with key result indicators providing an overview of the previous performance used as reference. Performance indicators pinpoint what has to be done with KPIs specifying what has to be done to increase performance and impact. The dissemination of information through appropriate data visualization is important. It may be significant to choose the most appropriate unit of measurement, graph or chart.

Figure 2 – KPI evaluation elements

3.3 KPI development lifecycle

The AUTOPILOT KPIs for design, testing and validation, concern autonomous vehicles and IoT pilot impact. The KPI development lifecycle in the AUTOPILOT project are illustrated in Figure 3. Five actions must be carried out various stages of the development: 1) define a number of potential relevant KPIs; 2) collection of the most relevant KPIs; 3) work out a composition based on sensible and manageable groups according to fields/areas, etc.; 4) implement the KPIs in a feasible and unambiguous way; and 5) assess the functionality of the KPIs. The cycle checks if the KPIs work as intended. If not, it is requested to identify the problem and enter the development lifecycle at the correct place to solve the problem.

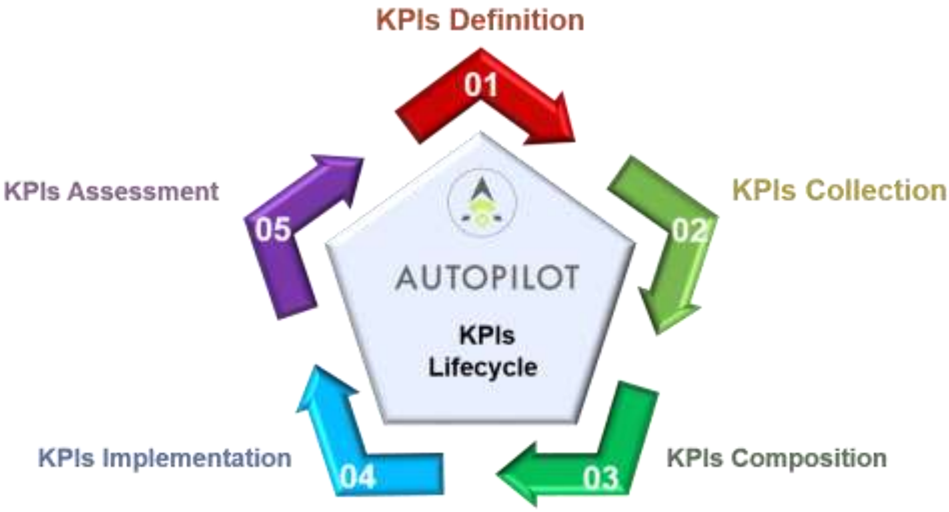

Figure 3 – KPIs development lifecycle

3.4 Objectives and impact measurements

The overall objective of AUTOPILOT is to bring together relevant knowledge and technology from the automotive and the IoT value chains in order to develop IoT architectures and platforms which will bring AD towards a new dimension. This is realized through five specific objectives defined in the AUTOPILOT Description of Action (DoA).

According to the description of work in the DoA (available at ProjectPlace), AUTOPILOT will use the following objectives and high-level KPIs to measure its impacts. The project targets given in Table 1 are defined in the DoA for the overall project. Based on these high-level KPIs this delivery goes deeper and analysis and provide an extensive number of KPIs for autonomous vehicles and IoT pilot impact measurement, categorize them into fields and map to the different AUTOPILOT use cases. The results of this work are presented in the consecutive section (section 4).

Table 1 - Objectives and initial KPIs

Objective	KPI	Project target
Objective 1 **Define and implement an IoT architecture for Automated Driving**	Integration of existing IoT deployments into AUTOPILOT architecture	> 7 existing IoT systems from pilot sites
	Number of IoT devices integrated	> 1000 IoT devices
	Number of vehicles with AUTOPILOT IoT platforms	> 20 cars
	Number of in-car sensor connected to IoT	> 10 different sensors, > 100 sensors
	Number of federated IoT platform instances	> 10 platforms federated

	External information sources used	> 100 data streams
	Number of smart edge devices	> 50 edge devices
	Number of virtual entities	> 1000 entities
Objective 2 Realize IoT-base Automated Driving Use Cases	Use cases realized	> 7 use cases realized
	Improved perception/Local dynamic map	> 20 IoT data streams used
	Number of hours in real traffic situations	> 500 hours
	Demonstrations	> 20 demonstrations
	Number of pilot services transferred between test sites	> 3 pilot services transferred
Objective 3 Advanced Business Models and Services	Test rides	> 200 test rides
	Developed business models	> 7 business models
	New IoT/AD services	> 7 IoT/AD services developed
	Podium discussion	> 12 podium discussions on new business models
Objective 4 Involve Users, Public Services, and Business Players	End Users tested AUTOPILOT solutions	> 1000 end users
	Workshops organized	> 4 workshops organized
Objectives 5 Contribute to Standards	Contributions to standards	> 5 contributions
	Article about IoT/AD standards	> 3 publications about standards in IoT/AD
	Presentations	> 10 presentations about IoT/AD standards

4. KPIs for autonomous vehicles and IoT ecosystems

The performance and key performance indicators for autonomous vehicles and IoT pilot impact measurement are defined in Task 5.4 (Cross-fertilization with loT and Autonomous Transport Focus Areas). The focus is on the use of common methodologies and KPIs for design, testing, validation and impact assessment.

The KPIs are prepared in line with the document "Common methodology and KPIs for design, testing and validation" from the CREATE-IoT project (D01.04) [6] and adapted for the AUTOPILOT project and documented in this report. The prepared KPIs below are divided into fields and mapped to the different AUTOPILOT use cases.

In developing a set of common KPIs, consideration was given to achieving a balance between delivering a minimum standard and supporting future deployment of autonomous vehicles and IoT technologies and platforms. Consideration was also given to future developments in Intelligent Transport Systems (ITS), ensuring that the recommended KPIs remain relevant for the foreseeable future.

To have an efficient and effective overview of the domains, fields and the KPIs defined for each field, it is important to define an agreed structured taxonomy.

To supplement the KPI information obtained through publicly available data sources, the results need to be analysed for additional sources of information that must be provided: KPI description, KPI type, KPI supporting indicators (e.g. Km of network for autonomous vehicles in a given Member State or km covered by IoT infrastructure, IoT platforms, V2X, etc.), method of calculation, data requirements, data ownership, data privacy, geographic scope (key cities or locations, highways or urban, etc.).

