Ref. Ares(2020)2765700 - 28/05/2020

PLEDGER

D2.1 PLEDGER's Detailed Use Cases

Document Identification			
Status	Final	**Due Date**	31/05/2020
Version	1.0	**Submission Date**	28/05/2020

Related WP	WP2	**Document Reference**	D2.1
Related Deliverable(s)		**Dissemination Level (*)**	PU
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Keywords:
Use Case Description, Initial Requirements

(*) Dissemination level: **PU**: Public, fully open, e.g. web; **CO:** Confidential, restricted under conditions set out in Model Grant Agreement; **CI:** Classified EU RESTRICTED, EU CONFIDENTIAL, **Int =** Internal Working Document, information as referred to in Commission Decision 2001/844/EC.

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Document History			
Version	Date	Change editors	Changes
0	21/04/2020	i2CAT	Initial version that integrates the inputs from all UC responsible.
0.1	30/04/2020	i2CAT	The second round of UC contributions integrated, Acronyms added, and Introduction added.
0.2	12/05/2020	i2CAT	The third round of UC contributions integrated, Cross-UC Overview and Roadmaps added, Executive Summary added, and Conclusions added.
0.3	20/05/2020	I2CAT, ATOS, ENG	Feedback from reviews integrated, final request for inputs from UC leaders pending
0.4	25/05/2020	I2CAT, FILL, HOLO	Applying final request for inputs from UC leaders
0.5	26/05/2020	ATOS	Small format changes to fulfil quality guidelines
1.0	28/05/2020	ATOS	FINAL VERSION TO BE SUBMITTED

Quality Control		
Role	Who (Partner short name)	Approval Date
Deliverable Leader	Leonardo Ochoa-Aday (i2CAT)	26/05/2020
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List of Acronyms

Abbreviation/Acronym	Description
AR	Augmented Reality
ARES	AR Engineering Space
CAD	Computer-Aided Design
CPU	Central Processing Unit
DC	Data Centre
DoA	Description of Action
Dx.y	Deliverable number y belonging to WP x
EC	European Commission
EPC	Engineering, Procurement, and Construction
GDPR	General Data Protection Regulation
GPS	Global Positioning System
GPU	Graphics Processing Unit
GUI	Graphical User Interface
HMD	Head-Mounted Displays
IIoT	Industrial Internet of Things
KPI	Key Performance Indicator
ML	Machine-Learning
MR	Mixed Reality
NC	Numerical Control
OEE	Overall Equipment Effectiveness
OPC UA	Object Linking and Embedding for Process Control Unified Architecture
PLM	Product Lifecycle Management
PoC	Proof of Concept
QoS	Quality of Service
R&D	Research and Development
RAM	Random Access Memory
RAN	Radio Access Network
RTC	Real-Time Communication
SaaS	Software as a service
SBC	Single-Board Computer
SLA	Service-Level Agreement
SLAM	Simultaneous Localization and Mapping
SME	Small and Medium-Sized Enterprises
TTC	Time To Collision
UC	Use Case
UE	User equipment
VR	Virtual Reality
VRU	Vulnerable Road User
WebRTC	Web Real-Time Communication
WP	Work Package

Executive Summary

This deliverable documents the outcome of T2.1 “Use Cases detailed description”, containing the detailed description of the 3 use cases (UCs) that will be deployed in the PLEDGER project. The three UCs cover very varied scenarios, namely mixed reality applications, the enhancement of global road safety for vulnerable road users and the manufacturing of data mining with edge infrastructures.

In three equally structured sections, each dedicated to one UC, a detailed description of the UCs is provided. Each of these sections gives the necessary motivation and information to understand why each UC will be deployed and which high-level requirements exist to implement them. A short sub-section about similar projects is also presented to contextualize PLEDGER. Starting from this information, it is explained how the PLEDGER platform and its assets will be used to tackle the challenges of each UC and which features are required to enable the different processes in the UC workflows.

This analysis reveals that there is a need for new assets or in some cases extensions of existing assets to implement the UCs, which gives an understanding of any future development and integration work to be done. Further, the two infrastructures on top of which the UCs will be deployed are presented and an initial development and deployment plan is provided. While UC1 and UC3 will be deployed in the same manufacturing premises in Gurten, Austria, UC2 will be deployed as part of a city-wide testbed in Barcelona. Each deployment comes with its challenges and risks that are captured in this deliverable.

The three sections dedicated to the different UCs are followed by a cross-UC overview and roadmaps section which captures key characteristics of each UC in an overview format. It also identifies which role each UC plays in the roadmap of fulfilling the project’s objectives and which are its main contributions. This summary and comparison show that the UCs each contribute in a different way to fulfilling PLEDGER’s objectives, leaving only a few objectives to be addressed separately by other lines of work, such as the platform development or the implementation of specific modules.

This deliverable serves as input for deliverable D2.2 “Requirement Analysis” and is expected to be used as the base reference for the future work on implementing the workflows of each UC.

1 Introduction

This deliverable presents the outcome of the work performed in "T2.1: Use Cases detailed description", presenting the three use cases (UCs) in the context of the PLEDGER project. Based on real-life applications and needs, the UCs make use of the assets and features provided by the PLEDGER platform to contribute towards demonstrating and validating the objectives presented in the project proposal. Any missing assets to fill the gaps towards implementing the UCs are identified and their functions are detailed briefly.

The UCs cover three relevant scenarios taken from the ambit of industrial engineering and urbanistic mobility that will all rely on the technological advances introduced in the project:

- UC1, *Mixed Reality Application on the Edge*, uses augmented reality (AR), computer-aided design (CAD) in conjunction with edge and cloud technology to efficiently improve engineering workflows and to cut costs by introducing pipework and assembly projections.
- UC2, *Edge Infrastructure for Enhancing the Safety of Vulnerable Road Users*, proposes to integrate the PLEDGER platform with an enhanced, edge compute powered city infrastructure to improve the safety of vulnerable road users (VRUs).
- UC3, *Manufacturing the Data Mining on the Edge*, intends to achieve self-organisation of cyber-physical systems by entrusting crucial data offloading and edge-device tuning to the PLEDGER platform.

This deliverable provides a detailed description for each of the UCs, serving as a basis for the requirement analysis covered in D2.2 "PLEDGER Requirements Analysis" [1].

Document structure

The deliverable is structured in six main sections and provides a detailed description for each of the UCs, serving as a basis for the definition of the technical use case requirements to be covered in D2.2 [1]:

- Section 2 presents UC1 "Mixed reality applications on the edge" and how this use case can effectively cut costs and improve engineering workflows via the PLEDGER framework.
- Section 3 describes the UC2 "Edge Infrastructure for enhancing the safety of vulnerable road users", which aims at the minimization of traffic accidents by integrating with the PLEDGER framework to introduce risk avoidance mechanisms for pedestrians, cyclists or users of electric scooters in Europe.
- Section 4 defines the UC3 "Manufacturing the data mining on the edge" that provides a digital strategy for machine and plant development that will enable the secured transfer of data from edge devices to the cloud using the PLEDGER platform.
- Section 5 summarizes, in a cross-UC overview, how each UC contributes to the main goals and results of the project and which features it implements. The overview lists the available and required assets, the objectives achieved, an initial outlook on the replicability, and the involvement of stakeholders for the three UCs.
- Finally, Section 6 concludes the deliverable.

2 Use Case 1 (UC1): Mixed reality applications on the edge

Holo-Light delivers a collaborative Augmented Reality (AR) software suite to efficiently cut costs and improve engineering workflows. Holo-Light's AR Engineering Space (ARES) enables engineers to visualize, manipulate and share 3D CAD data with others in a real environment. Mixed Reality (MR) brings information from a 2D screen directly into the production hall. This enables industrial workers to directly see and use information where it is needed, which is right at the machine.

By means of AR, the projected pipework and assemblies can be visualized and manipulated directly at their envisaged destination. Going out into the field, viewing the assembly on-site, even though it does not exist yet, makes the planning considerably easier. This allows determining whether everything is in order on the spot or whether modifications on a specific stage in the project are needed. Furthermore, "what if" testing scenarios expand the digital toolbox of the engineer and give him a better understanding of the projected asset. PLEDGER acts as an enabler for the mixed reality applications by providing the necessary tools, i.e. bypassing device limitations through the remote rendering functionality.

2.1 Motivation

In the PLEDGER project, we will investigate new modalities for MR and AR applications as part of a multilevel offloading scheme. This scheme will include infrastructure edge nodes and more powerful cloud nodes. Device edge nodes, which are compute nodes located very close to the users with for very low latency, but with low capacities, are not considered. While resources on the infrastructure edge are further away (physically and logically) from users than resources on the device edge, they are still close enough to provide low round-trip latencies (5-10 ms) to most devices and they are also capable of housing equipment that is orders of one magnitude more powerful than what exists on the device edge. The infrastructure edge can be viewed as a mid-point between the device edge and the traditional centralised cloud, aiming to combine the advantages of both. The specific new modalities introduced in PLEDGER will also include the ability of the device edge node to perform under specific Service-Level Agreement (SLA) terms and Quality of Service (QoS) requirements that have been negotiated dynamically between the application user (on the device edge) and the provider (on the infrastructure edge). Moreover, the MR application deployed in the UC will adopt an innovative privacy-preserving mechanism of visualising content on the edge while filtering out any content that should be no further transmitted on the backend edge/cloud infrastructure.

2.2 Detailed description (scenario/business-centric)

2.2.1 Description of the UC

The goal of this UC is to enhance the capabilities of AR/MR/Virtual Reality (VR) solutions by coupling them with edge computing technologies and the corresponding load allocation and optimisation tools, in order to provide high-level services in industrial environments. More specifically, the industrial environment which will run the pilots of UC1 is the one provided by FILL in Use Case 3 (UC3, Section 4): *Manufacturing the data mining on the edge*). FILL occupies a key role in process automation and data organisation for complex manufacturing facilities and has the necessary human resources and infrastructure to implement automated production lines. In particular, the UC will focus on three case studies integrating machine data into MR interfaces and optimising them via edge computing technology:

- Collaborating in Fast Prototyping
- Assisting in Manufacturing and Service & Utility procedures

● Enhancing Training & Interaction

As one of the biggest demands for AR solutions lies in the visualisation of a company's content, the Fast Prototyping approach specialises in providing optimal representation along the value chain. By transforming a variety of file formats into three-dimensional holograms, Holo-Light's CAD solution ARES provides new value especially for fast prototyping and product presentation (see Figure 1). This out-of-the-box solution enables fast visualisation of 3D CAD Models as holograms, while it offers a broad variety of features to manipulate components and assembly groups of the corresponding visualisation. As this type of visualisation also allows people from other locations to connect and view them, these AR solutions also strengthen collaboration with partners, colleagues, suppliers, or other departments. While this method of "fast" prototyping certainly adds a benefit to current methods, its biggest advantage arises when combining this technology with remote rendering technology via edge computing. By outsourcing the limited computing power of smart-glasses to external sources like e.g. a small server with consumer-grade GPU, the computational power increases dramatically, enabling the visualisation of up to 50x larger data. A much higher level of detail and impeccable resolution are the results.

Figure 1: AR design review

Regarding the Manufacturing and Service & Utility procedures, one possibility is the aggregation of information on a 3D model and the visualisation of all these data (see Figure 2) as an overlay on the real object. This helps, indicatively, on figuring out if something is wrong with a complex machine (through a diagnostic which highlights potential problems on the machine) and displaying step by step instructions to properly fix errors. Another more granular approach is to engage an expert on an interactive AR workspace created using ARES and remote rendering technology. This allows the detailed presentation of e.g. a machine to be repaired and the inter-site manipulation of the same, both by the intervention of the expert and the worker on site. As a result, the further procedure of the repair can be discussed in detail and also defective components, which are located somewhere within the visualized object, can be discussed and considered more closely.

Figure 2: AR machine interface

Regarding the aspect of Training & Interaction, industrial environments define very clear guidelines when it comes to working processes. Therefore, to smoothly and properly complete such operations, the obligatory training processes are very complex and time-intensive. To communicate work processes like these, Holo-Light created a training case which playfully transfers knowledge. The application can guide the user through the right tools and visually describe every step in pictures, videos, and animations to manage the process on the real-life object (see Figure 3). As the above-mentioned obligatory training processes are very complex, so is their corresponding work environment, which is why it is important to have a flawless and powerful visualisation of the trainees' surroundings and tools. Therefore, the remote rendering technology can support the best training experience, visualising entire assembly lines or e.g. huge pieces of machinery most accurately. So, by combining these two technologies and by adding a certain gamification factor as well, the application can provide both theoretical and practical training and ensures optimal results.

