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D7.1: Initial Defined Architecture

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Abstract

This deliverable describes a first version of the overall system architecture – the Initial Defined Architecture (“IDA”) – which specifies how the different modules of WP4, WP5 and WP6 are set up and interact with each other. The architecture is to be finetuned step by step and finalised in D7.3, based on growing insight as the project progresses.

The IDA is the first attempt at designing a technical blueprint for 5G-enabled teleoperated transport. The IDA is broken down into (i) basic building blocks, modules upon which any use-case conform to the IDA will be built, and (ii) a configuration of those building blocks into a use-case of 5G-enabled teleoperated transport (e.g., the four WP4 use-cases that will be piloted in 5G Blueprint). Depending on the requirements of a specific use-case, building blocks will be combined and interfaces will be set up.

Keywords: Initial Defined Architecture, System Architecture

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Disclaimer

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EXECUTIVE SUMMARY

This deliverable describes a first version of the overall system architecture – the Initial Defined Architecture ("IDA") – which specifies how the different modules of the system including communications, functionality for teleoperation (developed within WP4, WP5 and WP6) are set up and are to interact with each other. The architecture is to be finetuned step by step and finalised in D7.3, based on growing insight as the project progresses.

The figure below provides a **schematic view** of the IDA.

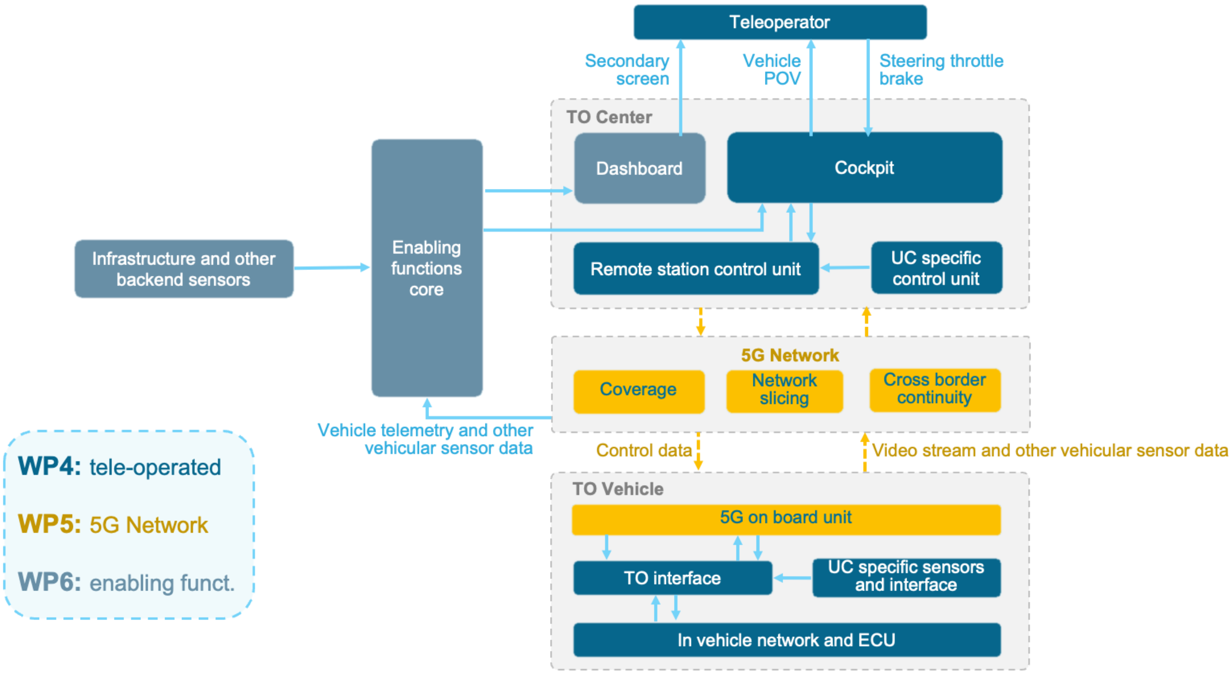

Figure 1 High-level overview of the Initial Defined Architecture (IDA).

This IDA encompasses three basic building blocks:

<u>**The Teleoperation Core**</u> in which all necessary elements are present to make teleoperation possible. The Teleoperation Core will always include the following two entities:

- The **Teleoperated Vehicle (TO Vehicle)** is the road vehicle or barge that is being remotely controlled. The TO Vehicle contains a set of modules (the **TO interface**) which takes in the control data from the Teleoperation Centre (see below) and translates these into electric signals that the **Electric Control Unit** inside the TO Vehicle can understand, as well as sends out the data required for teleoperation (camera streams, sensors, etc.). In addition, the TO vehicle also contains a **5G on-board unit** which makes cross-border, 5G-enabled communication from and to the TO vehicle possible.