Regarding to the project targets for each KPI given in the tables of section 4 , they are prepared by the different partners participating in task T5.4. In this context, the high-level KPIs depicted from section 3.4, are kept as defined in the AUTOPILOT DoA. The KPIs presented in this document are categorized into fields and mapped to the different AUTOPILOT use cases, to ensure that we cover all relevant aspects through simplified navigation and increased applicability. The KPIs capture the balance between positive impact and negative barriers to the autonomous vehicles and the IoT ecosystems development and deployment. All project targets will therefore be subjected to evaluation throughout the project life time.

4.1 IoT devices and modules

KPIs for IoT devices and modules must differentiate between software development and software running phases. For example, it is necessary to measure software quality and detect errors during software development phases, as a previous step to execution. Nevertheless, during the software execution phase, too, possible errors or malfunctions need to be checked to provide feedback to the software development cycle.

The KPIs presented in the table below relate to the functionality, complexity heterogeneity and level of intelligence of IoT devices and modules.

Table 2 - KPIs for IoT devices and modules

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Standardised interfaces	The number of standard interfaces for easy implementation.	Number	How many standard interfaces per IoT component?	1
Adherence with the AUTOPILOT in-vehicle IoT platform architecture	The IoT device implements the architecture defined in D1.5 [17].	Yes/No	Is the IoT device applying the architecture defined in D1.5?	Yes
Implementation of the in-vehicle API	The IoT modules implement all the APIs defined in D1.5 [17].	Yes/No	Are the IoT modules implementing the APIs?	Yes
Mean time between outages	Mean time between outages because of a forced (or not) reboot, software update, malfunction, etc.	Time	Monitoring mechanisms to detect the amount of time where device was down, with independence of the reason.	< 1 month
Number of errors	Number of identified IoT component errors for new releases.	Number	Carry out defined components acceptance tests according to the specifications for each new release. Log the number of errors per release.	< 5
Errors detected during execution	By monitoring malfunction of a device or auto-diagnostic with reporting.	Number	Monitoring tools to detect malfunction: either remote detection or auto-diagnostic. Is the software running? Is the software responding correctly? Number of errors since last software release.	< 5
Component acceptance test	Percentage of the IoT components released, which fail to pass the acceptance tests.	Percentage	Carry out defined components acceptance tests according to the specifications for each new release. Calculate the fraction (percentage) of fails per release.	< 15%

Release incidents	Undesirable incidents caused by introducing new component releases. Also, those that affect other components or parts of the IoT system.	Number	Logging the number of failure incidents attributable to new releases. The number of incidents per release.	< 3
Time for error fixing	The time from the error message reported until the error is fixed.	Time	Identify when error occurs/reported and when the error is fixed. Calculate the consumption of time per error fixing.	< 48 working hours
Mean time for error fixing	Mean time until issue/error is fixed by a service/software/project.	Time	Mean time to fix an issue based on the issue tracker of a project in a specific period of time or software release.	< 7 working days
Service acceptance test	Percentage of service acceptance tests, which fail to obtain the customer's sign-off.	Percentage	Carry out service acceptance tests after each service installation. Calculate the fraction (percentage) of failed service acceptance tests.	< 15%
Communication data security	Communication throughput including data security number of treated messages per time.	Number per time unit	PI: a number, e.g. 1000 messages treated per ms including crypto / security Collection method: self-assessment from solution provider.	>1000 msg/ms

Table 3 - Use case mapping for the IoT devices and modules KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Standardised interfaces	x	x	x	x	x
Adherence with the AUTOPILOT in-vehicle IoT platform architecture	x	x	x	x	x
Implementation of the in-vehicle API	x	x	x	x	x
Mean time between outages	x	x	x	x	x
Number of errors	x	x	x	x	x
Errors detected during execution	x	x	x	x	x
Component acceptance test	x	x	x	x	x
Release incidents	x	x	x	x	x

Time for error fixing	x	x	x	x	x
Mean time for error fixing	x	x	x	x	x
Service acceptance test	x	x	x	x	x
Communication data security	x	x	x	x	x

4.2 IoT platforms

KPIs for IoT platforms take into account the types of IoT platforms (cloud-, edge-, industrial-, connectivity-, device- centric, etc.), their components (i.e. analytics, storage, management, etc.), features (i.e. end-to-end security, etc.) and openness level (i.e. open-source, open-architecture, closed ecosystem, etc.), as well as interoperability and standardisation are summarised in Table 4.

Table 4 - KPIs for IoT platforms

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Wireless interoperability	The number of wireless standards supported by the IoT in-vehicle platform.	Number	More than 3 different wireless standards are supported per platform.	> 3 wireless standards
Open platforms / existing systems that are supporting IoT need to be used in the pilot sites	How many existing systems that are supporting IoT need to be used in the pilot sites, including open source implementations.	Number	More than 7 existing systems that are supporting IoT need to be used in the pilot sites.	>7 existing IoT systems from pilot sites
Interoperability/ Federated IoT Platforms and Interoperability	Number of IoT platforms that are federated and able to interoperate.	Number	More than 10 IoT platforms can interoperate with each other and can be federated.	> 10 platforms federated
Scalability spec / Pilot services transferred between test sites	Number of pilot services transferred between test sites.	Number	More than 3 Pilot services transferred between test sites.	> 3 pilot services transferred

Scalability spec/ IoT devices connected to AUTOPILOT IoT servers	Number of IoT devices connected to AUTOPILOT IoT servers.	Number	More than 1000 IoT devices (in total) need to be integrated in the AUTOPILOT pilot sites; Not clear whether smart phones that are running and/or are used in IoT related apps are also being considered as IoT devices.	> 1000 IoT devices
Scalability spec / Vehicles within AUTOPILOT IoT Platforms	Number of vehicles within AUTOPILOT IoT platforms.	Number	More than 20 cars (in total) that are supporting IoT enabled AUTOPLOT use cases/services need to be used in the AUTOPLOT pilot sites.	> 20 vehicles
Scalability spec / External information sources used	Number of external information sources used.	Number	More than 100 data streams coming from external information sources; Assume that these external sources can be sources providing information such as, weather information, traffic light information, navigation information, point of interest, and any information coming from apps used in the IoT enabled AUTOPLOT use cases/services.	> 100 data streams
Scalability spec / Smart Edge Devices	Number of smart edge devices supported.	Number	More than 50 smart edge devices; support IoT capabilities, e.g. discovery, device management, etc.	> 50 smart edge devices
Scalability spec / Virtual Entities	Number of virtual entities.	Number	More than 1000 Virtual Entities; A Virtual Entity is a digital representation of the physical entity.	> 1000 virtual entities
Scalability spec / Use Cases Realized	Number of use cases realized.	Number	More than 7 use cases realized.	> 7 use cases realised