Figure 3: Example of AR training

To sum up, industrial environments are characterised by complex and extensive provisions which regulate certain workflows and complicate simple training processes. High worker turnover is monotonous work, leading to a waste of resources in training new workers. Moreover, no immediate access to machine data or expertise to properly maintain machinery is always available, and the same applies to a uniform way to check quality control issues, costing the manufacturer time and money. MR applications though support the learning process both theoretically and practically and offer interfaces which allow the retrieval of all the necessary information in various ways, combining real-time and historical information visualisation, data entry, and documentation. This not only reduces cost and time expenditures but also creates better-trained employees.

The benefits of the aforementioned self-sufficient head-mounted displays (HMD) for industrial use, such as Microsoft HoloLens, also come with the disadvantage of limited memory and processing power. At the same time, computation capacity for achieving high-resolution graphics at the edge is imposing new requirements for performance, scalability and QoS: features that bring in a necessary trade-off capability between what computation has to be implemented on the edge (even using GPU processing) and what needs to be transmitted for further processing to the cloud infrastructure. High-resolution models also cause very fast battery consumption. Nevertheless, business and industrial players are increasingly demanding applications of greater complexity which require a higher level of performance in general.

To resolve these competing issues, PLEDGER will explore the possibilities of utilising edge computing, making the usage of technologies such as remote rendering possible. The basic idea lies in the outsourcing of demanding work processes like calculations, application logic, or content rendering to other edge devices, the fog nodes or (if this is not sufficient) the cloud. This means that the computing power does not need to come from the HMD itself but instead can come from an external source (another device, network of devices or virtual fog/cloud resources) which can more efficiently complete the processing.

By successfully utilising the full potential of edge/fog/cloud technologies and the corresponding available infrastructure, PLEDGER will enable the stakeholders in this use case to achieve even faster and more powerful visualisation of 3D CAD models, display 3D models of even higher performance in real-world environments, offer the possibility of secure upload of confidential data, and enhance the experience of MR collaborative sessions and enable people to work with components and assembly groups. All these will result in cost-effectiveness, reduction of current cycle times, simplification and standardisation of the working process, and faster and more highly intuitive training processes for new workers while requiring fewer resources.

2.2.1.1 High-level/basic requirements

Based on the description above, a series of high-level requirements are identified for UC1:

- On-site, GPU-based edge nodes (sensible Product Lifecycle Management (PLM) data must not be transferred to the public cloud)
- Easy and fast accessible high-performance resources for Simultaneous Localization And Mapping (SLAM) based AR devices (outsourcing rendering capability)
- Edge-based user authentication and permission system via blockchain (smart contracting)
- Edge-based orchestration system for multiple App instances with QoS
- A scalable framework to distribute Apps on an edge node system
- Fast accessible machine information for real-time dashboards

To render high-resolution graphics during the execution of UC1, support of GPU-based processing at nodes comprising the edge infrastructure is strongly required. As a result, the 3D CAD models can be properly rendered as holograms while also ensuring network connections with low latency and high bandwidth. Additionally, during the exchange of data between the cloud and edge layers, any data that might be sensible for the business operation should be not shared with the public cloud. To that end, a blockchain-based system is needed to not only handle the exchange of such data but also the smart contracts that will ensure the expected QoS for the execution of this use case. Last but not least, a dashboard providing an intuitive GUI as the system entrypoint is required. This web interface will allow users to interact with the PLEDGER framework and to constantly visualize diverse parameters of deployed applications and services.

2.2.2 Stakeholders involved

For UC1, the following stakeholders are identified:

- **Customer:** UC1 is a customer-oriented use case, therefore it will be demonstrated at FILL headquarters, where it will support engineers in the manufacturing hall. The infrastructure that will be deployed for the implementation of the use case will focus on the offloading of tasks to the cloud. Detailed analysis of the specific infrastructure is provided in D2.2 [1]. In this context, we have identified two departments:
    - **Customer - Engineering Department:** Engineers will be able to visualize and work with industrial 3D CAD models in Augmented Reality and collaborate with colleagues to lower costs for product design and increase the quality of products.
    - **Customer - IT Department:** The IT department of a company is responsible for data security and therefore needs to know what mechanisms are provided. Outsourcing rendering power to edge nodes need proper bandwidth, therefore the IT infrastructure needs to be able to handle this amount of data. They also need insight into how the blockchain-based smart-contracting system works for authentication and permission.
- **Edge and Cloud Provider:** The cloud providers need information about the resource's requirements (i.e. CPU, RAM, Disk, and GPU) of the mixed reality services to dimension the hardware in such a way that it can satisfy the latency and bandwidth requirements.

2.2.3 UC workflow

One major advantage of Holo-Light's remote rendering framework is that this solution has no special dependencies to a specific cloud provider. Customers are free to host the physical remote rendering infrastructure and the related software in their private corporate cloud.

The application logic of ARES is hosted on edge cloud servers. When a user starts the application on an AR/VR device, it starts the edge server-side AR/VR application. The AR/VR application is executed in a cloud server with packaging format that is related to the actual resource availability and latency requirement like, for example, containers on the edge to improve reactivity. For this purpose, the orchestrator will select the appropriate server and start the instance where more appropriate. For this purpose, an orchestrator selects an appropriate server and starts a new VM instance or Docker container with the server application. The client application and server application use a signalling server to exchange ICE candidates to establish a direct Peer-to-Peer connection between client and server application.

Pledger Public Cloud/Edge Solution for ARES

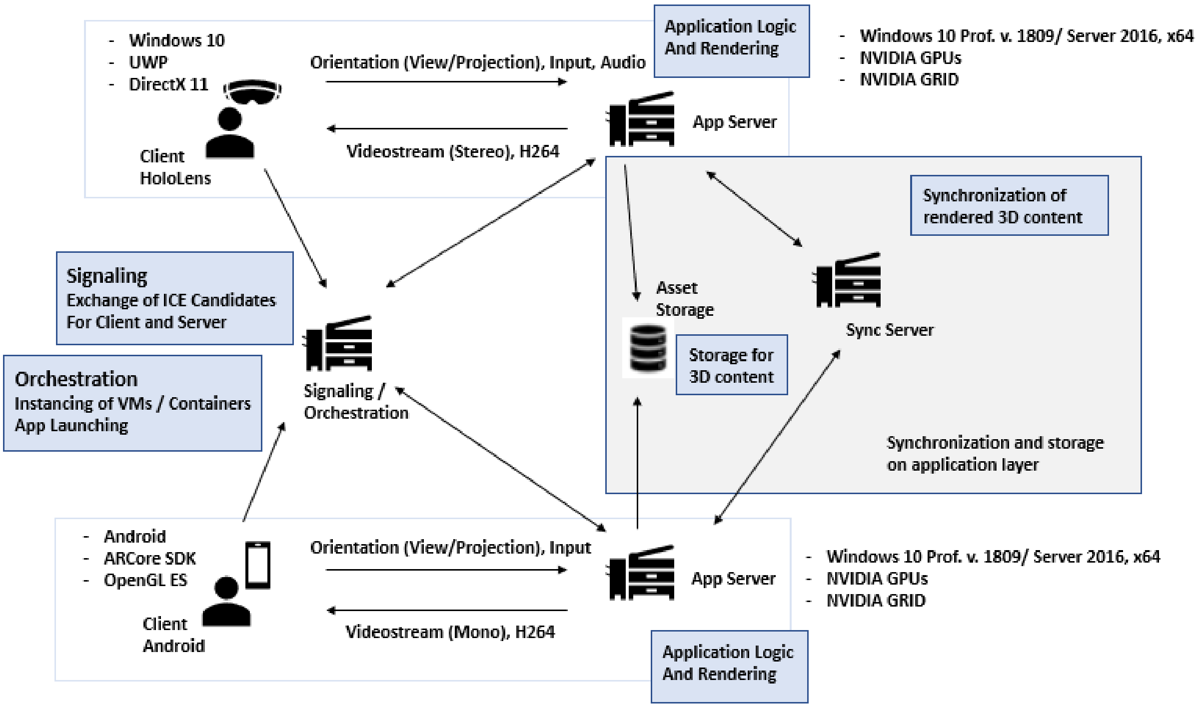


Figure 4: Concept for data streaming using Edge/Public cloud

Figure 4 shows how a possible public cloud/edge cloud setup can look like. The AR/VR users are connecting to the orchestration system and receive information about the nearest edge server to connect or the one with more resources available. To access the relevant 3D data a secure smart-contracting way can be applied to get permission for a specific 3D file from asset storage. Depending on latency and bandwidth of specific edge server, the orchestration system coordinates how much resources are granted and which level of resolution quality (QoS) is allowed.

2.2.4 Candidate data to be used/shared/produced

The remote rendering service is divided into two parts, process and stream of "rendered" views of a 3D scene. 3D scenes are generated on a powerful GPU-based device, i.e. PC, through a user's applications and are then passed "down" to the AR Device. The remote rendering service accesses this data at GPU-level. The rendered views are 32 Bit Data (Red, Green, Blue, Alpha) per pixel per image. For example, this results in two times 720p images for HoloLens per Frame and an average throughput of 5 - 10 Mbit/s.

The AR Device is streaming spatial data. This means position & rotation from the AR Device according to the room frame of reference. This set of data (~5 KBit/s) is sent from the AR device to the GPU, in order to compute the view matrix for the next view to render the next pair of images.

The base for data transmission is Web Real-Time Communication (WebRTC) which is an open-source project that provides real-time communication (RTC) via simple application programming interfaces. Moreover, it enables audio, video and data stream by direct peer-to-peer communication.

2.3 Integration with PLEDGER

With a growing infrastructure for edge computing applications for MR/AR, devices can run data for the visualisation process on the server closest to the user's location in contrast to the sparse region-based availability of ordinary cloud infrastructure. By rendering 3D content remotely on edge servers with low-latency data transmission, for scalability, a good system for orchestration is required.

To extend security concept is a key point if Small and Medium-Sized Enterprises (SMEs) and enterprises want to adopt MR/AR for 3D CAD collaboration and interaction. If a user needs to have a streamed MR/AR application, a trusted way to connect a SLAM capable device to the edge server application is crucial.

Based on the requirements of low latency and high bandwidth, only an edge cloud infrastructure can reach these parameters. A smart, reliable, and scalable orchestration system as offered by PLEDGER is needed to distribute requests from AR/VR devices. For example, if hundreds of engineers need to have collaborative sessions for reviewing their CAD data, then a huge amount of data needs to be handled by the system. Due to limited edge cloud resources, a dynamical system is needed to distribute the resources to achieve a maximum QoS level. Here it is expected that PLEDGER introduces the necessary dynamic orchestration and resource management mechanisms. To provide proper QoS in a remote rendered environment, the resource management system in the background needs to allocate resources and communicate with the application.

The interconnections between the AR/VR device and edge node are dynamically established during instantiation time. It is these differences that allow the platform model approach to be agile and for reconfiguration to occur as part of deployment configuration, rather than at design time, which can imply time-consuming re-coding of the interfaces.

2.3.1 Infrastructure/Hardware to be used

The successful implementation and execution of UC1 depends on four main components (see Figure 5):

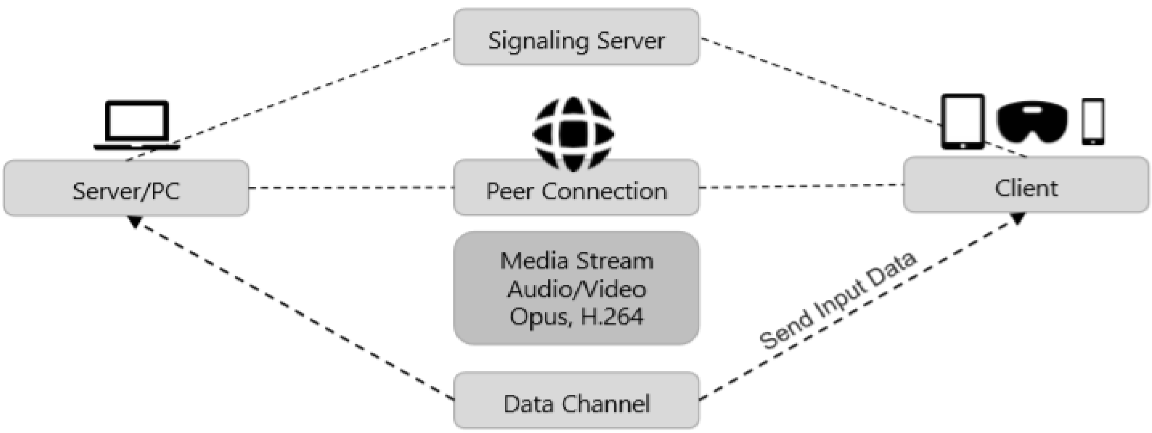


Figure 5: Concept for data stream between client and server

- AR/VR devices (client side)
- Render server
- Radio access network
- Signalling server

Clients (AR/VR device)

As visible in Figure 5, the client app will request an instance from the render server to pass input and sensor data to it. In return, the app will receive and display the content stream. The main benefit of this, the rendering process is not occurring on the target device itself, but instead, it merely displays the rendered frames, which bridges potential performance limitations of the AR/VR device.