- The **Teleoperation Centre (TO Centre)** is the physical place where the TO vehicles are being remotely controlled from. The heart of the TO Centre is the **Remote Station Control Unit** which controls what the teleoperator sees, and processes the operational input received from the teleoperator. The actual teleoperation takes place in the **cockpit** where the teleoperator is presented with audio-visual streams from the TO vehicle and where the teleoperator can provide inputs (steer, throttle, brake) to operate the TO vehicle. The TO Centre also contains a **dashboard**, which is a set of secondary screens that show non-safety-critical but still relevant information, as well as a **use-case specific control unit** which processes data flows that are not critical for teleoperation but are required to correctly carry out a specific use case of teleoperated transport.

<u>**The Enabling functions core**</u> which consist of modular services which enable, facilitate or enhance teleoperated transport. Modularity allows for the flexibility to integrate a required

combination of services as needed by the demands of the specific use-case. Ten enabling services spread out over 8 enabling functions are to be present in the enabling functions core. These services take in vehicle telemetry and other vehicular sensor data from the TO vehicle; they also may take in data from other sources, such as roadside infrastructure or external data feeds. The combination of services provide output to the TO Centre in the form of a feed to be implemented in the primary display (in the cockpit), or as a dashboard to be shown on a secondary display.

A set of 5G blocks are required to set up, operate, monitor, and manage the 5G-based connectivity needed. The 5G architecture applied in the project builds on standardized components. The Teleoperation core and the Enabling Functions core will require certain telecommunication services from the 5G network, often at the same time and location. The challenge within this project is to allocate the network resources in such a way that the network can provide these services simultaneously while respecting all requirements set by use cases and enabling services. **The chosen option for addressing this challenge is Network Slicing**, which allows the optimization of the network behaviour to the need of the specific use cases and individual customers. For each of the use-cases and enabling functions that are being developed in this project, a formulation of slice types has been defined so that a network can be realized which supports these use-cases and enabling functions. Importantly, the 5G network will also provide Network Data Analytics Functions which may be used by the Teleoperation and Enabling Functions Cores to predict upcoming changes in network performance and take necessary actions to maintain service levels in the face of these changes.

The IDA should be seen as a first attempt at designing a technical blueprint for 5G-enabled teleoperated transport. In the context of 5G-Blueprint, the IDA will be applied to specific WP4 use-cases which are under development and will be demonstrated and validated. For each use-case an application of the IDA can be defined, which is a configuration of the three IDA building blocks and interfaces between them in such a way that it meets the requirements of the specific use-case. More detailed schematic views of the application of the IDA to the four use-cases under development in 5G Blueprint are presented in this document.

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ABBREVIATIONS

ACA	Active Collision Avoidance
CACC	Cooperative Adaptive Cruise Control
E2E	Edge to Edge
EAD	Enhanced Awareness Dashboard
EBA	Emergency Brake Assist
ECU	Electric Control Unit
EF	Enabling Function
eMBB	enhanced Mobile Broad Band
GNSS	Global Navigation Satellite System
hMTC	high performance Machine Type Communication
IDA	Initial Defined Architecture
iTLC	intelligent Traffic Light Controller
MIoT	Massive Internet of Things
mMTC	massive Machine Type Communication
MVP	Minimum Viable Platform
NWDAF	Network Data Analytics Function
OBC	On-Board Computer
OBU	On-Board Unit
POV	Point-Of-View
RSCU	Remote Station Control Unit
TO	Teleoperated
TOV	Teleoperated Vehicle
UC	WP4 Use-Case
URLLC	Ultra Reliable Low Latency Communication
V2X	Vehicle to Everything (communication)
VRU	Vulnerable Road User
WP	Work Package

PARTNERS DIRECTLY INVOLVED IN INTERFACES

VTR	V-Tron
ROB	Roboauto
HAN	HAN
KPN	KNP
TEL	Telenet
BEM	Be-Mobile
SWA	SWARCO

LN	Locatienet
IMEC	IMEC
SEN	Sentors
SEA	Seafar

1 INTRODUCTION

This deliverable is part of the documentation of the works on WP7. It describes the first version of the overall system architecture – the Initial Defined Architecture ("**IDA**") – which specifies how the different modules of WP4, WP5 and WP6 are set up and are to interact with each other. The architecture is to be finetuned step by step and finalised in D7.3, based on growing insight as the project progresses. This deliverable takes references from the work documented on WP4 (5GBlueprint, 2021), (5GBlueprint, 2021), (5GBlueprint, 2021) and WP6 (5GBlueprint, 2020), (5GBlueprint, 2021), (5GBlueprint, 2021), while also in line with the work on WP5, which is about to be documented.