Demonstration / IoT Platform operation and Interoperability	Number of demonstrations IoT platform operation and/or Interoperability.	Number	More than 20 demonstrations of / IoT Platform operation and/or Interoperability.	> 20 demonstrations
Standardised interfaces	The number of standard interfaces for easy implementation.	Number	More than 2 standardised interfaces: Northbound, Southbound and Westbound/Eastbound.	> 2 standardised interfaces
Dissemination / Contributions to Standards	The number of contributions to standards.	Number	More than 5 contributions to standards.	> 5
Security and Privacy / Security and privacy measures implemented by design	Security and privacy measures implemented by design.	Percentage	Percentage of security and privacy measures implemented by design.	100%
Privacy protection	Is privacy ensured according to law / GDPR, i.e. no info about localization and real-time speed transmitted to the cloud?		PI: "0" or "1" Collection method: self-assessment by platform provider.	Yes

Table 5 - Use case mapping for the IoT platforms KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Wireless interoperability	x	x	x	x	x
Open platforms / existing systems that are supporting IoT need to be used in the pilot sites	x	x	x	x	x
Interoperability/ Federated IoT Platforms and Interoperability	x	x	x	x	x
Scalability spec / Pilot services transferred between test sites	x	x	x	x	x
Scalability spec/ IoT devices connected to AUTOPILOT IoT servers	x	x	x	x	x
Scalability spec / Vehicles within AUTOPILOT IoT Platforms	x	x	x	x	x
Scalability spec / External information sources used	x	x	x	x	x

Scalability spec / Smart Edge Devices	x	x	x	x	x
Scalability spec / Virtual Entities	x	x	x	x	x
Scalability spec / Use Cases Realized	x	x	x	x	x
Demonstration / IoT Platform operation and Interoperability	x	x	x	x	x
Standardised interfaces	x	x	x	x	x
Dissemination / Contributions to Standards	x	x	x	x	x
Security and Privacy / Security and privacy measures implemented by design	x	x	x	x	x
Privacy protection	x	x	x	x	x

4.3 Use of open IoT platforms

The use of open technologies, devices and platforms includes the ability to apply existing and widespread used technologies, devices and platforms.

It is important to differentiate between 'open' and 'standard'. 'Open' means that it can be accessed and used by different stakeholders, implementations, etc. 'Standard' implies that the interface is managed under a standardization body. For example: FIWARE Context Broker is open and based on an OMA NGSI (Open Mobile Alliance - Next Generation Services Interface) standard interface. But at the same time, it could be used through a proprietary networking protocol.

Table 6 - KPIs for use of open IoT platforms

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Internet gateways to interconnect AUTOPILOT sites	IoT platform applications using internet gateway to interconnect pilot sites.	Number	More than 5 IoT platform applications using internet gateway to interconnect pilot sites (due to the 6 AUTOPILOT sites)	> 5
Operating system	Operating systems by the IoT platform applications.	Percentage	The fraction (percentage) of operating systems implemented which support smartphones/ tablets, against the total number of IoT platform applications.	> 50%
Proprietary platforms and protocols	The software implementing functionality running inside a device/ gateway. Or a protocol managing communication by any layer.	Percentage by device	Percentage of proprietary platforms/ protocols running in each kind of device/ gateway.	< 20%

Open IoT architecture	Number of open APIs used in the AUTOPILOT architecture.	Number	More than 2 open APIs in the AUTOPILOT architecture (northbound, southbound and westbound/eastbound).	> 2

Table 7 - Use case mapping for the use of open IoT platforms KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Internet gateways to interconnect AUTOPILOT sites	x	x	x	x	x
Operating system	x	x	x	x	x
Proprietary platforms and protocols	x	x	x	x	x
Open IoT architecture	x	x	x	x	x

4.4 Use of supported standards

The use of supported standards includes the ability to count on existing, well-renowned and market-adopted standards. Some of the KPIs and the project targets below refer to objective 5 (Contribute to Standards) and the initial DoA KPIs in Table 1.

Table 8 - KPIs for use of supported standards

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Standard contribution	Contributions to IoT/AD standards.	Number	Regarding the IoT/AD standardization initiatives; How many contributions to standardization have taken place and given positive results?	> 5 (According to DoA)
Standardization articles	Article about IoT/AD standards.	Number	How many articles on IoT/AD standardization have been published?	> 3 (According to DoA)
Standardization presentations	Presentations about IoT/AD standards.	Number	How many presentations on IoT/AD standardization have been presented?	> 10 (According to DoA)
IoT Open platform	Open standards supported by the IoT platform.	Number	How many open standards are used and implemented?	> 3

Standard wireless interoperability	The number of wireless standards supported by the IoT in-vehicle platform.	Number	How many different wireless standards are supported per platform?	> 3
Standard interoperability interfaces	The number of standard interfaces for easy implementation.	Number	More than 2 standardised interfaces: Northbound, Southbound and Westbound	> 2 standardised interfaces
Use of existing standards	Compliance with the existing certification programs (e-g. ISA/IEC 62443 Cybersecurity Certificate Programs).	Number	How many different IoT use implementations are compliant with existing standards?	> 4
Security	IoT platform security level.	Percentage	The fraction (percentage) of wireless communication standards in compliance with data regulations data security, against all wireless communication standards used within the IoT platform.	> 10%

Table 9 - Use case mapping for the use of supported standards KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Standard contribution					
Standardization articles					
Standardization presentations					
IoT Open platform	x	x	x	x	x
Standard wireless interoperability	x	x	x	x	x
Standard interoperability interfaces	x	x	x	x	x
Use of existing standards					

Security	x	x	x	x	x

4.5 IoT system monitoring

Monitoring IoT implies a new problem for traditional monitoring with devices where the energy consumed is a critical aspect. In these cases, monitoring efforts (energy, bandwidth, CPU) need to consider the potential impact on performance, whether the monitoring is implemented remotely or internally by each device. Table 10 lists KPIs for autonomous monitoring of the IoT system components over the lifetime of the IoT application deployment, taking into account upgradability features and compatibility with legacy systems.