Render Server

As described previously, the actual application is hosted and managed on the render server, which will have to meet minimum GPU requirements, to ensure functionality. If all requirements are met, this remote rendering application will subsequently be integrated into apps with the Render Plugin for 3D engines (e.g. Unity 3D).

Radio access network

The next component is the radio access network. To achieve the desired outcome, communication between the SLAM capable AR device and edge server needs to be wireless. Hence, every customer will have to consider if wireless communication is allowed in their factory and if it does not interfere with other critical systems.

Signalling Server

An essential component is the signalling server, which manages device requests and builds the peer connection between render server and client. When the signalling server receives a request from a client, an instance of the application is started on the server. As soon as the instance completely runs, the peer connection is released and initializes the rendering process. The client sends input and sensor data to the server, which renders the scene based on that data and sends it back to the client.

2.3.2 Similar UCs & Other relevant projects

In a broader context, the following section will address a similar use case of this project and then move on to other relevant projects which also target objectives like PLEDGER. The main reason behind addressing the latter is underlining the increasing importance of the edge-based systems - key requirements for AR/VR scalable industrial solutions. In comparison, their investigation is going in the direction of scalability and integrability into enterprises and SMEs.

Use Case 3

Please find a detailed explanation of the UC within the respective description. Having said that, UC1 heavily depends on UC3’s infrastructure (see Section 4.3.1) as it runs on top of it.

Public Project: AR Twin (Project No. 856994)

AR Twin is set on providing the European Industry and Construction 4.0 ecosystem with a sovereign ARCloud platform that meets their ever-growing needs for increased productivity, improved product quality as well as reduced time and cost. To this end, the main concept of AR Twin is to research and develop a system able to continuously maintain a Digital Twin or BIM model that is as close as possible to the factory or the construction site in order to deploy a wide range of services such as AR devices localization and Digital Twin/BIM real-time update.

Public Project: XR4All (Project No. 825545)

Interactive technologies such as Augmented Reality (AR) and Virtual Reality (VR) are set to transform the ways in which people communicate, interact and share information. The XR industry has now reached a stage, following years of research and development, where technology has become commercially viable.

The industrial projects listed below are taken from a list of many proofs of concepts (PoC) in the industry all around the globe. AR/VR enables great new use cases, which are currently at a PoC level. To overcome the PoC-level scalability and integrability for enterprises is needed. To overcome the limits of mobile devices the usage of Edge Computing gives the perfect tool for low-latency, high-bandwidth performance. The PLEDGER platform focuses precisely on those objectives to generate a highly secure, reliable, manageable and industrial scalable Edge/Public Cloud platform.

Industrial Project: Factory Planning at BASF [2] (internal project)

The projected pipework and assemblies can be visualized and manipulated directly at the target facilities. Going out into the field, viewing the assembly on-site, even though it doesn't exist yet, makes the planning considerably easier.

Industrial Project: Automotive Supplier Magna uses AR for its Quality Control [3] (internal project)

The global automotive supplier Magna is working toward the intelligent factory of the future. One of its most beneficial use cases is guided quality control using Holo-Light's Software on Microsoft's HoloLens.

Industrial Project: Deutsche Telekom supports Holo-Light in Prototyping program [4]

Deutsche Telekom is working on building a complete infrastructure of edge servers to support the realization of edge computing. Their Low Latency Prototyping program, organized by Telekom's incubator hubraum, provided a platform which allowed us to make productive advances in this field. It also has made it possible for Holo-Light to create a simulation of the solar system and a realistic, scale model of the International Space Station (ISS) rendered in real time. This edge computing prototype could process 14 million vertices, 80 million polygons, and 4.5 GB of random-access memory (RAM) at a rate of 40-60 frames per second, while a self-sufficient HoloLens can only run smoothly below approx. 200,000 polygons.

2.3.3 Candidate Assets to be used

Below are described the most relevant assets that have been identified to implement this UC. However, the full list of available assets to be used (or implemented) within the PLEDGER platform can be found in Table 4.

- **AS2 - *Benchmarking Suite (BMARK):*** Stand-alone tool for measuring the performance of the cloud infrastructure. In addition, it should be checked whether all necessary hardware elements are installed.
- **AS7 - *Edge-To-Cloud Data Orchestration (which data is visible to whom):*** It must be possible to define for each data point whether it is transferred to the cloud or not. Additionally, it should be possible to define which target group is allowed to view the data. (e.g. public/manufacturer/customer).
- **AS11 - *Microtransactions Framework for the Edge:*** A blockchain-based microtransactions framework concept based on cryptocurrencies (in particular ETH and XRP) that would let big media outlets implement micro-subscription models for their web readers and pay per view/reading of specific articles through cost-effective micro-transactions. INNOV brings the blockchain transactions interconnection and interoperability capabilities to Pledger edge nodes.

- **AS13 - *Augmented Reality Engineering Space (ARES):*** enables engineers to visualize and interact with 3D CAD data in an AR and MR environment. Taking prototyping, factory planning, quality control, and technical education to the next level.
- **AS14 - *Interactive Streaming for Augmented Reality (ISAR):*** is the remote rendering solution to visualize high-polygon content via local or cloud processing power. In real size and time, with every detail, and without using polygon reduction.

2.4 Legal limitations

As per possible ethical issues related to data involved in the UC1 "MR Application on the edge" by applying our remote rendering technology, the PLEDGER platform will stream just the rendered images of the scene and not collect, store and distribute proprietary data of the end user (in this case FILL).

The testing effort will be carried out in 2 phases. Phase 1 is the internal testing of the software. In this phase, we will use all available resources to simulate actual usage. All found issues will then be addressed and the software will be retested. Upon completion phase 2 will begin, which will now include the end user of the pilot. At this stage, the end user's employees will test the app on the field. A detailed analysis of the Ethics aspects in relation to this use case is provided in the specific WP7 D7.1 "*H – Requirement No.3*" deliverable [5].

2.5 Development and deployment plan

The UC1 deployment foresees the following milestones throughout the project:

Development Phase

- Implement PLM and CAD interface based on FILLs system, (M18, M30)
- Configure ARES remote rendering in GPU capable VM Container within the edge node for larger file streaming (M18, M30)
- Implement Machine interfaces based on Fills system (M18, M30)

Deployment Phase

- Deployment of assets on edge infrastructure (M24, M36)
- Deployment of assets in Fills factory (M24, M36)

- Running several demos scenarios and analyse user acceptance and quality aspects (M24, M36)

2.5.1 Risk analysis

The main identified risks have been described in Table 2, as well as its probability of occurrence and impact on the UC execution.

Table 1: Risks analysis for UC1

Description	Probability	Impact	Impact Description
Real-Time Communication with industrial machines	Medium	High	Depends on the used method (REST, OPCUA, CAN Bus, etc.). Some of them provide a real-time capability, some have an expensive overhead. AR Devices renders 60 frames per second basically, which gives a natural boundary for real-time applications

Description	Probability	Impact	Impact Description
Connectivity issues	Low	High	In some industrial facilities, neither Wi-Fi nor Bluetooth is allowed by 3rd party devices. AR devices rely on wireless communications; therefore, it can be a critical thing
Issues with hardware integration	High	High	Depending on the accuracy of the SLAM, the environment, lighting conditions, etc. for each scenario in industrial facilities, it is hard to predict if the accuracy of the SLAM is good enough to allow precise overlay from digital information over real objects
Impossibility to perform street works on time due to Covid-19 restrictions	Low	High	In modern industrial facilities usually, the machines are produced based on a digital plan, which is referred to as CAD Data. But it is still not guaranteed that the CAD data matches the real-world objects, therefore you will see mismatches, which can influence certain UCs

3 Use Case 2 (UC2): Edge Infrastructure for enhancing the safety of vulnerable road users

While the number of traffic accidents resulting in serious injuries or deaths has been decreasing over the last years in Europe, the number of accidents that involve vulnerable road users (VRUs) in cities is stalling or has even increased. In many cities, the road infrastructure is not laid out to support an increasing number of VRUs, such as bicycles or new types of transportation, such as electric scooters. Also, regulations of the mobility of bikes and scooters are often missing or not correctly applied. As a result, they are often involved in traffic accidents.

The use case presented in this section proposes infrastructure enhancements to increase the safety for said VRUs. We intend to introduce risk avoidance mechanisms for pedestrians, cyclists or users of electric scooters, by integrating the PLEDGER framework with the city infrastructure: using radio equipment, networking infrastructure, compute nodes and dedicated applications – all controlled by PLEDGER – situations of risks for VRUs can be detected and measures can be taken to avoid said risks.

3.1 Motivation

The European Commission has released a new European Mobility Package and *Vision Zero*, with the goal of a reduction of 50% in fatalities and serious injuries by 2030 and a reduction to 0% by 2050. While there is a general decrease of road victims in Europe, the number of VRU victims has a great share and is still high, even tending to increase in cities.

In Barcelona, one of the priorities for the municipal government is to make the city a friendlier, safer and more sustainable place for pedestrians. In order to achieve safer mobility, it is necessary to protect the most vulnerable groups that travel around urban areas. Protecting pedestrians means improving safety for everyone.

As such, there is a particular interest in increasing safety for VRUs and PLEDGER will investigate how they can be assisted to avoid accidents. A dedicated Edge infrastructure that integrates the PLEDGER framework will be developed to enable the detection of VRUs and potential situations of risk they might face, as well as the means to warn VRUs in such situations.

In the following subsection, we provide a detailed description of the use case and its aims. Further, we identify the key stakeholders of the use case and what role they play, as well as the workflow of the use case which is then used to determine the data that is produced, and which circulates during the execution of the use case.

3.2 Detailed description (scenario/business-centric)

3.2.1 Description of the UC

The main goal of this UC is to increase safety for VRUs using an edge compute-enabled infrastructure, as it is provided by the PLEDGER framework. In general terms, there are many ways to provide and to increase safety for VRUs in cities. Safety can come from having a well-defined regulatory framework that considers VRUs and their interactions with other vehicles and the infrastructure. Safety can also be implemented by building dedicated infrastructure elements and by adapting the city layout to respect the mobility of VRUs, such as dedicated bicycle lanes or pedestrian areas. Safety can also come from using state of the art ICT technologies to implement a "smart" infrastructure: using sensors to gather data about the position and trajectory of VRUs and other mobile elements (cars, public transport, etc.), algorithms to process the gathered information and notification systems to alert VRUs if situations of risk are detected. This latter approach to increase security is the one that is investigated in this UC.

From a high-level perspective, this UC will address the three aspects of i) detecting the positions of VRUs and where they are headed to, as well as detection of other “actors” such as public transport or vehicles that may put the VRUs in risk, ii) the processing of the gathered position data to detect possible situations of risk, such as collisions between VRUs and vehicles, iii) implementing the means to send an alert or notification to VRUs to avoid a possible accident. Having determined these basic three steps that can lead to a reduction and even complete avoidance of the risks for VRUs, we proceed to focus on one realistic scenario that can be validated in the city of Barcelona within the duration of the project.

In Barcelona, the layout of some areas where VRUs and public transport are coexisting can be problematic, leading to potentially dangerous situations. A repeating scheme is the case where a public transport stop (bus, tram) and bicycles/electric scooters are next to each other and where pedestrians exiting the public transport have to cross a bicycle lane. Figure 6 depicts such a scenario: whenever people are exiting a tram that halts at a tram stop (like the one on the bottom), they have to cross the bicycle lane in order to leave the tram stop area and access the pedestrian lane. This crossing of the bicycle lane by pedestrians happens on both sides of the separation element which is normally a metallic/glass structure that has some info panels. Similar situations are also observed at bus stops.