The IDA should is the first attempt -initial version- at designing a technical blueprint for 5G-enabled teleoperated transport. The IDA can be broken down into (i) **basic building blocks**, modules upon which any use-case conform to the IDA will be built, and (ii) a **configuration of those building blocks** into a use-case of 5G-enabled teleoperated transport (e.g., the four WP4 use-cases that are to be piloted in 5G Blueprint). Depending on the requirements of a specific use-case, building blocks will be combined and interfaces will be set up.

The remainder of the document is structured as follows:

- In Section 2, we present and discuss the IDA and its main building blocks.
- In Section 3, we present and discuss the application of the IDA to the 5G-Blueprint teleoperation use-cases.
- Finally, in Section 4, we draw a conclusion of this deliverable and express the next steps of the work on WP7.

2 HIGH-LEVEL INITIAL DEFINED ARCHITECTURE (IDA)

In this section we will provide a first generic and high-level view of the Initial Defined Architecture (IDA), based on Figure 1.

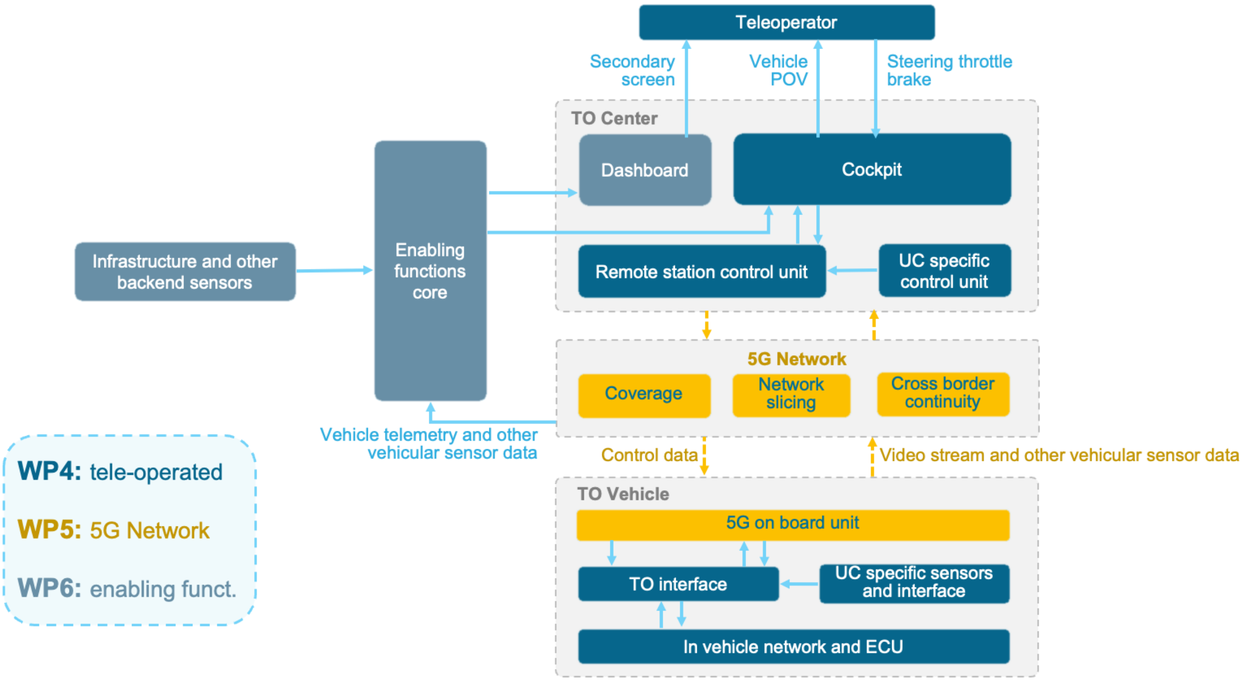

Figure 2 IDA components.

The IDA encompasses three types of building blocks:

1. Teleoperation core: The building blocks in the Teleoperation core are the necessary elements to make teleoperation possible and include (i) the teleoperation centre (**TO Centre**) in which the teleoperator who actually realizes the remote monitoring and control is located and (ii) the teleoperated vehicle (**TO Vehicle**).
2. Enabling functions core: This consists of modular enabling services, provided in the context of the WP6 Enabling Functions, which enable, facilitate or enhance teleoperated transport. The enabling services can be plugged into the Teleoperation Core depending on the specific requirements of the teleoperation use case.
3. 5G blocks: These elements are required to set up, operate, monitor, and manage the 5G-based connectivity enabling specific teleoperation use cases and enabling services.