Table 10 - KPIs for IoT system monitoring

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
System uptime	System availability and uptime percentage metric: Mean time between outages, total fraction of defects, direct coverage, unit testing coverage.	Percentage	Logging the system uptime in a specific area and over a given period. Calculate the fraction (percentage) of system uptime.	100%
Latency	The demand for low latency/delay systems is increasing (data collection, processing and transmission).	Time	Measure best and worst-case latency for specified scenarios. Note: The E2E latency is scenario dependent.	< 1mS (worst-case)
Packet Loss Rate	Network transmission quality.	Percentage	Observe the packet loss rate. Note: Acceptable loss rate depends on application/use case and type of data.	100%
Information rate	The rate of updating information.	Times/ time unit	Measure (or according to specifications) the rate of information updates. Note: Necessary information rate depends on the application/use case.	> 1mS
Transmission range	Transmission range of the IoT platform.	Distance	Measure (or according to specifications) the coverage area. Note: Use case dependent.	> 10 km

Transmission capacity	The platform transmission capacity.	Bit rate	Measure (or according to specifications) the transmission capacity for a specific scenario. Note: Scenario/use case dependent.	> 2 Mbits/s
Location accuracy	The accuracy for location services (if applicable).	Distance	Measure the distance deviation. Note: Scenario/use case dependent.	< 10 cm
Device performance	Device performance diversity.	Number	Number of different sensor parameters available.	> 10
Battery lifetime	Lifetime for battery powered IoT units/systems.	Time	Measure (or according to specifications) the interval between power source change.	> 2 years

Table 11 - Use case mapping for the IoT system monitoring KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
System uptime	x	x	x	x	x
Latency	x	x	x	x	x
Packet Loss Rate	x	x	x	x	x
Information rate	x	x	x	x	x
Transmission range	x	x	x	x	x
Transmission capacity	x	x	x	x	x
Location accuracy	x	x	x	x	x
Device performance	x	x	x	x	x

4.6 IoT architecture

This section provides information on the IoT topologies used and their mapping to the existing IoT architectures.

Table 12 - KPIs for IoT architecture

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target

Standard IoT architectures	Standard based IoT architectures.	Percentage	What is the fraction (percentage) of the applied standard based IoT architecture frameworks against the total number of IoT architecture frameworks used?	> 50%
Open IoT architecture	Number of used open APIs in the AUTOPILOT architecture.	Number	More than 2 open APIs in the AUTOPILOT architecture (northbound, southbound and westbound).	> 2
End to end Security and Privacy / Security and privacy measures implemented by design	Ensure end-to-end security/ privacy by design.	Percentage	What is the fraction (percentage) of the applied end-to-end security/ privacy by design mechanisms?	100%

Table 13 - KPI and use case mapping

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Standard IoT architectures	x	x	x	x	x
Open IoT architecture	x	x	x	x	x
End to end Security and Privacy / Security and privacy measures implemented by design	x	x	x	x	x

4.7 IoT system functional design

This section presents the KPIs for IoT system functional design methodologies to optimize performance, data exchange, connectivity, overall power consumption, etc.

Table 14 - KPIs for IoT system functional design

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Application layer	The application layer of the functional model.	Yes/No	Are the functional design methodologies available for the application layer?	Yes
IoT layer	The IoT layer of the functional model.	Yes/No	Are the functional design methodologies available for the IoT layer?	Yes
Network layer	The Network layer of the functional model.	Yes/No	Are the functional design methodologies available for the network layer?	Yes

Table 15 - Use case mapping for the IoT system functional design KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Application layer	x	x	x	x	x
IoT layer	x	x	x	x	x
Network layer	x	x	x	x	x

4.8 IoT verification, validation, testing and certification

A first step towards IoT verification, validation, testing and certification is to determine the existence of a clear methodology, tools and procedures to ensure consistency with expectations of IoT use cases/applications. Once conformity to existing standards is confirmed, specific verification, testing and certification related to AUTOPILOT specific requirements, in particular on autonomous behaviour, must be added.

All incidents (and reasons) where the vehicles' behaviour deviates from the autonomous mode during testing must be reported for failure detection and safe operation [1]. The reporting needs to use comparative data regarding mileage, time period, cause category and distinguish between highways, urban roads, etc.

Some of the KPIs and the project targets below refer to objective 2 (Realize IoT-base AD use cases) and the initial DoA KPIs in Table 1.

Table 16 - KPIs for IoT verification, validation, testing and certification

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Use cases	Use cases realized.	Number	How many use cases are realized?	> 7 (According to DoA)
Dynamic map	Improved Perception/ Local Dynamic Map.	Number	How many IoT data streams are used?	> 20 (According to DoA)
Real traffic - hours	Number of hours in real traffic situations.	Hours	How many hours are carried out in real traffic environment?	> 500 hours (According to DoA)
Demonstrations	Number of demonstrations.	Number	How many demonstrations are carried out?	> 20 (According to DoA)
Service transfer	Number of pilot services transferred between test sites.	Number	How many pilot services are transferred between the test sites?	> 3 (According to DoA)

IoT/communication test procedures	Technical testing according to IoT and communication standards/ guidelines.	Yes/No	Are the tests carried out in line with prevailing IoT standards/ guidelines?	Yes
E2E test cases	Number of test cases demonstrating E2E interaction between autonomous application features and IoT platform interactions.	Number	How many end-to-end test cases developed?	2 to 5 test cases per applications
Conformity checking AUTOPILOT key specifications/ features	Conformity according to end2end tests.	Yes/No	Are the tests carried out in line with the AUTOPILOT conformance tests specifications and requirements?	Yes
Risk and vulnerability	Risk and vulnerability analysis of the IoT infrastructure.	Fraction	Are a risk and vulnerability analysis of the IoT infrastructure carried out (passed versus no passed)?	All passed
Certification or conformity assessment	Certification according to tests.	Yes/No	Are the constituent parts of the IoT and communication system certified or tested (type approved)?	Yes
Regulation compliance	IoT regulatory requirements compliance.	Yes/No	Is the IoT application and implementation in line with the requirements of regulatory authorities (international, national, regional)?	Yes
Real traffic - all incidents	Reporting all incidents in real traffic environment, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents, distance per time period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).

Real traffic - weather condition incidents	Reporting incidents in real traffic environment, caused by weather conditions, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by weather conditions), distance per time period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).
Real traffic - inattentive road user incidents	Reporting incidents in real traffic environment, caused by inattentive road users, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by inattentive road users), distance per period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).
Real traffic - unwanted vehicle manoeuvring incidents	Reporting incidents in real traffic environment, caused by unwanted vehicle manoeuvrings, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by unwanted vehicle manoeuvrings), distance per time period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).