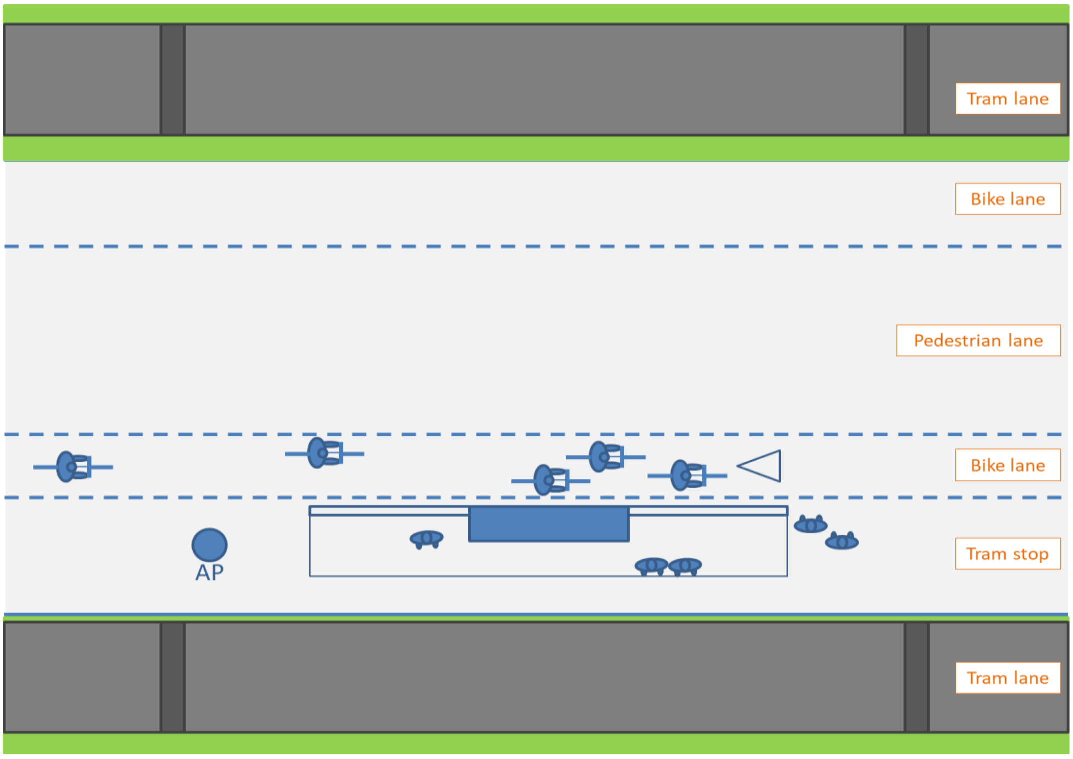


Figure 6: Layout of tram stops and vVRU lanes as present in the Diagonal street in the district of St. Martí, Barcelona

This UC will focus on a such a public transport stop, given the risks in this scenario are a reality that needs to be addressed and the fact that such scenario layouts can be found close by to the i2CAT and Institut Municipal d’Informàtica (IMI) infrastructures in Barcelona. Having the compute and networking infrastructure close to where the evaluations are to be performed is, by all means, a key requirement that needs to be fulfilled: it reduces the costs of the constructions necessary to set up and connect the on-street area with the rest of the PLEDGER infrastructure and it leads to a minimization of the distance from the on-street scenario to the PLEDGER edge compute nodes necessary to achieve the required performance of the UC. For simplicity, in the following, we will refer to the type of scenario we are considering as “tram stop” scenario, without restricting to tram stops, but considering alternatives, such as bus stops. Similarly, when referring to bicycles, we also assume other, similar VRUs, such as electric scooters are eligible.

3.2.1.1 High-level/basic requirements

To implement the UC, three main requirements need to be addressed.

First, it is needed to be able to detect where bicycles or electric scooters are and where they are heading to. It is also needed to be able to detect when a tram arrives at the stop and, if possible, when the pedestrians are exiting the tram. This detection process will require a certain set of sensors equipped on bicycles, worn by users or as part of the infrastructure that captures the required facts (e.g. positions/direction of movement) and it will require a communication channel in order to share the localization data with the PLEDGER framework that is running in the compute infrastructure.

Second, the gathered information needs to be processed at the edge, so a quick reaction is possible if a dangerous situation is detected. The processing needs to consider where bicycles are located, where they are heading to and when pedestrians are about to cross the bicycle lane. Dedicated algorithms will use the positioning data to detect possible risks.

Third and last, if a dangerous situation is detected, the VRUs awareness has to be raised about the possible risk. This requires the infrastructure to be able to relay such a warning/alert message to the VRUs.

3.2.2 Stakeholders involved

The following Stakeholders participate in the UC:

- **Pedestrians:** Once a tram stops at a station, pedestrians may leave the tram and might have to cross a lane dedicated to bicycles. As such, pedestrians are the main candidates for being exposed to risk in the analysed scenario and they need to be alerted if a possible collision with a VRU is imminent. While situations of risk can be avoided by checking the bicycle lane before crossing it, a pedestrian is likely distracted (listening to music, checking the smartphone, etc.).
- **Bikes/electric scooters:** The dedicated lanes for bicycles are parallel and next to the tram stops. As such, when a bicycle approaches the tram stop – possibly at high speed – it represents a possible danger for pedestrians exiting the tram. PLEDGER will detect the position and moving direction of bicycles.
- **Municipality/on-street infrastructure owner:** The infrastructure is owned by the municipality, as such, any modification of the infrastructure to host PLEDGER hardware and the interconnection between the tram stop and the rest of the PLEDGER infrastructure via fiber needs to be approved and handled by the municipality. An agreement for maintenance and operation of the infrastructure determines how the power supply, reparations and mounting activity is handled throughout the project.
- **Platform hoster:** The PLEDGER framework is hosted by i2CAT in Barcelona, which includes the edge and main DC compute nodes and any radio hardware at the tram stop.
- **Mobility (*Mobilidad*):** The regulations and management of the city’s mobility strategies are in charge of the mobility department. The use case procedures for alarming and managing different VRU flows have to be aligned with the local regulations and agreed by the mobility department. Use case workflow (UML)

3.2.3 UC workflow

To execute UC2, there are several steps to follow, which include but are not limited to the setup of a dedicated end-to-end slice. Although several “slice” concepts are currently used on the literature [6], slice henceforth refers to a collection of resources (compute, network and radio) and network functions (physical or virtual) that form a dedicated network providing end-to-end connectivity towards hosted application and services. The slicing that is intended to be used in this UC allows to reserve and to orchestrate a portion of the compute and radio resources available in the city-wide testbed, which assures isolation of the UC from other services that might be running in parallel but also makes sure that the resources by the UC can be provided during runtime, assuring optimal performance. Figure 7 depicts the essential steps from the setup of the infrastructure and the services to the actual detection and warning process that cover the high-level requirements explained in Section 3.2.1.1. In this section, we explain the different steps of the workflow.

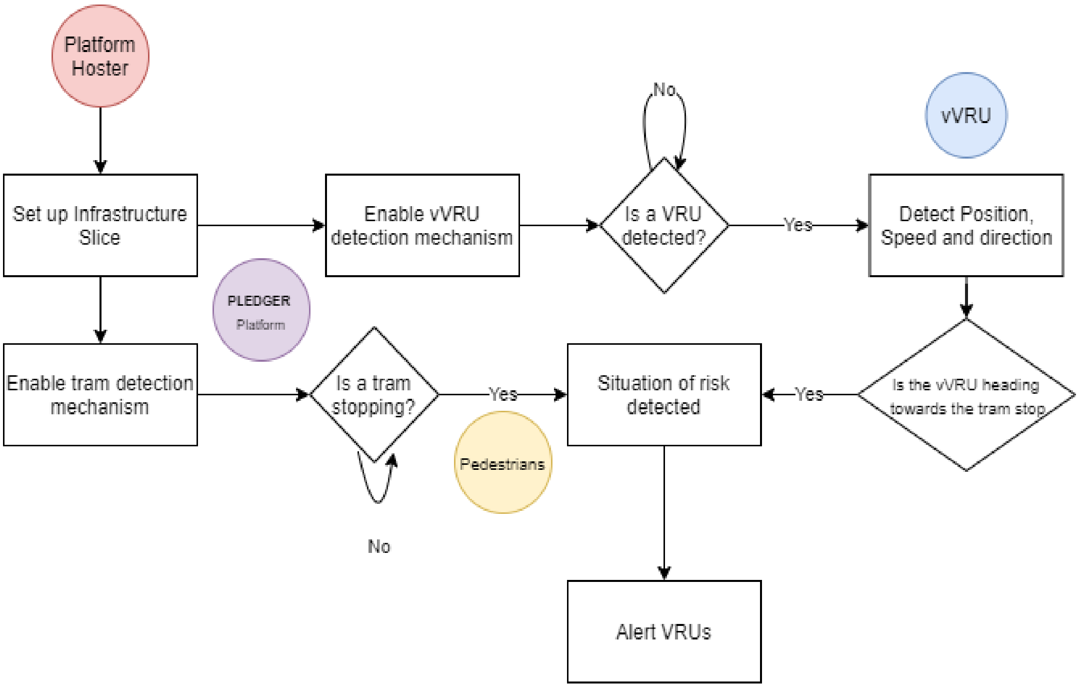


Figure 7: UC2 workflow

In the first step, the infrastructure slice is set up: compute resources and radio resources are reserved for the UC. The compute is necessary to later on host the different services that will be responsible for the location of VRUs and the risk detection and warning mechanisms. On the radio-side the on-street RAN infrastructure requires to be configured, e.g. a Wi-Fi AP needs to be configured and initialized so that UEs can communicate with the infrastructure. The details of the desired end-to-end slice configuration are handed over via descriptors that contain any relevant information about desired RAM, vCPUs, radio channels, etc.

With the end-to-end slice set up, services can now be installed and launched on top. The services are the detection mechanisms that run algorithms on the edge and use inputs from the on-street deployment (radio transmissions, positioning system, etc.) to determine when VRUs or trams are approaching the area. Once a tram that stops at the station is detected, the information is cross-checked with whether a VRUs is detected and whether it is approaching the tram station. If so, this is identified as a situation of risk and the service that alerts VRUs sends out a notification to any possible endangered VRUs.

Finally, the integration of DLT/blockchain technologies should help to validate the trustfulness of services added to the end-to-end slices and to control/determine which data will be flowing through the network.

3.2.4 Candidate data to be used/shared/produced

User data (registration with username and some personal data): Pedestrians that want to be able to connect to the services offered in this UC need to register beforehand. This is necessary to ensure that only devices and users that have been authorized can introduce data into the system (e.g. positioning data, see below). The registration data can be limited to usernames and email addresses but may include further details to assure the identity of a user.

Position and direction of VRUs: The localization of VRUs is necessary to detect possible risk situations. Positioning data (e.g. obtained via Galileo) is gathered at bicycles/scooters and is then shared with the infrastructure fur further evaluation.

Detection of VRUs inside the tram: Tram passengers who will exit the tram at the tram stop need to be detected. Once outside of the tram and when about to enter the potentially dangerous bicycle lane, they have to have been identified by the system, so an alert or notification can be sent to warn them.

Alarm for specific VRUs: If a risky situation is detected, a warning message needs to be sent to VRUs that are potentially in danger or are endangering other VRUs. The content of such an alarm can be considered to be simple, e.g. it can trigger an audiovisual signal on any UE of a user (e.g. smartphone in the case of pedestrians, a gadget worn by pedestrians or cyclists, etc.).

3.3 Integration with PLEDGER

When looking at the high-level requirements presented in Section 3.2.1.1, from a technical perspective, a set of fundamental building blocks are required to implement this UC: i) a multi-tier, cloud-enabled compute and networking architecture that is capable to host the services required by the UC, ii) a software solution (service) that is capable to implement algorithms and to process the data necessary to detect endangered VRUs, as well as to notify them as described in the UC workflow (Section 1.3.3), and iii) support for radio access technology to connect UEs to obtain said data and to enable connectivity between the infrastructure and RUs. Designing, implementing and deploying such a framework is a complex task that requires expertise in a variety of topics and features/architectural elements that go beyond what's available to i2CAT and IMI. However, the assets brought by the consortium partners to the PLEDGER project and the main features introduced with the PLEDGER platform seem capable of satisfying the requirements of this use case: the PLEDGER platform allows to easily reserve and access cloud, edge and radio resources for the different services of the UC that will be developed throughout the project. Further, the UC will be evaluated in a real city infrastructure that will be deployed and hooked up to this platform, allowing for real users to form part of the validation scenario for this use case in a real environment.

3.3.1 Infrastructure/Hardware to be used

The UC is planned to be deployed and validated in the city of Barcelona in the 22@ area, close-by to an already existing i2CAT/IMI infrastructure that hosts edge compute capacities and which is connected to the data centre (DC) at i2CAT premises on the other side of the city (Zona Universitaria), as shown in Figure 8[1].

[1] The area close to i2CAT and other potential areas might be considered as pontential locations for the on-street deployment of PLEDGER and the necessary walk outs/evaluations are to be performed.

Figure 8: Barcelona infrastructure high-level overview

This infrastructure will be expanded with on-street elements that are required to host the radio elements to communicate with the on-street users, sensors to detect VRUs, and the necessary network connectivity (mostly fiber) to connect these on-street elements with the rest of the already existing infrastructure. Such extensions in public spaces may require public procurement and construction. This subsection specifies the key infrastructure elements and the equipment necessary to implement the use case.