We will run through each of these types of building blocks in turn. **Note that we will not provide a full detail on the internal architecture within these building blocks – for this we refer to the relevant deliverables in WP4 (R4.3), WP5 (D5.1) and WP6 (D6.3)**. We distinguish between three types of building blocks, as detailed in the sections 2.1, 2.2, and 2.3. In addition, in Section 2.3 we also provide an overview of the 5G-Blueprint architecture and map the components of the IDA to the project's general architecture.

2.1 Teleoperation Core

Each use-case of teleoperation will include the following entities:

- The Teleoperated Vehicle (TO Vehicle). This is the road vehicle or barge that is being remotely controlled.
- The Teleoperation Centre (TO Centre). This is the physical place where the TO Vehicles

are being remotely controlled from. The TO Centre receives video streams and other vehicular sensor data from the TO Vehicle and in turn sends out control data, which are further processed inside the TO Vehicle and lead to the vehicle doing what the teleoperator in the TO Centre told the vehicle to do.

The **TO Vehicle** consists of the following basic components.

- The 5G on-board unit (OBU): This 5G communication module makes cross-border, 5G-enabled communication from and to the TO Vehicle, possible. The 5G on-board unit receives and sends data towards the TO interface.
- The TO interface: This interface makes teleoperation possible on the TO Vehicle side. It will typically contain the on-board computer (OBC) which (i) takes in data from the streaming nodes (the set of camera's, microphones and other sensors installed on the TO Vehicle), processes these data and sends the processed output via the 5G OBU towards the TO Centre; and equally (ii) receives control data from the TO Centre to be processed into teleoperation commands. The TO interface will also contain a CANbox module which is developed as an intermediate element for interaction between the OBC and the vehicle (controlled via the Electric Control Unit – see below). The acceleration and the steering commands received from the OBC will be transformed in a way for the vehicle to comprehend and actuate the required vehicle signals.
- The Electric Control Unit (ECU) (and other components of the in-vehicle network) which carries out the control commands received via the CANbox module.

Besides these components, other UC-specific sensors and interface components may be added to the TO Vehicle setup, depending on the specifics of the use-case. For example

- UC4.1 will also require on-board (i.e., non-teleoperated) operation of the barge.
- UC4.2a will require automated driving functionalities.
- UC4.3 will require CACC control functions.

The **TO Centre** contains the following basic components:

- Remote Station Control Unit (RSCU): This unit (i) controls what the teleoperator sees in her/his cockpit, based on input received from the TO Vehicle; (ii) processes the operational input received from the teleoperator (see below) and sends this back to the TO Vehicle; and (iii) controls how UC-specific functionalities are integrated into teleoperation.
- Cockpit: This is the operational system collecting and presenting all audio-visual streams and feedback systems available to the teleoperator enabling her/him to carry out teleoperation. It will typically include (i) a set of primary displays, showing the point-of-view of the TO Vehicle along with other relevant information; and (ii) the Steering Throttle Brake module through which the feedback of the teleoperator (steering, accelerating, or braking) is received (and then further processed by the RSCU).
- Dashboard: This is a (set of) secondary screen(s) that show relevant information that is not safety-critical but may support and help the teleoperator to make the most appropriate decision during the course of operation.
- UC-specific control unit: Processes and data flows that are not critical for teleoperation but are required to correctly operate a specific use case of teleoperated transport, are controlled via the UC-specific control unit.

2.2 Enabling services

Teleoperated transport can be enabled or facilitated by plugging in several modular services. Important to note is that these services may be provided either directly to the TO Centre, or indirectly via other enabling services. It is important that these enabling services are modular so that there is sufficient flexibility to integrate the required services into the teleoperation setup.

Why "enabling services" instead of "Enabling Functions"?

By using the term "services" we want to put emphasis on the actual service provided by these enabling functions rather than their base functionality which may include several services. These services may be sourced separately (i.e. it is not the case that the TO centre will always need the full functionality of an EF). For example, EF1 essentially provides two services – an EAD feed for display on the primary screen, and a map-based view for display on the secondary screen – which are available separately and may also be used independently from each other.