Real traffic - perception discrepancy incidents	Reporting incidents in real traffic environment, caused by perception discrepancies, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by perception discrepancies), distance per time period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).
Real traffic - HW discrepancy incidents	Reporting incidents in real traffic environment, caused by HW discrepancies, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by HW discrepancies), distance per period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).
Real traffic - SW discrepancy incidents	Reporting incidents in real traffic environment, caused by SW discrepancies, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by SW discrepancies), distance per period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).

Real traffic - roadworks incidents	Reporting incidents in real traffic environment, caused by roadworks, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by roadworks), distance per period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).
Real traffic - emergency vehicle incidents	Reporting incidents in real traffic environment, caused by emergency vehicles, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by emergency vehicles), distance per period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).
Real traffic - road surface conditions	Reporting incidents in real traffic environment, caused by road surface conditions, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by road surface conditions), distance per period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).

Real traffic - objects in the roadway incidents	Reporting incidents in real traffic environment, caused by objects in the roadway, which require human intervention, (i.e. number of disengages from the AD).	Incident rate	Recording the number of incidents (caused by objects in the roadway), distance per period (e.g. per month), and calculate the average incidents per distance unit (e.g. per 100Km). Compare data from consecutive time periods to identify improvements or not. Distinguish between highways, urban roads, etc.	Incident rate improvements over time. (Zero at the end of the project).

Table 17 - Use case mapping for the IoT verification, validation, testing and certification KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Use cases	x	x	x	x	x
Dynamic map	x	x	x	x	x
Real traffic - hours	x	x	x	x	x
Demonstrations	x	x	x	x	x
Service transfer	x	x	x	x	x
IoT/communication test procedures	x	x	x	x	x
E2E test cases	x	x	x	x	x
Conformity checking AUTOPILOT key specifications/ features	x	x	x	x	x
Risk and vulnerability	x	x	x	x	x
Certification or conformity assessment	x	x	x	x	x
Regulation compliance	x	x	x	x	x
Real traffic - all incidents	x	x	x	x	x
Real traffic - weather condition incidents	x	x	x	x	x
Real traffic - inattentive road user incidents	x	x	x	x	x
Real traffic - unwanted vehicle manoeuvring incidents	x	x	x	x	x
Real traffic - perception discrepancy incidents	x	x	x	x	x

Real traffic - HW discrepancy incidents	x	x	x	x	x
Real traffic - SW discrepancy incidents	x	x	x	x	x
Real traffic - roadworks incidents	x	x	x	x	x
Real traffic - emergency vehicle incidents	x	x	x	x	x
Real traffic - road surface conditions	x	x	x	x	x
Real traffic - objects in the roadway incidents	x	x	x	x	x

4.9 Capacity to solve interoperability and connectivity issues

The capacity to solve interoperability and connectivity issues includes the ability to obtain interoperability and connectivity support for communications, data exchanges, etc.

Table 18 - KPIs for capacity to solve interoperability and connectivity issues

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Standardised interfaces	The number of standard interfaces for easy implementation.	Number	More than 2 standardised interfaces: Northbound, Southbound and Westbound	> 2 standardised interfaces
Network interoperability	Network interoperability for communication and availability.	Number	More than 1 network interoperability standards.	> 1
Semantic interoperability	Semantic interoperability for data management and control.	Number	More than 1 semantic interoperability standards used.	> 1

Table 19 - Use case mapping for the capacity to solve interoperability and connectivity issues KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Standardised interfaces	x	x	x	x	x
Network interoperability	x	x	x	x	x
Semantic interoperability	x	x	x	x	x

4.10 Scalability

The topic of scalability takes into consideration the ability to rapidly adapt to an increased user-base.

Table 20 - KPIs for scalability

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Edge-devices	The maximum number of edge-devices possible.	Number	How many connected edge-devices are tested or specified?	> 25
Subscribers	The maximum number of subscribers.	Number	How many subscribers are tested or specified?	> 10
Coverage area (rural areas)	The maximum coverage area.	Area	What is the maximum coverage in rural areas?	> 1km^2
Coverage area (urban areas)	The maximum coverage area.	Area	What is the maximum coverage in urban areas?	> 10km^2

Table 21 - Use case mapping for the scalability KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
End-nodes	x	x	x	x	x
Subscribers	x	x	x	x	x
Coverage area (rural areas)	x	x	x	NA	x
Coverage area (urban areas)	x	x	x	x	x

4.11 Efficiency of maintenance, deployment and life-cycle of services and software running

The complexity of managing the inventory of an IoT infrastructure currently is clear. It might be even more complicated to maintain the infrastructure (potentially very heterogeneous) keeping it always correctly upgraded. Traditional methodologies for maintaining upgraded running software (download and burn a firmware to a device directly connected to a computer) have to be considered as a minimum requirement. New methodologies to automatize these tasks over the air must also be taken into account and supported.

Table 22 - KPIs for efficiency of maintenance, deployment and life-cycle of services and software running

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Manual deployment (per device)	Manual deployment of software over IoT devices.	Time by device in seconds	Time elapsed since a new software build is ready to make it available (up and running) by device.	60s

Automatic deployment (per device)	Automatic deployment of software over IoT devices.	Time by device in seconds	Time elapsed since a new software build is ready to make it available (up and running) by device, without human intervention.	10s
Manual deployment (all devices)	Physical deployment of software on IoT devices.	Time to deploy a new service/ firmware into the whole infrastructure	Time elapsed since a new software build is ready to make it available (up and running) in all the devices.	10min
Automatic deployment (all devices)	Over-the-air deployment of software on IoT devices.	Time to deploy a new service/ firmware into the whole infrastructure	Time elapsed since a new software build is ready to make it available (up and running) in all the devices, without human intervention.	1min

Table 23 - Use case mapping for the efficiency in the maintenance, deployment and life-cycle of services and software running KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Manual deployment (per device)	x	x	x	x	x
Automatic deployment (per device)	x	x	x	x	x
Manual deployment (all devices)	x	x	x	x	x
Automatic deployment (all devices)	x	x	x	x	x

4.12 Integration with the existing and new infrastructure

KPIs for the integration of IoT technologies and platforms for IoT applications, using new and existing infrastructure, concerning efficient deployment, sustainability and the lifetime of the IoT application. Some of the KPIs and the project targets below, refer to objective 1 (Define and Implement an IoT architecture for AD) and the initial DoA KPIs in Table 1.