- **Main DC / Cloud compute**: Processes that do heavy processing, require lots of hard disk space or large amounts of RAM can be executed in the main DC hosted in i2CAT premises. The DC will host system elements that don't need to be running at the edge where less resources are available, such as the majority of PLEDGER platform elements.
- **Edge compute**: Services that require low latency and need to be close to the user to reduce the amounts of data transported in the network will be placed at the edge. The edge compute for PLEDGER is more limited in terms of CPUs, RAM and storage than the main DC, making it a very valuable resource. For this UC, key parts of the service will run at the edge, such as the processing of the data gathered from the VRUs on-street to detect situations of risk.
- **Fiber network and switches**: Fiber connectivity with a capacity of 10 Gbps will be used to connect the main DC at i2CAT with the edge compute in 22@ and the on-street infrastructure. This end-to-end fiber connection uses a series of optical and electro-optical networking at key switching points to relay the signal. The capacity of the fiber is sufficient to carry any data generated on-street that is then handed over to the infrastructure and it also suffices to quickly move large amounts of data from one end of the city to the other (such as VM images).
- **Street furniture**: Deploying on-street equipment requires to find a dedicated place to be installed that covers three main aspects: i) power supply for the on-street equipment needs to be available if possible 24/7 ii) (wired) network connectivity needs to be available to connect the on-street equipment with the infrastructure, iii) the on-street equipment needs to integrate as seamless as possible with the urban infrastructure. In general, street furniture like lamp posts or facades of buildings considers all these aspects. Previous projects where on-street equipment has been deployed have led to the design of dedicated solutions such as the *Radomo* to host on-street equipment (an example is shown in Figure 9).

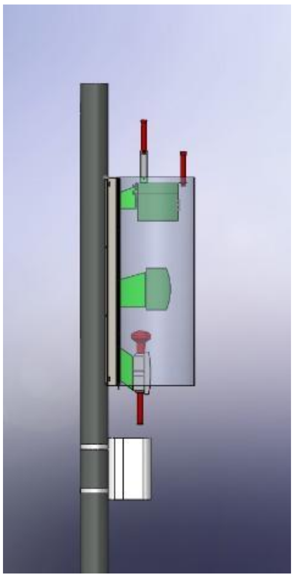
* 

Figure 9: Example of a Smart Tower: a lamp post with Radomo system to integrate a group of radio

* **Radio nodes**: Integrated with the street furniture, one or more nodes equipped with radio transceivers will be deployed. The nodes will be single-board computers (SBCs) that can host different radio technologies to communicate with the VRUs at the street level. Other types of sensors can also be integrated with these nodes, if necessary. The radio nodes will be connected over 1 Gbps fiber with the PLEDGER infrastructure.
* **User equipment (for bikes/scooters)**: Bikes or electric scooters participating in the UC will be equipped with a small form factor SBC that can host the necessary radio and positioning technology to communicate with the PLEDGER infrastructure to share and also receive its position and other types of information. The prototype of this hardware will be based on SBCs used in previous projects (referenced later in Section 3.3.2), extended with the necessary additional hardware and software components needed for the UC.
* **Public transport stations for executing the pilot:** The 22@ area and the area around i2CAT have several tram stops in their vicinity, which are potential candidates for the deployment of the UC. These stops are close to the already existing infrastructure available to the project and they feature the schema considered for improving the security of VRUs shown in Figure 6. A side view of one of a tram stop is presented in Figure 10, where the tram lane, the station area, as well as the bicycle and pedestrian lanes can be clearly identified.

Figure 10: Side-view of a tram stop close to the existing edge compute infrastructure

3.3.2 Similar UCs & Other relevant projects

In Barcelona, IMI and i2CAT have jointly worked on three projects that contributed to the design and deployment of the city-wide testbed infrastructure: FLAME, 5GCity, and GrowSmarter. In GrowSmarter, the concept of the *smart tower* was introduced. The smart towers solution converts a traditional lamp post into a new telecommunication micro-site that integrates wireless communication devices and sensors. Towers are connected to the fiber optic backbone network and thus offer hyper-connected areas to resolve the growing demand for connectivity in the city. Within GrowSmarter, the towers were used to host different sensors including traffic, pollution and noise. FLAME [7] and 5GCITY [8] have combined the use of the smart towers to host different communication equipment and the use of a two-tier compute infrastructure that will be similarly deployed in PLEDGER. In FLAME, media services have been deployed to provide services to end-users on the street, whereas 5GCity has defined a neutral hosting model on top of a neutral hosting platform that enables to define slices that include dedicated radio access network (RAN) and compute resources. This work relates to PLEDGER in the sense that the RAN and compute resources required to implement this UC should also be assignable on-demand, as if the UC was on among other services running on top of the PLEDGER infrastructure.

The EIT Urban Mobility [9] in the MOBY living lab project sets several goals, such as the integration of safe and accessible urban e-micromobility solutions and the generation of new services. i2CAT participates as a partner in this project that has pilots in Copenhagen, Munich and Tel Aviv. We expect valuable insights to be gained from this project that could be valuable to the implementation of UC2.

i2CAT has also participated in a showcase for MWC 2019 for the 5G Connected Car project [10] that showed how sensors and radio technology can help to improve security for VRUs and vehicles and to reduce the risks of accidents.

3.3.3 Candidate Assets to be used

In the context of UC2, the key assets intended to be used are listed below:

- ***AS3 - Distributed Ledger Technologies (DLT) / Blockchain-based solution for a trusted and secure ICT infrastructure):*** The compute and radio infrastructure elements controlled and managed by PLEDGER in this UC are distributed across the city of Barcelona. Any software module or hardware element that forms part of UC2 will have to be connected to the rest of the distributed infrastructure. Trust and security among some of the core elements of this UC can be implemented via a DLT-based approach, using a permissioning and admission system to assure only trusted nodes join the network. Further, smart contracts will be set up to capture a set of configurations and SLAs determining their behaviour and how specific data flows will be treated.

- **AS8 + AS9 - *Slice Orchestration Framework for Cloud, Edge and Radio Infrastructures (SOE) + PLEDGER RAN-Controller*:** The Neutral Host platform / 5G Slice Manager will allow assigning a dedicated slice from the PLEDGER infrastructure for the UC including the required RAN and compute resources, but also the services that will run on top. This asset is to be extended to support the management of containers (so far only KVM-style VMs) and to support additional radio technologies, such as IEEE 802.11p.
- **AS15 – *Barcelona City infrastructure:*** The currently existing city-wide infrastructure provides a subset of the features necessary for this UC, hosting compute (main DC + edge), networking equipment and fiber connections. Yet, on top of this, dedicated infrastructure extensions will have to be made that will include the construction and deployment, as well as the hooking up to the rest of the infrastructure of a new on-street deployment to host the radio and sensorial elements that will interact with the VRUs.
- **AS16 - *Risk Detection and Notification System (RDNS):*** Using the positioning data gathered from the VRUs circulating in the pilot area, an AI software module running in the PLEDGER infrastructure will correlate the inputs from each user and calculates possible risk situations. The data sets need to be evaluated on the fly and in a short margin of time so VRUs can be warned quickly in case a situation of risk is detected. Further, this service will notify users for example via a dedicated APP in their smartphones that allows receiving collision alerts identified by the PLEDGER solution. This asset has to be built from scratch and will be developed by one of the PLEDGER developer partners.
- **AS17 - *Gadget for VRUs:*** The bicycles or electric scooters VRUs in this UC will be equipped with a dedicated gadget that allows determining the position of the VRU (e.g. via GPS) and will host a radio (e.g. IEEE 802.11p) to communicate with the city infrastructure. This asset has to be built from scratch; i2CAT has experience in designing such integrated hardware, including devices used for V2X communications, which will facilitate the design and implementation of this gadget.

3.4 Legal limitations

The use case will require the participation of different VRUs to test the deployment of the PLEDGER architecture. As such, the vehicles involved in the testing and pilot should follow the national and local regulations regarding the mobility of VRUs. This includes the national *Royal Decree on General Vehicle Regulation* [11] and the Barcelona *Ordinance on the movement of pedestrians and vehicles* [12].

Regarding the deployment of the hardware in the street, the project should take into consideration that all the elements that are placed in public space have to follow the *Ordinance on the uses of the urban landscape* [13]. This ordinance regulates all the elements that can have a visual impact at the street level. Therefore, the aesthetics of the solution deployed have to be carefully considered.

Similarly, there are regulations for the use of the radio spectrum to which we need to comply in terms of allowed frequencies and transmit powers. These limitations are stated in the *regulació de les telecommunicacions* [14].

3.5 Development and deployment plan

The development and deployment in Barcelona consider main workflows: the construction of the additional on-street infrastructure to cover the area in which the trials will be executed and the development of additional hardware and software assets to implement key functionalities of UC2. The following tentative[2] deployment milestones for the Barcelona infrastructure extension are considered:

- MI1 (Dec 2020) - Walkout – Infrastructure evaluation in order to determine the best location (Tram station) to deploy the use case.
- MI 2 (June 2021) – Infrastructure and equipment construction/installation – Infrastructure and equipment are operative and ready to start the testing phase.
- MI 3 (June 2021) - Start maintenance contract.
- MI 4 (Dec 2022) - End maintenance contract
- MI 5 (Dec 2022) - Decommission process

Note that from July 2021 until July 2022 will be the appropriate period of time to test and monitor the UC, keeping the last quarter of the project to make the evaluation phase. Further, the following development milestones are foreseen for the hardware and software-based assets that are to be implemented for UC2:

- MHS 1 (Dec 2020) – Start of WP5, gather requirements and design proposals for the software
- MHS 2 (June 2021) – Initial, testable version available, submodules available start of integration work
- MHS 3 (Dec 2021) – Final application development, full-integration testing and integration in demonstration setups.
- MHS 4 (Sep 2022) - Integration and testing finalized.
- MHS 5 (Dec 2022) – Validation in trials and UC pilot.

3.5.1 Risk analysis

A series of risks have been identified and summarized in Table 2, along with their impact and probability of occurrence during the execution of the UC2.

Table 2: Risks analysis for UC2

Description	Probability	Impact	Impact Description
Not having the public tender on time	Medium	High	The fact of not having a contract for the construction of the on-street infrastructure extension in time implies that the infrastructure deployment will be delayed and that might result in a delay of the integration and Demonstration Setup, the Pilot Operation and the final validation and evaluation
Not having the permissions from the district/urban landscape department	Low	High	Every street construction and related activity requires to have the permissions from the current district and the urban landscape department if needed. If the permission is not granted, the infrastructure cannot be deployed and therefore the pilot will not be executed

[2] Tentative, because the public procurement process can take longer than anticipated, even including margins. Other external factors, like the ongoing Covid-19 crisis can affect the timeline as well.

Description	Probability	Impact	Impact Description
Issues with HW integration	Low	High	The use of different HW components can produce integration issues that might lead to delays in the development and therefore in the pilot execution
Impossibility to perform street works on time due to Covid-19 restrictions	Medium	High	The Covid-19 restrictions to mobility and on-site presence might delay the infrastructure planning, deployment, or pilot tests
Obstruction of trial/pilot execution because of external causes (e,g, meteorological conditions)	Low	Medium	Outdoor trials/demos are always at risk if meteorological conditions are unfavourable. This has been experienced in other projects, forcing a reschedule or an alternative trial setup.

4 Use Case 3 (UC3): Manufacturing the data mining on the edge

The collection and analysis of machine tool data provide many insights into both the engineering and the running process. Recurring patterns as well as the calculation of meaningful indicators, such as the overall equipment effectiveness (OEE), enable the evaluation of the processes and offer the possibility to identify optimization potential. This can lead to services in predictive maintenance to reduce downtimes and costs as well as providing indicator numbers for the customers enabling them to optimize their processes.

Edge devices offer the possibility to record the data of a single machine and making simple evaluations. However, the combination of diverse data and the establishment of big datasets enables the modelling of complex relationships. The more complex relationships in the data are, the more computational power is required to model them. Here the edge device reaches its limits in terms of data storage and computational power. Transferring data and computational power to the cloud offers the possibility for more advanced analysis and training, of complex and computationally intensive models. As a result, FILL can offer better services for their customers as well as gain deeper knowledge about the machines for optimizing the engineering process.

During the execution of this UC, various machines at various customer sites are equipped with an edge device. As every customer's process is different, miscellaneous machine data is collected and transferred to the cloud. This opens up many possibilities for analysing this data in the cloud, which can be explored during this project.