In what follows we provide a brief overview of the 10 identified services (also with a mapping to the EF's) (for further information on these services, we refer to the relevant deliverables of WP6)[1]:

- **EAD feed [EF1 - EAD]** provides a feed which contains (i) speed advice, (ii) the next instruction in the turn-by-turn navigation, and (iii) an upcoming warning, providing the teleoperator with all the necessary information to safely operate the transport on public roads clearly and concisely without being overloaded with information.
- **Road map viewer [EF1 - EAD]** provides a map-based view of the trajectory of the teleoperated transport, to be shown on a secondary screen. This map-based view will allow the teleoperator to make better decisions to navigate the route further up ahead.
- **VRU warning [EF2 – VRU]** provides warnings to teleoperators for VRU's in the anticipated path of the TO Vehicle, intending to avoid conflicts (and collisions) between the TO Vehicle and VRU's.
- **Time slot reservation [EF3 - iTLC]** provides a time slot for conflictless crossing at the next intersection on the trajectory of the teleoperated transport, to allow for efficient and uninterrupted transport, particularly in the context of platooning.
- **Distributed map layer [EF4 – DP]** provides a layer with detected objects that can be superimposed onto a map, showing objects outside the teleoperator's field of view by combining different camera angles from different point-of-views.
- **Yard map viewer [EF4 - DP]** provides a real-time dynamic helicopter view of the yard where teleoperated manoeuvres are taking place, allowing the teleoperator to navigate the yard without risk of collision.
- **ACA [EF5 – ACA]** provides active collision avoidance measures during teleoperated transport;
- **Container ID service [EF6 – CID]** provides a message which contains the container ID of the relevant container (e.g. attached to the spreader of the crane), allowing the teleoperator to efficiently ensure that the correct container has been picked up.
- **ETA info [EF7 – ETA]** provides detailed and real-time info on ETA for teleoperated transport.
- **Scene Analytics-based warnings [EF8 – SA]** provides a feed which warns of detected anomalies prior or during the start of the teleoperated transport, thus informing the teleoperator of incidents and events that took place out of sight of human monitoring.

These enabling services take in vehicle telemetry and other vehicular sensor data from the TO Vehicle; they also may take in data from other sources, such as roadside infrastructure or external data feeds. The combination of services provide output to the TO Centre in the form of a feed to be implemented in the primary display (in the cockpit), or as a dashboard to be shown on a

[1] See deliverables D6.1 [4], D6.2 [5] and D6.3 [6].

secondary display.

2.3 5G connectivity

Bilateral communication between the TO Vehicle and the TO Centre and from TO Centre to the Enabling Functions core (and within elements of the Enabling Functions core) will run over a 5G network. The baseline 5G network architecture shown in Figure 3 is applied in the project, and thus illustrated in Figure 4, building on standardized components. The overall 5G network architecture is described in detail in the first WP5 deliverable, i.e., D5.1.

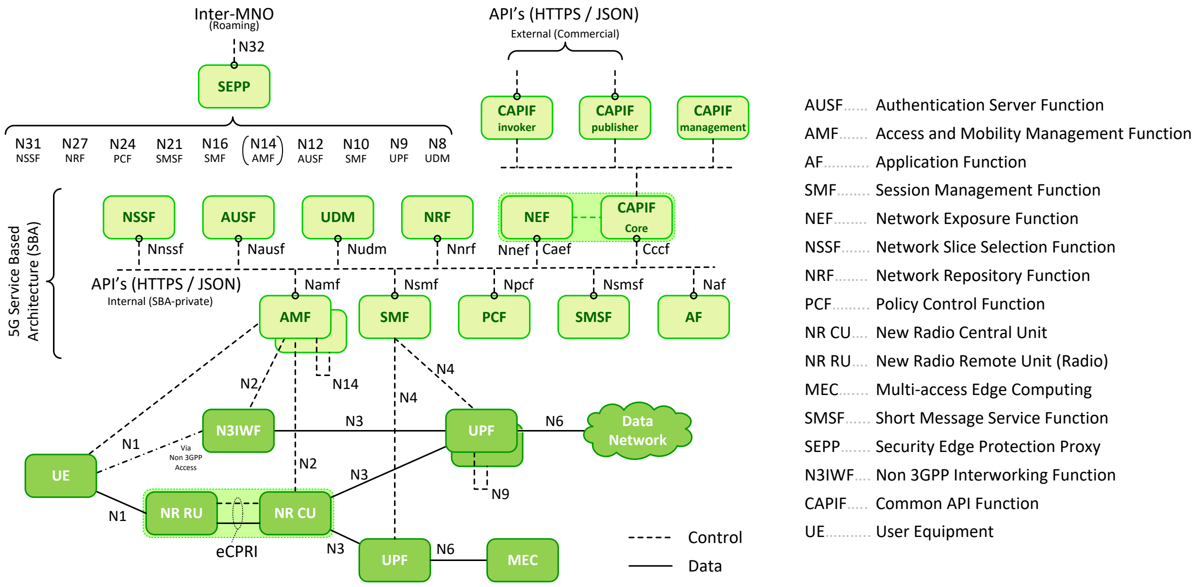

Figure 3 Generic 5G architecture used as a baseline for creating 5G-Blueprint architecture.