Table 24 - KPIs for integration with the existing and new infrastructure

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
IoT pilot deployment	Integration of existing IoT deployments into AUTOPILOT architecture.	Number	How many existing IoT systems are integrated into the pilot sites?	> 7 (According to DoA)
IoT devices	Number of IoT devices integrated.	Number	How many IoT devices are integrated in the pilot sites?	> 1000 (According to DoA)

Vehicles IoT platforms	Number of vehicles with IoT platforms.	Number	How many vehicles have an integrated IoT platform?	> 20 (According to DoA)
Different in-vehicles IoT sensors	Number of different in-vehicles sensor connected to IoT.	Number	How many different types of sensors in the vehicle are connected to IoT?	> 10 different (According to DoA)
Total in-vehicles IoT sensors	The overall number of in-vehicles sensor connected to IoT.	Number	What is the total number of sensors in the vehicle connected to IoT?	> 100 (According to DoA)
Federated IoT platforms	Number of federated IoT Platform instances.	Number	What is the number of federated IoT platform instances?	> 10 (According to DoA)
External sources	External information sources used.	Number	What is the number of data streams used?	> 100 (According to DoA)
Smart edge devices	Number of smart edge devices.	Number	How many smart-edge devices are integrated?	> 50 (According to DoA)
Virtual entities	Number of virtual entities	Number	What is the number of virtual entities?	> 1000 (According to DoA)
Seamless integration	Seamless integration with existing infrastructure.	1 - 4	Does the existing infrastructure need updates, changes, etc.? 1) None 2) Minor 3) Major 4) Not possible	2
Re-use	Re-use of existing infrastructure.	Percentage	What is the re-use of existing infrastructure?	30%
Installation complexity	Installation complexity like individual/local adjustments etc.	1-10	Easiest 1, most difficult 10	6

Table 25 - Use case mapping for the integration with the existing and new infrastructure KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
IoT pilot deployment	x	x	x	x	x
IoT devices	x	x	x	x	x
Vehicles IoT platforms	x	x	x	x	x
Different in-vehicles IoT sensors	x	x	x	x	x
Total in-vehicles IoT sensors	x	x	x	x	x
Federated IoT platforms	x	x	x	x	x

External sources	x	x	x	x	x
Smart edge devices	x	x	x	x	x
Virtual entities	x	x	x	x	x
Seamless integration	x	x	x	x	x
Re-use	x	x	x	x	x
Installation complexity	x	x	x	x	x

4.13 Ecosystem awareness

Ecosystem awareness refers to the pilots' capability to understand the ecosystem landscape with the existing connections and relationships in place there, while outlining their own position in it and visioning vis-à-vis the overall ecosystem and industry.

Table 26 - KPIs for ecosystem awareness

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Players and roles	Understanding the ecosystems players and their roles.	Textual	Face-to-face Interview.	Open Q
Connections	Understanding the existing connections and relationships among ecosystem players.	Textual	Face-to-face Interview.	Open Q
Vision	AUTOPILOT's current collocation within the IoT ecosystem.	Textual	Face-to-face Interview.	Open Q
Roadmap	AUTOPILOT's ecosystems approach and planned evolution in the short and long-term.	Textual	Face-to-face Interview.	Open Q
Ecosystem Members	Systematic mapping of actors within their own ecosystem.	Number	Online survey; Face-to-face Interview. Number of start-ups identified; Number of SMEs identified Number of large companies/ corporates identified; Number of IoT platform providers; Number of third-party service providers identified; Number of hardware suppliers identified.	> 20

Table 27 - Use case mapping for the ecosystem awareness KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Players and roles	x	x	x	x	x
Connections	x	x	x	x	x
Vision	x	x	x	x	x
Roadmap	x	x	x	x	x
Ecosystem Members	x	x	x	x	x

4.14 Stakeholder engagement

Stakeholder engagement includes the ability to reach out to the appropriate stakeholders involved in the pilots and the ability to engage and motivate them, ensuring a solid and reactive operative framework.

Table 28 - KPIs for stakeholders' engagement

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Stakeholder numbers	Number of stakeholders involved.	Number	Online Questionnaire.	> 20
Stakeholders' Industries and Skills	Stakeholders' sectors and capabilities	Textual	Online Questionnaire.	List
Partner Roles	Partners' roles within AUTOPILOT.	Textual	Face-to-face Interview.	Open Q
Engagement Frequency	Frequency of partner interactions and meetings.	Textual	Online Questionnaire.	List
Engagement Mode	Mode/ type of partner meeting and interactions.	Textual	Online Questionnaire.	List
Effort Parity	How AUTOPILOT's efforts are shared across partners.	Textual	Online Questionnaire.	List
Reward system	How partners are rewarded and motivated for their AUTOPILOT involvement.	Textual	Face-to-face Interview.	Open Q

Table 29 - Use case mapping for the stakeholders' engagement KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Stakeholder numbers	x	x	x	x	x
Stakeholders' Industries and Skills	x	x	x	x	x
Partner Roles	x	x	x	x	x
Engagement Frequency	x	x	x	x	x

Engagement Mode	x	x	x	x	x
Effort Parity	x	x	x	x	x
Reward system	x	x	x	x	x

4.15 External partnerships and collaboration

External partnerships and collaboration include the ability to expand the pilots' network, building alliances and strategies, to foster their capabilities and solidity, while enforcing and facilitating go-to-market channels. The more the stakeholders' ecosystems cover different expertise, industry subsectors and technology areas, the more pilots' strength and opportunities will grow. The field includes the capability to involve trusted customers in after-sale activities, collecting feedback on operative systems and on-field pilot behaviours, while collaboratively developing new features.