4.1 Motivation

FILL edge computing devices face strict customer requirements. They must not consume a large amount of energy and the hardware must be robust as they are hosted in harsh environments. On top of that, they must also be cheap. Because of these limitations, *Cybernetics*, FILL's Industrial Internet of Things (IIoT) platform, is forced to outsource computationally intensive operations (e.g. machine learning or advanced data analytics) to a cloud service. PLEDGER enables the exploration, implementation and testing of data transfer as well as computational transfer to the cloud. In the course of that, a special eye is kept on data quality, data size and security. In the context of PLEDGER, it is possible to evaluate the architecture of *Cybernetics* according to which data and software will be transferred to the cloud and which will remain on the edge. PLEDGER enables the feature extension of *Cybernetics* whilst still guaranteeing or even improving the high quality of service.

4.2 Detailed description (scenario/business-centric)

4.2.1 Description of the UC

In manufacturing, especially the machine tools are relevant and so FILL developed a product portfolio of different types and sizes of machine tools to be integrated into turnkey solutions for FILL's customers over different industry sectors. UC3 will pick up the needs of machine tools operators, especially workers and maintenance engineers and the developed assets will be tested and demonstrated in the UC. By now the assets are most likely to assist operators, guide maintenance and service tasks and prepare data for algorithms designed for machine learning. The foreseen distributing of data and computations across the edge and cloud might have the following benefits:

- **Rich data sets for better machine learning:** For machine learning applications, a large dataset with high quality is essential. Centralising data and consolidating machine data in a cloud, therefore, is a necessary basis for sophisticated machine learning. PLEDGER will enable FILL to evaluate which data should be consolidated in a cloud and which data should stay at the edge.
- **High-performance computing:** Edge devices have limited computation power. Running software in the cloud allows FILL to perform computationally intense analysis or machine learning. PLEDGER will enable FILL to experiment with cloud computing and determine novel applications.
- **Security:** The edge solution of *Cybernetics* is isolated from the internet and runs locally close to FILL machines. Moving data and computation to the cloud imposes security challenges. Edge devices have limited computation power. Running software in the cloud allows FILL to perform computationally intense analysis or machine learning. As part of PLEDGER, FILL will develop a strategy that ensures a secure and trusted communication between edge devices (FILL customer side) and cloud services (FILL side).

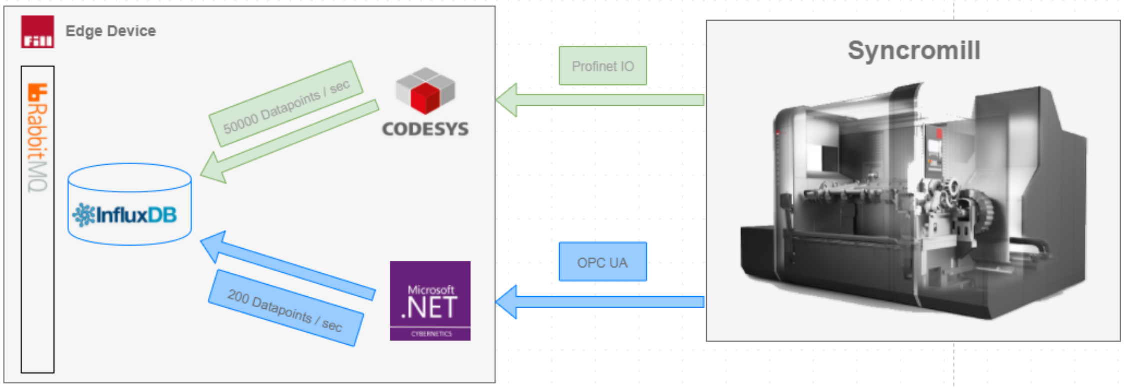


Figure 11: State-of-the-Art data acquisition to the edge device

Figure 11 shows the current architecture connecting the machine to an edge device. PROcess FIeld NET (PROFINET) is an industry technical standard for data communication via Industrial Ethernet enabling data collection from controlling equipment in almost real-time (in the order of 1 ms). OPC Unified Architecture (OPC UA) is a machine-to-machine communication protocol for industrial automation. PROFINET is suitable for controller-device communication, whereas OPC UA enables communication within controllers and builds the basis for data integration to the cloud. This architecture is currently available as well as the software architecture of *Cybernetics*. *Cybernetics* consists of components that are hosted on an edge device in the control cabinet of FILL machines at the customer site.

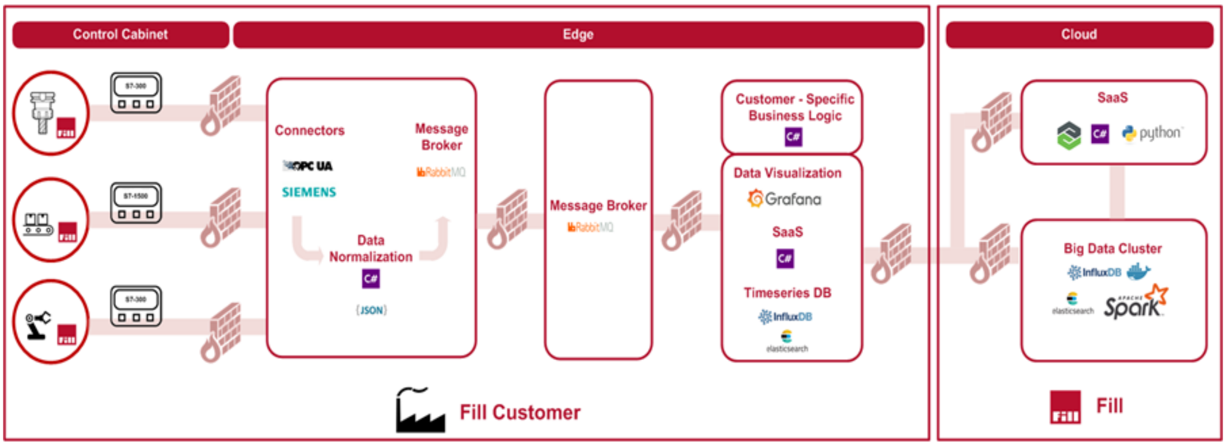


Figure 12: Logical diagram of the infrastructure in FILL *Cybernetics* available to PLEDGER

Figure 12 shows the individual components of *Cybernetics* and their relationships. The individual components of *Cybernetics* are:

- **Control Cabinet:** Automation is done using PLCs. *Cybernetics* connects to different PLCs and reads all relevant sensor, machine, and production data from these PLCs.
- **Connector:** *Cybernetics* implements connectors to PLCs. These connectors implement industry-standard protocols (e.g. OPC UA) but also proprietary protocols (e.g. the Siemens S7 protocol).
- **Data Normalisation:** Every data point is normalised and converted to a standardised format, formatted as a JSON object.
- **Message Broker:** All data is distributed among all other components in *Cybernetics* using a message broker (RabbitMQ)
- **Customer-Specific Business Logic:** Varying customer requirements are implemented in customer-specific business logic modules.
- **Data Visualisation:** *Cybernetics* provides basic data visualisation and data analysis features on the edge device. These local services are important e.g. for FILL's service team, which can then troubleshoot issues using historical data.
- **Software as a Service (SaaS) on the Edge:** *Cybernetics* offers many different software features (e.g. for condition monitoring). These features are hosted on the edge device.
- **Time series DB:** *Cybernetics* stores all machine and production data for a certain amount of time (ring buffer). This data can be used e.g. for troubleshooting or performance analysis.
- **SaaS in the Cloud (currently under development):** *Cybernetics* hosts software services that require an extensive amount of computation power in the cloud (hosted by FILL).
- **Big Data Cluster (currently under development):** Large and complete datasets are of high value for good machine learning and data analysis. Hence, *Cybernetics* transfers machine data also from the edge to the cloud, where it can be stored infinitely.

Several types of applications are conceivable. First and foremost, training machine learning models for predictive maintenance is an essential aspect to be encouraged. This goes along with applications for general machine health state monitoring and processing data sets over long periods. One aim of PLEDGER is to extend the existing architecture by a cloud solution to enable the developments of these applications within the cloud.

A further application will be the integration of UC1, where the results of the previously mentioned applications will be visualized and evaluated using MR/AR techniques.

4.2.1.1 High-level/basic requirements

The identified needs for the effective implementation of UC3 are:

- Security between Edge / Cloud
- Big Data platform (Data Storage, Computational Power (CPU/GPU), Data Management System)
- Cloud services benchmarking
- Edge-To-Cloud Data Orchestration
- Interface GUI (easy-to-use Dashboard)
- Customizable Software-Stack (Updates, Versioning, Libraries, etc.)

The first and very important need is the establishment of a secure connection from the edge to the cloud. Data must be encrypted to ensure non-manipulable data transmission between the two points of the deployment. This goes along with an Edge-To-Cloud data orchestration allowing to organize the release of specific data to those who need it. Furthermore, an automated usage-list should be generated to prove who received which data at what time. This information can, later on, be used to establish a new business model for software as a service (SaaS) based on pay-per-use.

Benchmarking cloud services is required, to find an appropriate service satisfying the above-mentioned needs. For enabling the processing of the data, a Big Data platform with appropriate infrastructure regarding the calculation power (CPU, GPU) as well as the required amount of storage to be defined during the course of the project. To be able to offer an easy-to-use and understandable software for visualizing the analysed results to the customer, an Interface GUI with a Dashboard will be required. This goes also along with a customizable software-stack to enable updating and versioning of software products as well as easy integration of libraries.

4.2.2 Stakeholders involved

In the context of the UC3, the identified stakeholder are listed below:

- **FILL Engineering:** The mechanical design department would like detailed information on the durability of the machine. They are interested in statistics about replaced parts as well as if optimal parameters enable longer operation periods of the machines.
- **Customer:** The customer would like a detailed statement about the performance of the machine regarding their processes (e.g. the number of produced parts as well as various key figures like OEE). It must also be ensured that data transmission is secure. Besides, the customer wants to determine separately for each data point whether it is transferred to the cloud or not. In manufacturing, customers react very sensitively to the use of their data, as their machine data transfer the complete know-how they invested to achieve an optimal business process. Therefore, they are interested in a secure data transmission and in and knowing who has access to the data in order to prevent access by the competition.
- **Data-Analysts:** The Data-Analysts provide a detailed analysis of the data. This includes pre-processing and cleaning relevant data and calculating the statistics, in which the customers and engineering experts are interested in. Furthermore, they are interested in picking informative features to train models for predictive maintenance. These resource-intensive models are meant to be run in the cloud predicting failures of the machine or machine parts and forecasting maintenance services.
- **Product-Owner:** The product manager needs a detailed statement about which services can be offered. For each of the services offered, there must be a definition of how it will be billed (per usage, per time, etc.).
- **Cloud-Provider:** The cloud provider needs a detailed statement about the required resources. (CPU, GPU, RAM, Up/Downlink, etc.) to provide a sufficient infrastructure. To be able to check this, the cloud provider needs to get a tool that checks if the infrastructure is sufficient.

4.2.3 UC workflow

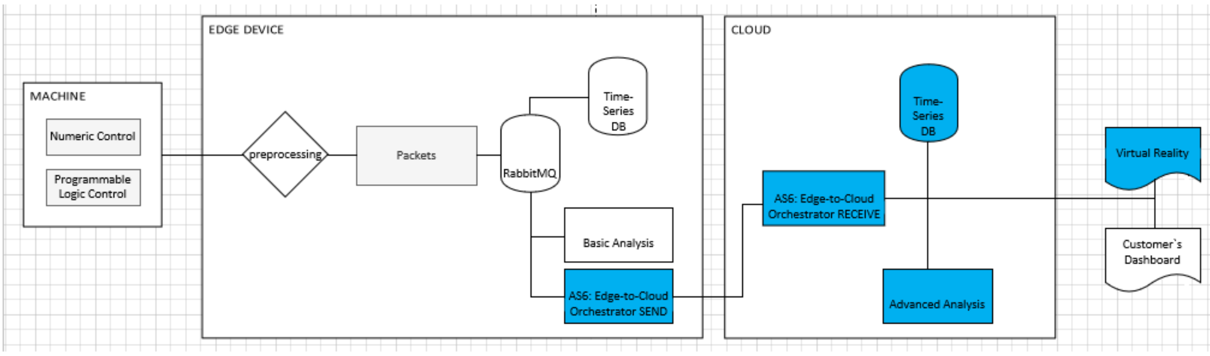


Figure 13: Illustration of the UC workflow

Figure 13 presents a diagram of the UC3 workflow. The parts of the diagram in white represent the current status, while the parts in blue represent the future status, which will be developed in the course of the project. FILL's machines generate a continuous stream of real-time data which needs to be processed. Our processing pipeline consists of a backend which translates raw and unstructured machine data into a portable format. The resulting data is packed into messages and sent to a RabbitMQ server running on the edge device. One part of our pipeline permanently stores these messages into a time-series database. Another part uses them to perform basic analyses. Below we give a few examples:

- Clean the raw data from errors
- Calculate KPI from data
- Asses machine state
- Asses tool state

These analyses are developed as python software and are executed on the edge device. The orchestration of the data, from the edge to a Big Data platform (AS10) running on the Cloud, will be performed combining a Blockchain Framework (AS3) and an Edge-to-Cloud Orchestrator (AS7). Description for aforementioned assets can be found in Section 4.3.4 of this document. To evaluate the performance of the used Cloud System, a benchmarking framework (AS2) is planned to be used. It is not yet clarified which data/analysis will stay on the edge and which will be transferred to the cloud. Validation of the data is accomplished after receiving it in the cloud.