The 5G-Blueprint architecture (Figure 4) showcases the interactions between use cases and enabling functions, but also the interaction between various UC/EF components and UEs (vessels, cars, trucks, skid steers) over 5G network. In Figure 4, we map the elements of the IDA to the 5G-Blueprint architecture. While D5.1 is entirely focused on the 5G network aspects from Figure 4, this deliverable will explain how IDA is envisioned and implemented for use cases and enabling functions.

Concerning the overall 5G-Blueprint architecture, the radio network shown in Figure 4 consists of 5G NR gNodeBs deployed in three pilot sites, i.e., Antwerp, Vlissingen, and Zelzate. On the UE side, the project will extensively use either prototype or commercial cars, trucks, barges, and skid steers, which depends on a piloting activity, i.e., use case and a testing teleoperation scenario. All these UEs are equipped with 5G communication capabilities, i.e., 5G modems (NSA/SA) and necessary antennas, which allow them to communicate with the teleoperator. In addition, the setup on the UEs is including various sensors, and Central Control Unit (CCU) that executes the commands sent by the teleoperator. All architectural components are in more detail described in D5.1, whereas in this deliverable we keep the overview of the architecture as a guideline for developing integration and piloting activities that will be further described in subsequent version of WP7 deliverables, i.e., D7.2 and D7.4.

The Teleoperation core and the Enabling Functions core will require certain telecommunication services from the 5G network, often at the same time and location. **The challenge within this project is to allocate the network resources in such a way that the network can provide these services simultaneously while respecting all requirements set by use cases and enabling services**. The chosen option for addressing this challenge is **Network Slicing**, which allows the optimization of the network behaviour to the need of the specific use cases and individual customers.