Table 30 - KPIs for external partnerships and collaboration

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
External partnership agreements	Number of recorded formal or informal agreements between the project consortium and other companies or project consortia that establish a two-way relationship.	Number	Online Questionnaire.	> 4
External Stakeholders' Industries and Skills	External stakeholders' sectors and capabilities.	Textual	Online Questionnaire.	List
External Stakeholders' Support	What added value do external stakeholders bring to AUTOPILOT or what skill/capabilities gaps do they fill?	Textual	Face-to-face Interview.	Open Q
Customer Interaction	AUTOPILOT's ability to collect feedback on operative systems and on-field products, thanks to a continuous interaction with customers.	Textual	Online Questionnaire.	List
Collaboration Strategy	Assessment of the processes in place to identify and approve new alliances and partnerships.	Textual	Face-to-face Interview.	Open Q
Contributions to SDOs and Industry Alliances	Contributions to Standards.	Number	More than 5 contributions to SDOs and Industry Alliances.	> 5 SDOs and Industry Alliances

Contributions to SDOs and Industry Alliances	Article about IoT/AD standards.	Number	More than 3 publications in scientific conferences/journals about standards in IOT/AD.	> 3
Contributions to SDOs and Industry Alliances	Presentations about IoT/AD standards.	Number	More than 10 presentations about IoT/AD standards.	> 10

Table 31 - Use case mapping for the external partnerships and collaboration KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
External partnership agreements	x	x	x	x	x
External Stakeholders' Industries and Skills	x	x	x	x	x
External Stakeholders' Support	x	x	x	x	x
Customer Interaction	x	x	x	x	x
Collaboration Strategy	x	x	x	x	x
Contributions to SDOs and Industry Alliances	x	x	x	x	x

4.16 Public and government engagement

Public and government engagement includes the ability to reach out and engage with public authorities and regulators. These may be city councils or municipalities, but also public organizations (e.g. hospitals, retirement homes, schools and charity associations), industry-specific regulators, and trade associations.

Some of the KPIs and the project targets below refer to objective 4 (Involve users, public services and business players) and the initial DoA KPIs in Table 1. This objective may be relevant for section 4.14 (Stakeholder engagement) as well.

Table 32 - KPIs for public and government engagement

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
End-user	End-users tested	Number	How many end-users have tested the AUTOPILOT solutions?	> 1000 (According to DoA)
Workshops with public and government representatives	Increased engagement with public and government through workshops.	Number	How many workshops are organized?	> 4 (According to DoA)

Municipalities connection	Number/country/role of Municipalities involved in AUTOPILOT as partners or external stakeholders.	Number	Online Questionnaire – Face-to-face Interview.	Open Q
Public organizations connection	Number/type/role of Public organizations (e.g. hospitals, retirement homes, schools, charity associations) involved in AUTOPILOT as partners or external stakeholders.	Number	Online Questionnaire – Face-to-face Interview.	Open Q
Regulators and trade associations connection	Number/type/role of regulators and trade associations involved in AUTOPILOT as partners or external stakeholders.	Number	Online Questionnaire – Face-to-face Interview.	Open Q

Table 33 - Use case mapping for the public and government engagement KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
End-user	x	x	x	x	x
Workshops with public and government representatives	x	x	x	x	x
Municipalities connection	x	x	x	x	x
Public organizations connection	x	x	x	x	x
Regulators and trade associations connection	x	x	x	x	x

4.17 Value chain openness

Value chain openness reflects pilots' openness to third party suppliers and market channels, guaranteeing equal access and same rights to all potential value chain actors.

Table 34 - KPIs for value chain openness

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Suppliers equality	Assessment of AUTOPILOT's ability to guarantee equal rights to potential suppliers, avoiding exclusive licenses/authorisations and geographical barriers.	Textual	Online Questionnaire.	List
Sale channels equality	Assessment of AUTOPILOT's ability to guarantee equal rights to their selected sale channels, avoiding exclusive licenses/authorisations, geographical barriers and cost disparities.	Textual	Online Questionnaire.	List

Sale channels conditions	Sellers' possibility to set their own prices, advertise and market their goods while avoiding unfair quality standards or production costs.	Textual	Online Questionnaire.	List
Supplier information	Have end-users equal access to information? Are they influenced by external parties in their reseller choice? Are there any implicit cost for changing supplier?	Textual	Online Questionnaire.	List

Table 35 - Use case mapping for the value chain openness KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Suppliers equality	x	x	x	x	x
Sale channels equality	x	x	x	x	x
Sale channels conditions	x	x	x	x	x
Supplier information	x	x	x	x	x

4.18 Inclusiveness and participation for third parties

Inclusiveness and participation for third parties includes the possibilities for third parties to use AUTOPILOT's products and services and with which rights.

Table 36 - KPIs for inclusiveness and participation for third parties

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Third-party platform resources access	Possibility for third parties to access AUTOPILOT's platforms.	Yes/No	Online Questionnaire.	Yes
Licensing Model	Description of the licensing mechanisms in place to assure equal right access to third parties.	Textual	Face-to-face Interview.	Open Q
Usage rights level	Description of the usage rights AUTOPILOT's have in place on their materials/ products/ services.	Textual	Face-to-face Interview.	Open Q

Table 37 - Use case mapping for the inclusiveness and participation for third parties KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Third-party platform resources access	x	x	x	x	x

Licensing Model	x	x	x	x	x
Usage rights level	x	x	x	x	x

4.19 Openness of business models

Openness of business models includes the business models' ability to serve vertical-specific needs or horizontal/cross-vertical needs. Some of the KPIs and the project targets below refer to objective 3 (Advanced business models and services) and the initial DoA KPIs in Table 1.

Table 38 - KPIs for openness of business models

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Test rides	Test rides regarding advanced business models and services.	Number	How many test rides are carried out?	> 200 (According to DoA)
Business models	Developed business models.	Number	How many business models are developed?	> 7 (According to DoA)
New services	New IoT AD services developed.	Number	How many new IoT/AD services are developed?	> 7 (According to DoA)
Podium discussions	Podium discussions on new business models and services.	Number	What is the number of podium discussion participations?	> 12 (According to DoA)
Business model replicability	Usage of business models on different cases.	Number	Ability for valid business models to be used on different verticals with similar value chains and stakeholders involved. What is the number of verticals addressed?	> 4
Incumbent existence	Ability to transform the market.	Number	Assessment on the critical mass of incumbents inside the ecosystem needed to disrupt and transform the market.	> 2
New business model adoption	How fast or agile change can IoT business models sustain depending on applications and stakeholders' profiles in the IoT ecosystem.	Number	Frequency of business model's changes or frequency in the number and type of revenue streams generated by AUTOPILOT. What is the number of types of business models and revenue streams?	> 2

Table 39 - Use case mapping for the openness of business models KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Test rides	x	x	x	x	x
Business models	x	x	x	x	x
New services	x	x	x	x	x
Podium discussions	x	x	x	x	x
Business model replicability	x	x	x	x	x
Incumbent existence	x	x	x	x	x
New business model adoption	x	x	x	x	x

4.20 Open source strategy

Open source strategy refers to the degree of open source elements in the ecosystem.