Due to the computation power, as well as the greater storage capacity, of the cloud systems, it is possible to execute more advanced analysis, for example:

- Fault-Tree analysis
- Detect unusual behaviour
- Predictive Maintenance

The processed machine-data and the derived data can then be visualized via a VR based digital-twin (AS12) or a customizable dashboard.

4.2.4 Candidate data to be used/shared/produced

Data to be used

FILL machines produce data from Programmable Logic Controllers (PLC) – and Numerical Control (NC)-sources as well as messages concerning operation and failure (i.e. alarm data). This includes data about operating states, hydraulic pressures, pneumatic data as well as information about the axes' positions, torques and velocities. Furthermore, data provided by servicing personnel (e.g. broken and exchanged machine parts) is integrated. Additional data provided by the customer as KPIs completes the used data set.

Data to be produced
In a first step, data is processed according to the workflow described in Figure 13, including calculation of OEE, statistics of servicing data and assessment of the machines' general health state. The combination of PLC-, NC- and alarm data, as well as the information about executed maintenance work, provides a solid base for integration into predictive maintenance models. For this purpose, appropriate training and test sets have to be defined. Moreover, experiments using different models and parameters have to be carried out to evaluate the most suitable model.

Data to be shared
Resulting data can be shared in either two ways. First, derived parameters as OEE, statistics about the operating process and information concerning the machine health state are provided to the customers via the FILL *Cybernetics* dashboard. Furthermore, they are informed about the machine learning model's results in case of maintenance at hand. This information helps the customers to improve their processes.

Second, evaluating the combination of machine data and the machine parts' condition provides meaningful insights for the engineering experts. Using this knowledge, engineering design processes can be further optimized.

4.3 Integration with PLEDGER

Strict customer requirements for the service implemented in UC3 imposes the following limitations to the edge computing device of FILL:

- **Low energy:** An edge device must not consume a large amount of energy. This limits the extensive use of GPU computing power at the edge.
- **Harsh environment:** *Cybernetics* edge devices are hosted in harsh environments. Hence, it is only possible to use hardware that resists those conditions. Edge hardware for *Cybernetics* is hence limited to industrial computers (e.g. Siemens IPC or TTTechs NERVE device).
- **Low budget:** The estimate of what the customers are willing to spend for an edge device is about 2500 € for the hardware and 1500 € for software.

These limitations force *Cybernetics* to outsource computationally intensive operations (e.g. machine learning or advanced data analytics) to a cloud service. Therefore, FILL plans to explore, implement, and test the following objectives as part of PLEDGER:

- **Data transfer to the cloud:** The first step towards outsourcing functionality from the edge to the cloud is *a data transfer to the cloud*. Data transfer from the edge (customer premise) to the cloud (FILL) is sensible and FILL wants to evaluate the following topics:

  - *Data quality*: unstable Internet connections and unscheduled downtimes of edge devices can reduce the quality of the data, which is sent to the cloud. Given the large number of edge devices sending data to the FILL cloud, we need an automated software feature that ensures data quality.

  - *Data size*: FILL machines produce an enormous amount of data (up to 1 MB/sec). Hence, FILL needs to filter or aggregate data before sending it to the cloud without limiting data quality.

  - *Security*: The data, which is sent from the edge to the cloud, needs to be properly protected. Secure communication between edge devices and the cloud is essential to establish trust between customers and FILL.

- **Computation transfer to the cloud:** FILL needs to host computationally intense software services in the cloud (e.g. training of machine learning models) and wants to re-evaluate the software architecture of *Cybernetics*. Since FILL plans to extend the existing *Cybernetics* software architecture towards a highly distributed architecture, time-critical features must be hosted at the edge whereas computationally intense features should be hosted on the cloud. FILL's goal is to determine how *Cybernetics* can be re-organised such that its feature-set is extended (by advanced machine learning algorithms, which are hosted in the cloud) but still guaranteeing the high quality of service (i.e. performance, latency, and real-time capabilities).
- **Tuning the Edge Device**: First investigations of requirements need improvement of the edge-device in terms of the certification process to fulfil existing knowledge, norms and standards (will be subcontracted to TTTech edge supplier).

4.3.1 Infrastructure/Hardware to be used

Due to its competences FILL acts as an Engineering, Procurement, and Construction (EPC) contractor from sales, project management, mechanical engineering, safety equipment, software engineering, assembling to start of the operation. As a widely recognized supplier FILL implemented in the last years different machines up to large fully automated production lines for different industrial sectors.

In the following, details about the infrastructure to be used are given: UC3 will be hosted in the FILL premises, which are shown in Figure 14

Figure 14: FILL Future Zone - Area for manufacturing UC3

Figure 15: February 2020 - first syncromill H is built up in FILL Future Zone

The first of four standard machine tools (syncromill) for UC3 is already set up and ready to be implemented (see Figure 15). It is hosted within the Research and Development (R&D) area in the FILL Future Zone, as shown in Figure 16, and the edge device is built into the machine tool. It is planned to transfer the data directly to the cloud, which will be hosted by the partner of AS11AS9 (Big Data Platform). There will be WiFi deployed to enable wireless data transfer within the Future Zone as well as the implementation and testing of UC1.

Together with the project's partners, the applications will be defined. It is foreseen to have early adopters included, this will be customers of FILL who are seeking innovation on the digitalisation topic and are interested to create new business scenarios based on the shopfloor of series production lines. It is planned to set up the infrastructure at the customer's site in the same way as in our Future Zone.

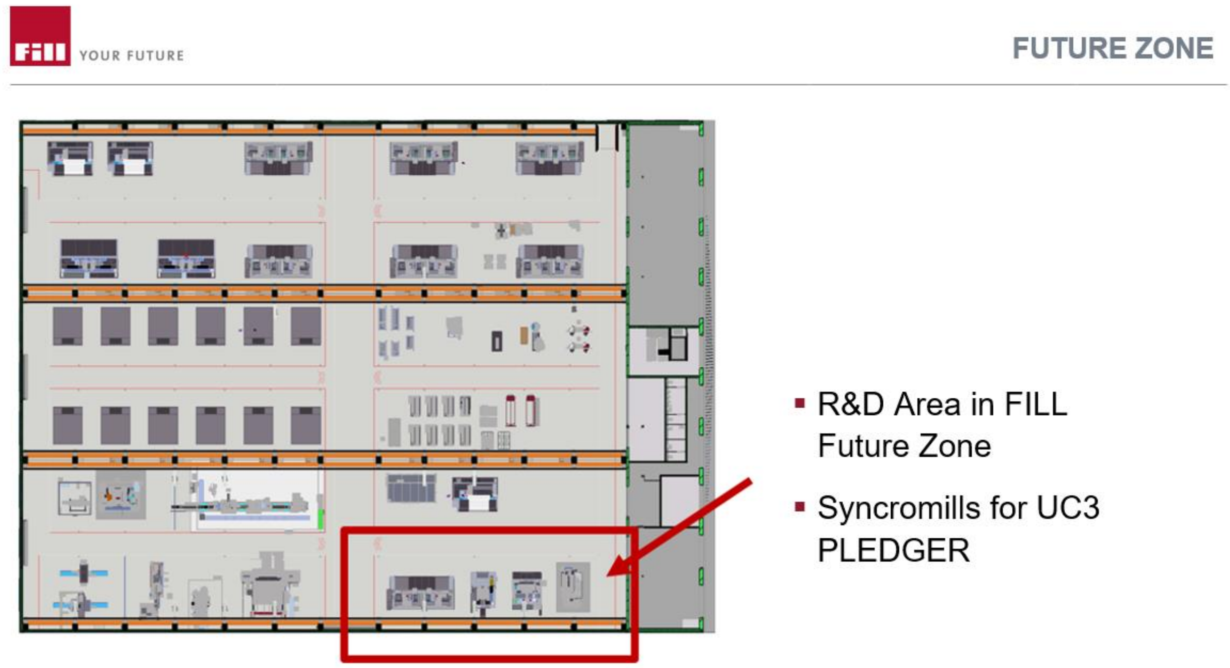


Figure 16: Layout of FILL Future Zone. The area marked in red is dedicated to PLEDGER activities

Figure 17: Rendering of CAD data for use in AR

The engineering, the detailed CAD data of the machine tools make it possible to be used for rendering and data for mixed reality/augmented reality. An example of such a rendering is shown in Figure 17.

4.3.2 Similar UCs & Other relevant projects

UC3 will collaborate with UC1, which will run on top of our infrastructure. Furthermore, there are several other relevant projects:

IoTwins [15] (GA 857191, Testbed 2 "predictive spindle behaviour") is one of these projects. The main target of the developments planned during IoTwins are: (i) design and installation of redundant IoT modules able to log data at high sample rates, and also to log and process in real time a set of data (stream processing) for creating embedded digital twin models of machine tools; (ii) creation or forecasting of data coming from individual subsystems in a machine tool by using simulation models of physical behaviour. Note that these data usually do not need to be processed in real time but can be within production cycle of a part or lot size of parts (batch processing); (iii) training of ML models for their successive utilization on edge device Nerve by TTT (smartification of systems); (iv) creation of data-driven performance models for machine tools; (v) early detection of failures for monitored subsystems; (vi) automated preparation of predictive maintenance plans; and (vii) optimization of machine tool spindle control systems.

Another project is H2020-ICT-2017-1- Smart Cyber-Physical Systems "BOOST 4.0 - Big Data Value Spaces for COmpetitiveness of European COnnected Smart FacTories". In this project, FILL is responsible for the set-up of technical validation, large scale experimentation & on-site trials. To perform rapid prototyping and early assessment of BOOST 4.0 data pipeline and tools on business impact. Instantiate and optimise BOOST 4.0 framework deployment in large scale and in-situ pilots for advanced big data driven engineering methods for zero-defect and lot-size one networked commissioning. Consolidate and generalise particular pilot findings into the general BOOST 4.0 impact evaluation framework.

4.3.3 Candidate Assets to be used

- **AS2 - *Benchmarking Suite (BMARK):*** Stand-alone tool for measuring the performance of the cloud infrastructure. In addition, it should be checked whether all necessary hardware elements are installed.
- **AS3 - *Hperledger Blockchain framework & Middleware (HBF)*:** Data transmission between Edge and Cloud must be secure. At this point, it is not yet clear whether a blockchain can be used to secure the data stream or not.
- **(AS7) - *Edge-To-Cloud Data Orchestration (which data is visible to whom):*** It must be possible to define for each data point whether it is transferred to the cloud or not. Additionally, it should be possible to define which target group is allowed to view the data. (e.g. public/manufacturer/customer).
- **AS10 - *Big Data platform:*** A high-performance cloud must be made available. Database server for storing the data (InfluxDB, RabbitMQ, ElasticSearch, etc.). Analysis server for data analysis. Further technologies are going to be evaluated during the project.
- **AS12 - *Holo-View*:** Display a digital twin of the machine as an overlay. Pop up of various information about this machine (KPI's, last fault messages, upcoming maintenance work).

4.4 Legal limitations

Standards and norms

Personal Data (GDPR): is not affected as personal data of employees or sales contacts is neither stored nor processed. On the edge-device, IP addresses of the machine as well as of the cloud connector are saved, which are not affected by GDPR. The only case where IP addresses are stored is for transparency of usage of data consummation for third-party services. In this case, additional contracts are mandatory, where the usage/storage of these addresses is handled separately.

Machinery Directive (2006/42/EC): Well established standard for improvements on safety and health, lowering emissions. Transparent Integration of third-party services within machine tools.

Machine-to-Machine Communication OPC UA (IEC 62541): OPC UA is an industrial M2M communication protocol that is capable not only of transporting machine data (i.e. controlled variables, measured values, parameters, etc.) but also of describing them semantically in machine-readable form. It is a well-established and broadly used solution, where a lot of branches are built on.

Measurement and control of the industrial process (IEC 61987): According to this regulation, industrial processes, data structures and elements in process equipment catalogues and measurement equipment need to be standardized.

Industrial communication networks – Network and system security (IEC 62443): Is related to cybersecurity for products intended for use in the industrial automation and control systems environment and provides guidance on how to meet the requirements. However, the guidelines are not state of the art due to technological progress is faster than standardization.