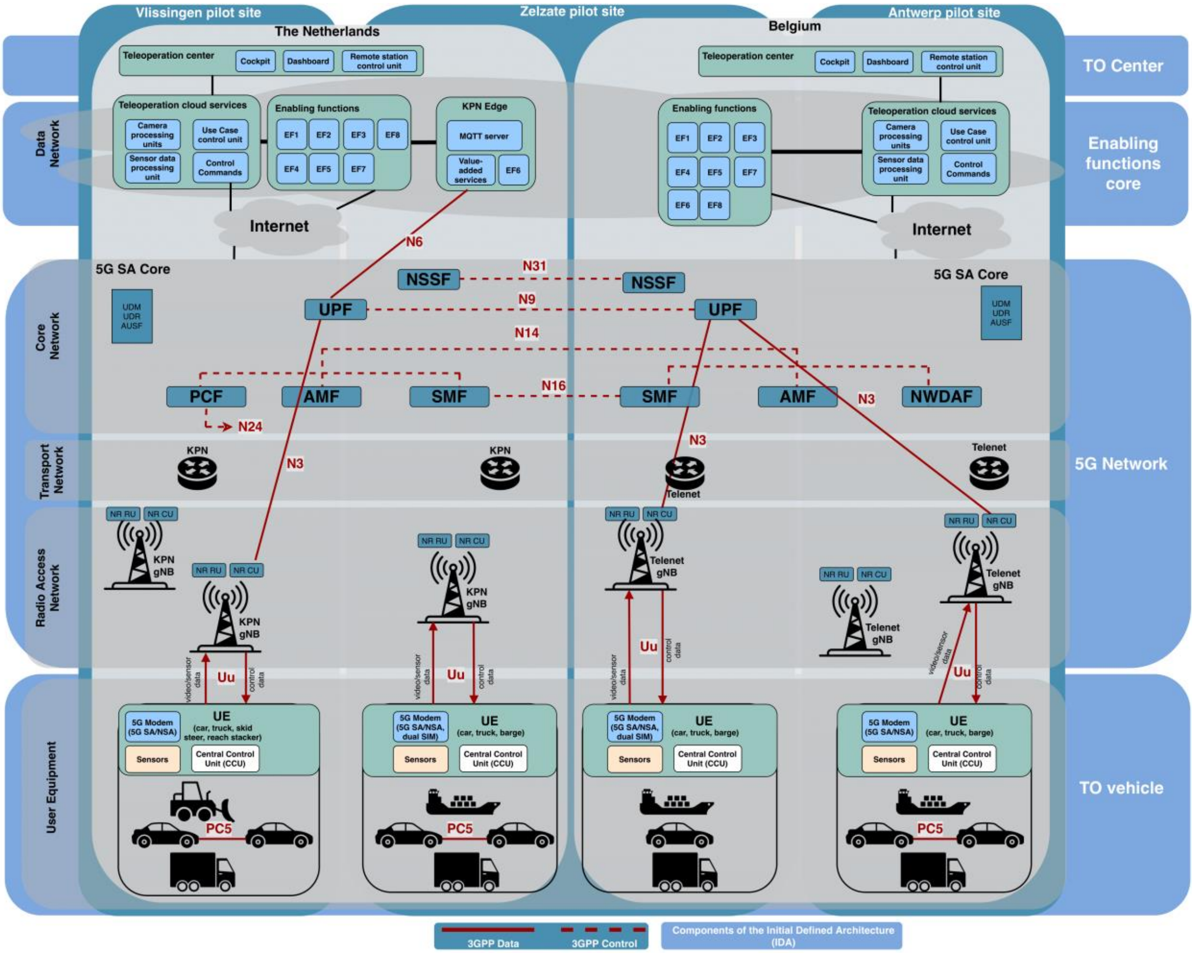

Figure 4 5G-Blueprint architecture mapped to the components of IDA.

In the 5G standard five basic slice types are fined – mMTC/MIoT, eMBB, V2X, hMTC/mcMTC, URLLC. Table 1 provides an overview of their attributes at a general level. In particular, it includes the types of services that the slice type can support. Each slice type can support specific types of services ("service types").

Note that these general level attributes are limited to qualitative characterisation for different performance metrics such as E2E latency, availability, throughput, etc. This information is included in the Table 1, in order to capture the difference in provided type of connectivity. The corresponding quantification to concrete numeric values is part of the requirements analysis performed in D5.1, and out of scope of the IDA definition of this deliverable D7.1.

As described in D5.1 (see Section 2), WP5 has looked at the various UCs and EFs and identified their requirements for 5G slices. This then leads to the formulation of slice types to be used to realize the network which supports these UCs and EFs. Here we summarize the main types of slices that are selected for different UCs and EFs, based on the analysis presented in D5.1:

- UC4.1 Automated Barge Control: For the uplink communication both eMBB and V2X types of slices are leveraged, for HD camera stream (required bandwidth between 5 and 25 Mbps), and for distance/depth sensor on the ship, respectively. At the same time, for the ship control requirements, URLLC will be suitable due to end-to-end latency requirement of maximum 35 ms.
- UC4.2a Automated-driver-in-loop-docking and UC4.2b Teleoperated Mobile Harbour Crane: Due to the same requirements for bandwidth on the uplink as for the case of UC4.1, UC4.2 (both a and b) requires also eMBB and V2X for HD camera and telemetry sources,

respectively, while URLLC is used for vehicle-control interface.
- UC4.3 CACC-based platooning and and UC4.4 Remote takeover operation: While this use case also uses eMBB and URLLC types of slices for HD camera stream and vehicle control interface, it also required V2N for telemetry sources and V2V for Lidar data stream.
- Enabling functions for Distributed perception and Vulnerable Road User Warning require eMBB due to the lidar data, while Timeslot Reservation from Intelligent Traffic Lights and Active Collision Avoidance require IoT and V2N types of slices, respectively.

Importantly, the 5G network will also provide a Network Data Analytics Function (NWDAF) which may be used by the Teleoperation and Enabling Functions cores to predict upcoming changes in network performance and take necessary actions to maintain service levels in the face of these changes.

In the below, we provide an overview of the relevant network slice types per UC and enabling service, indicating the processes that will require 5G communication, from and to which entity the communication goes, the envisioned slice type to be used, the envisioned service type within the slice type as well as the number of flows that need to be simultaneously supported within each slice.

Table 1 Generic properties of 5G Network Slices.