Table 40 - KPIs for open source strategy

KPI Name/Identifier	Description	Metric	Method of collection and measurement	Project target
Interoperability	Ability of the solution adopted to interact with external parties.	Percentage	Assessment on the degree of interoperability of the adopted solution, through a benchmark methodology with respect to the potential use of the deployed system of third party stakeholders providing solutions at different layers. What is the percentage of end devices supported?	>70%
Discovery	Promotion of resources.	Number	Ability of third parties to discover, locate and interact with open source services on the platform. What is the number of resource views?	TBD
Platform usage	Openness of third parties accessing to open API and resources.	number	Ability of third parties to make use of open resources in the platform, tracking their activity and interactions. What is the number of resource usage?	TBD
Mix of open sources communities	Balanced of open sources solutions coming from ITS and IoT.	Percentage	Ability to use open sources solutions coming from ITS and IoT worlds.	50%-50%

Table 41 - Use case mapping for the open source strategy KPIs

KPI Name/Identifier	Automated valet parking	Highway pilot	Platooning	Urban driving	Real-time car sharing
Interoperability	x	x	x	x	x
Discovery	x	x	x	x	x
Platform usage	x	x	x	x	x
Mix of open sources communities	x	x	x	x	x

5. Autonomous vehicles and IoT KPIs across application domains

Significant technical improvement is needed to achieve AD level 4 operation [7]. IoT technologies can support the increase of AD functions in the vehicle by providing additional sensing information, processing, analytics, connectivity and cognition capabilities. AD has high performance requirements and the sensors/actuators, computers and software must be robust, redundant and resistant to abuse. Several more years of development and testing will be required before regulators and potential users gain confidence that level 4 and 5 vehicles can operate as expected under all conditions [8][9]. In this context, in order to support the increase of AD functions, it is critical that IoT applications enforce these requirements across application domains that intersect with AD applications.

Current technologies allow autonomous vehicle operation in approximately 90% of all conditions; no current technology can operate safely in heavy rain or snow, since such conditions have an impact on the sensors, data transmission and software processing. Achieving 99% operability (vehicles are unable to make 1% of trips, or 10 times a year) will be exponentially more difficult, and achieving 99.9% of conditions (vehicles are unable to make 0.1% of trips, or once a year), a reasonable target for many regulators and customers, will be exponentially more difficult again [11]. Robust IoT technologies can support these cases by providing additional information, processing, connectivity, analytics and cognition.

Future autonomous vehicle ecosystems are heading toward the integration of multiple technologies, e.g. IoT V2X communication, Artificial Intelligence (AI), robotics, Machine Learning (ML), etc. The integration and shift in focus will make software-defined vehicles integrated with IoT platforms to be the essence of autonomous vehicles and IoT in the future.

Internet of Vehicles is an emerging field; merging the mobile internet and the internet of things, and crosses multiple disciplines, such as automotive, transportation, information and communications technology [2][3]. The IoV technology refers to dynamic communication systems that facilitate connected vehicles [2], which encompass vehicular mobile internet, inter-vehicle and intra-vehicle communication networks [4]. The V2X communication, which includes Vehicle-to-Network (V2N), Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), Vehicle-to-Device (V2D), Vehicle-to-Pedestrians (V2P), enables information gathering, sharing and advanced data processing through IoT platforms for utilization in autonomous driving.

As IoT technology and services transform autonomous vehicles, the ecosystem is influenced by new players and stakeholder roles, and a shift in the balance of "power" is emerging, e.g., the increasing relationship between automotive manufacturers and software providers [5]. The vehicles become increasingly software driven. A wide range of IoT sensors gathers information about the vehicles and its surroundings; this potentially huge amount of data is subjected to data processing, big data analysis and artificial intelligence development.

IoT platforms, sensors and V2X connectivity are the basis for vehicle connected autonomy in the new Mobility-as-a-Service (MaaS) paradigm. Autonomous vehicles and driving, as other domains, require multiple sensors embedded in all manner of smart devices across the IoT landscape [5], and are moving from products to services and experiences, from industry silos to complex connected ecosystems and value chains. All of this requires innovative use of KPIs across application domains to succeed.

Several KPI fields in section 4 are useful across IoT application domains, like AD, smart cities, smart farming, smart living/wearables, and aging well. For instance, the issue of scalability is important for preparation for a rapid increase in IoT devices and users. Another important IoT issue is the faster design cycles and needs for software upgrades, compared to what is being used traditionally in the automotive industry [5]. These upgrades demand scalable data processing and memory capabilities.

6. Conclusion

This document addresses the coverage of performance and KPIs for design, testing, validation and impact measurement/assessment of autonomous vehicles and IoT pilots across the priority areas, the identified taxonomy and benefit areas.

The availability of data is a key consideration in the identification of an appropriate list of KPIs. The document has identified that the generated data by the AUTOPILOT use cases is a key data source currently used in the performance and impact assessment of autonomous vehicles and IoT pilots.

The KPIs proposed in this document, typically request that information is classified in different types, such as road/areas, use cases, vehicle types and IoT infrastructure (e.g. platforms, connectivity, sensor/actuators, etc.). Practical and technological limitations may make this unfeasible in some instances and the use cases should therefore provide as much detail as possible within the existing constraints.

The proposed KPIs are based on the initial requirements and specifications. Managing the complexity of requirements for autonomous driving requires constraining operational concepts and engaging in a phased expansion of requirements. This will be implemented by the different pilot sites based on their use cases. The KPIs presented can be scaled in several directions and the pilot sites can apply different scenarios that include:

- Road access - limited access highways, dedicated lanes, rural roads, suburbs, closed campuses, urban streets, etc.
- Visibility - day, night, fog, haze, smoke, rain, snow, ice, etc.
- Vehicular environment - self-parking in a closed parking lot/parking building with no other vehicles moving, autonomous-only lanes, marker transponders on non-autonomous vehicles, etc.
- External environment - infrastructure support, pre-mapped roads, convoying with human-driven vehicles, platooning with other autonomous vehicles.
- Speed - lower speeds potentially lead to lower consequences of a failure and larger recovery margins

The KPIs are structured to consider the impacts achieved along the use cases where autonomous vehicles and IoT pilots are deployed for wider impacts of to be assessed.

One of the challenges of autonomous vehicles and IoT pilots is the ability to link, or attribute, observed changes in KPIs to specific pilot/use case investments. The difficulty in isolating autonomous vehicles and IoT derived benefits from the wide area and complex array of contextual influences can result in KPIs that are omitted from the list.

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