Along with the above-mentioned regulations, it is ensured, that high attention is paid to standardization.

Concerns in terms of contracts and warranties in digital products

New types of contracts might emerge during the project and post-project phase, which could be infringed by legal limitations. Moreover, warranties based on software-applications might cause a more detailed look into these limitations.

4.5 Development and deployment plan

The UC3 deployment foresees the following milestones throughout the project:

Development Phase

- Edge-to-Cloud Orchestration App finished (M18, M30)
- Design of required cloud resources finished (M18, M30)
- The security layer is evaluated and implemented (M20, M33)

Deployment Phase

- Deployment of assets on edge device (M24, M36)
- Deployment of assets on cloud (M24, M36)
- Pledger integrated prototype (M24, M36)

4.5.1 Risk analysis

In Table 3, the main risks identified within the context of the UC3 are described. Additionally, the probability of occurrence and the level of impact on the UC execution is also defined.

Table 3: Risks analysis for UC3

Description	Probability	Impact	Impact Description
Limited computational resources in edge devices	Low	High	On one hand, the computational power of edge devices might be not sufficient. As already described, edge devices face different limitations. These might result in too low computational power for our UC. Details for computational power requirements are further discussed in the deliverable D2.2. In the course of PLEDGER, computational power will be evaluated in terms of separation for computational operations on the edge and on the cloud
Low resolution in sensor devices	Low	High	On the other hand, the resolution of the sensor technology might be not sufficient, resulting in not satisfying the quality of the results and acquired models
Limitations in data complexity	Medium	High	If relations between machine data and failures are complex, the aggregated data might be not enough to represent these relations. Therefore, this might impact the quality of the generated datasets (i.e. training and test datasets), which can strongly affect the accuracy of designed models
The customer relies on predictions of Machine-Learning Model as a guaranteed result	Medium	High	Machine-Learning models provide results with a given accuracy. There is also the possibility that the predicted results will not arise. The results of these models must be interpreted as a suggestion in terms of a recommendation by an expert and not as a situation occurring for sure in the future
Customers concerns about data privacy	Medium	High	Customers machines' data is very sensitive as it might provide detailed insights about their business and processes. When in doubt, customers won't provide any data. To prevent this, information about data security and usage must be done very thoroughly

5 Cross-UC Overview and Roadmaps

This section provides a cross-UC overview of the assets that will be used by the UCs, as well as how the three UCs contribute towards the achievements of PLEDGER's objectives and the main results of the project. Further, initial planning is presented on how replicability will be addressed and how stakeholders are intended to be onboarded.

5.1 Overview of project-wide asset requirements

As detailed in Sections 2.3.3, 3.3.3, and 4.3.3, the deployment of the three UCs contributes towards the achievement of the goals defined for the project and towards its main results that are detailed in the DoA. The project considers an overall of 17 assets intended to implement the three UCs at the time of writing this deliverable, listed in Table 4. The majority of listed assets are brought to the project from the very beginning and they will be adapted or extended for PLEDGER (A1-AS15): Some assets, however, are to be developed from scratch (AS16-AS17). The table may be modified in the evaluations of the specific requirements done as part of the work for D2.2.

Table 4: Assets intended to be used by UCs

Asset ID	Short name	Name	UC1	UC2	UC3
AS1	3Alib	SLA monitoring library	X	X	X
AS2	Benchmarking Suite	Cloud and Edge benchmarking orchestrator tool		X	X
AS3	DLT / Blockchain	Hyperledger Blockchain framework & Middleware		X	X
AS4	-	Quality of Experience Toolkit	X	X	X
AS5	-	A bridge between SLAs definition & Smart Contracts creation	X	X	X
AS6	ATOS SLA Framework	SLA Framework	X	X	X
AS7	-	Edge-To-Cloud Resource Orchestration	X		X
AS8	RACOON	PLEDGER RAN Controller		X	
AS9	Pledger SOE Framework	Slice Orchestration Framework for Cloud, Edge and Radio Infrastructures		X	
AS10	-	Big Data platform			X
AS11	-	Microtransactions Framework for the Edge	X		
AS12	Holo-View	AR workspace	X		X
AS 13	ARES	Augmented Reality Engineering Space	X		
AS14	ISAR	Interactive Streaming for Augmented Reality	X		
AS15		Barcelona City Infrastructure		X	
AS16	RDNS	Risk Detection and Notification System		X	
AS17		Gadget for VRUs		X	

A subset of assets will be used by all UCs (e.g AS4, AS5, AS6), as they are foreseen to form part of the core asset that will form the PLEDGER platform. Several assets are UC-specific, such as AS13, AS14, and AS15. These assets will be developed and extended as part of a UC-specific deployment and they won't be reused by other UCs. The content of this table will be updated and maintained throughout the project, as the specific features of each asset and its relationship with the rest of assets is made clear. D5.4 [16] will provide the final release of this information.

5.2 Contribution of UCs to Objectives and Results

The development and validation of the UCs in the PLEDGER pilots is a natural way to demonstrate that the objectives and results of the project can be met: The UCs exposes how the PLEDGER platform implements key features and how it acts as an enabler to provide the required functionality to satisfy the UC requirements. As such, it is necessary to check whether all objectives are covered by the UCs. Table 5 captures to which Objectives each UC is contributing, confirming that all objectives are covered.

Table 5: Impact of UCs on the project's objectives

Objective	UC1	UC2	UC3
Objective 1: *Enhance edge/fog computing provider resource management practices that lead to improved stability of offered services and QoS/QoE for end users.*	X	X	X
Objective 2: *Architect and implement the coupling of edge/fog computing with blockchains and distributed ledger technologies.*	X	X	X
Objective 3*: Enhance Cloud/Edge services behaviour measurability and predictability in order to increase, operational trust, thus enabling their use in more critical applications and increase the synergies between cloud/edge infrastructures.*	X	X	X
Objective 4: *Define and apply sets of metrics that are meaningful to the end users for QoE and QoS Levels.*	X	X	X
Objective 5: *Define and implement new ways of increasing security and privacy on edge, filtering out (during the cloud moving process) with intelligent way the data that have to be kept on the edge.*	X		X
Objective 6: *Pilot and demonstrate the applicability and scalability of the tools on large scale edge/cloud infrastructures and for applications that typically need specialised oversized infrastructures.*	X	X	X
Objective 7: *Enable the extension of the Edge/Cloud combined business model and provide an extensive replicability and best practices framework.*			X

Note that UC2 does not contribute to Objective 5 since no cloud moving process is foreseen at the time of writing. Further, only UC3 contributes to Objective 7, given the project has a strong focus on the combined Edge/Cloud infrastructure use and contributing to an extension of a related business model is of high interest.

Similarly, Table 6 presents how each UC contributes to the 5 main results of the project. Again, all results are covered by the UCs. Note that UC2 will not contribute to Result 2, as it does not expect the migration of content to happen from the edge to the cloud and that UC1 will not contribute to Result 3 since no personal or sensible data will be handled.

Table 6: Impact of UCs on the project's results

Result	UC1	UC2	UC3
Result 1: *Pledger architecture blueprint*	X	X	X
Result 2: *Pledger tools and methods for edge/cloud migration and decision support*	X		X
Result 3: *Pledger privacy on the edge*		X	X
Result 4: *Pledger Validated Use Cases*	X	X	X
Result 5: *Replication plan*	X	X	X

Based on the overviews provided in Table 5 and Table 6, we can confirm that the design and planning of the UCs have been adapted in such a way to address all the challenges defined in the DoA.

5.3 Replicability roadmap

This deliverable does an effort to gather initial inputs related to the replicability of the UCs and the PLEDGER platform deployment in general. Replicability is necessary to assure the transcendence of the project's objectives and results during and beyond the project. A plan for replicability will not only be elaborated at a UC-level, but also in more generic terms when implementing and validating PLEDGER platform components. Throughout the project, the UCs will keep track of the progress from their starting point to the final deployed and evaluated status, once they are integrated with the PLEDGER platform. Apart from this initial statement on replicability given in this section, replicability will be further discussed and evaluated in deliverables D5.4 and D6.3 [17].

The three sections of this deliverable describing each UC capture the status of the infrastructures at the beginning of the project and how they will be extended or modified to satisfy the needs. Also, the motivation for each of the UCs is given, which plays an important role to understand why and how PLEDGER is intended to be used and which improvements to the daily business are expected to be observed. Possible replicators can use this information to grasp the scope and possibilities of PLEDGER to come up with new ways to leverage the platform.

Deploying a UC can be a complex task with multiple points of possible failure, which is crucial in terms of replicability. Figuring out which risks exist and proposing mitigation plans is a work that is started with an initial risk analysis in this deliverable and which will finalize with the execution of the UC pilots. Another important aspect to be taken into account is the limitation to replicability based on whether the UC is deployed in public or private spaces, whether the legislation of a country impacts certain aspects of a UC (e.g. for the use of radio), and whether a UC relies on proprietary software that is restricted to be used throughout the project. These are important factors to be taken into account when designing and designing a UC and they should be clear from the very beginning.

Further, at a later stage, UC will provide recommendations and lessons learned over the course of the project, mainly in written form, as part of future deliverables (D6.3, but also deliverables from WP5). Also, whenever applicable, the gained knowledge will be shared in other forms, such as audio-visual content (e.g. videos or slide decks) as part of presentations or distributable material.

5.4 Stakeholder involvement roadmap

Each UC involves a set of end users (or clients) that form part of the stakeholders listed in Sections 2.2.2, 3.2.2, and 4.2.2, respectively. These stakeholders are crucial to each UC from execution and business model point of views: the motivation of each UC evolves around delivering an improvement to the end user, while at the same time, they can be the main customers from a business point of view. Given the relevance of the end users, each UC intends to involve them in the design and validation process in order to obtain valuable feedback that can be used to further improve the UC and to assure the desired QoE. This deliverable does an initial step in identifying the stakeholders that need to be involved for each UC and proposing ways to onboard them, a work which is continued in D2.2.

In the following, an initial stakeholder involvement analysis is presented for the three UCs.

5.4.1 UC1: Mixed reality applications on the edge

A typical user for this UC is a company in the automotive and Tier 1,2,3 market. Stakeholders inside the company are engineering and IT department. Stakeholder engagement can be achieved through workshops, followed by feedback rounds. Furthermore, simple communication channels are expected to be useful too, as non-personal email chains can stifle information exchange.

5.4.2 UC2: Edge infrastructure for enhancing the safety of vulnerable road users

There are two main stakeholders in this UC, which are the VRUs, for whom safety is to be improved, and the city administration, who is the one that has the interest in improving the safety by deploying the UC. Challenges of how to set up and operate a city-wide testbed with an underlying multi-tier compute architecture could be shared in a webinar or as part of workshops in conferences, stakeholders being possible other cities or municipalities that are interested in the PLEDGER solution. Internally, the project will be presented in dedicated sessions to expose the UC and to obtain feedback. Since most of the staff can be considered a VRU and VRUs will be participating in the pilot, a solid user base for questionnaires to obtain feedback about the UC already exists.

5.4.3 UC3: Manufacturing the data mining on the edge

For UC3, workshops with the domain experts can be held. Surveys and direct contact with customers to evaluate their needs and interests are other important sources of feedback. The workshops could be held in an open day in the future zone to show the possibilities and chances to prospective customers. There will be close coordination with the engineers as well as the product owner in terms of the provided data to correlate them with the business model. Regular updates will be held for the whole FILL staff during the FILL newsflash to encourage new innovative ideas.

6 Conclusions

PLEDGER focuses on providing a toolkit not only to the infrastructure providers but also to the platform adopters. This framework will enhance the cross-layer knowledge while following a black-box approach through all the involved infrastructures (i.e. cloud, fog, and edge layers). To this aim, the project will exploit three main scenarios (i.e. mixed reality applications, enhancement of global road safety and manufacturing the data mining with edge infrastructures) to demonstrate the capabilities of PLEDGER platform over cross-vertical UCs.

This deliverable is a direct outcome of T2.1 “Use Cases detailed description” focussing on defining and describing the proposed UCs, as they are currently delivered by the associated industries. The specific UCs under consideration include: "UC1: Mixed reality application on the edge", "UC2: Edge infrastructure for enhancing the safety of vulnerable users", and "UC3: Manufacturing the data mining on the edge".

Moreover, the document includes also a description of the infrastructure and hardware to be used within the PLEDGER project and which are planned to host the execution of the three defined UCs. In addition to providing these initial technical descriptions, the document also presents how stakeholders can be involved and how replicability can be achieved. The next objectives of WP2 comprise an extensive analysis of the UCs' requirements (D2.2) as well as the definition of the overall PLEDGER system architecture (D2.3, “Pledger Overall Architecture” [18]).

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