	Network Slice Type				
	mMTC MIoT	eMBB	V2X	hMTC	URLLC
Full name	massive Machine Type Communication Massive Internet of Things	enhanced Mobile Broad Band	Vehicle to Everything (communication)	high performance Machine Type Communication	Ultra Reliable Low Latency Communication
Best suited for	Infrequent and small messages, potentially with a high geographical density of devices	Voice and Video services	Machine to machine communication whilst at least one of the parties is mobile	(precursor to URLLC which is not yet achievable with current tech in the Radio Access Network)	Mission critical services with low latency tolerance and high long-term reliability
Examples of supportable service types	Uplink[2]	Uplink Downlink[3]	E2E[4] V2V short range[6]	E2E Downlink/uplink	E2E Downlink/uplink
E2E Latency	Not very Sensitive	Not very Sensitive	**Highly Sensitive**	**Highly Sensitive**	**Extremely sensitive**
Availability	Regular	Regular	High	**High**	**Extremely High**
Throughput	Low	**High/Medium**	Low/ Medium	Low/ Medium/ High	Low/ Medium/ High
Hand-Over rate	Low	**High**	**High**	Medium	High
Radio Density	**High**	High	Medium/ High	Medium/ High	Medium/ High
Radio Coverage	**Full**	Full	**Full**	Localized/ Full	Localized

[2] An uplink is the transmission path from the mobile station (cell phone) to a base station (cell site).

[3] A downlink is the transmission path from a base station to the mobile station.

[4] End-to-end communication is communication on application level (this corresponds to OSI layer 7).

[6] Vehicle to vehicle short range communication is communication between vehicles, generally spoken over a distance of a few tens of meters.

3 APPLICATION OF THE IDA TO WP4 USE-CASES

In this section we apply the IDA to the specific WP4 use-cases which are under development and will be demonstrated and validated in the context of the 5G-Blueprint project. These then serve as examples of how the 5G-Blueprint IDA can be applied to actual use-cases.

3.1 UC4.1 – Automated barge control

Table 2 Key facts of UC4.1.

UC4.4	Remote takeover operation
Description	UC4.1 foresees in 5G-enabled, cross-border remote operation of two vessels on selected itineraries.
Pilot sites	Antwerp, Zelzate
EF's	N/A (No EF deployed in this use case)
Partners	Seafar, KPN, Telenet

In this UC, teleoperated barge shipping using 5G will be demonstrated and validated. The 5G connectivity and the 5G communication module will be demonstrated in parallel to the existing 4G setup, so as to explore the advantages of 5G in terms of among others latency and bandwidth.

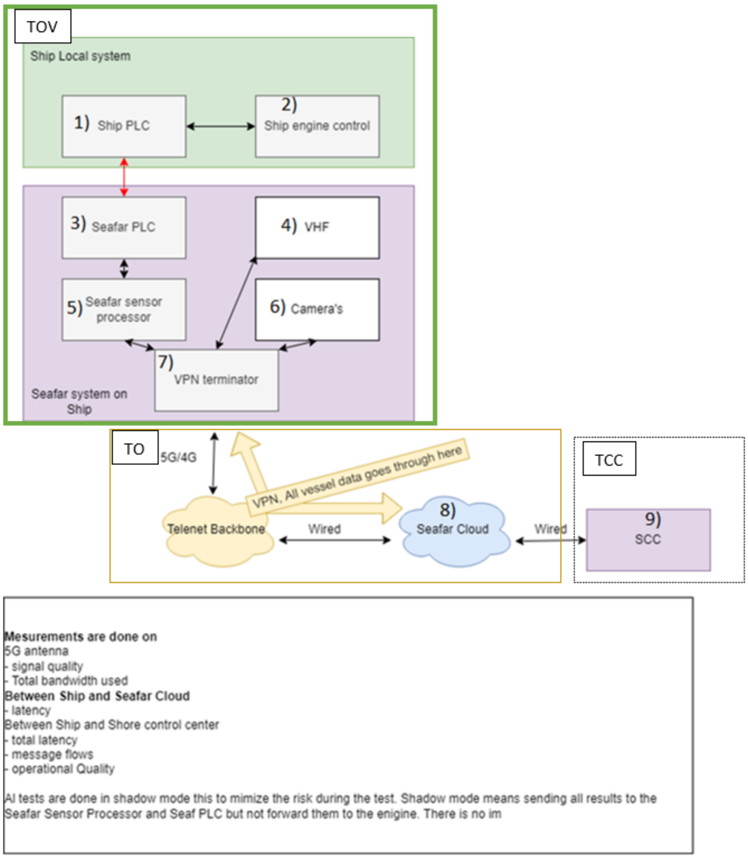

Figure 5 Automated barge control process flow

The building blocks of the Seafar system are illustrated in Figure 5. The number of the blocks are specified next to them. All commands are sent from the Shore Control Center (SCC) block number (9) to the Seafar Cloud systems (8). The SCC include primary display, steering module, remote station, and use case specific control unit.

In the cloud systems they will be sent to the vessel via a VPN (7). The VPN terminator on the ship distributes the traffic to the correct system on the ship

- video feed is requested from the cameras (6)
- the Radio over IP application will connect to the VHF (4) radio on board to send and recieve VHF audio messages
- all commands for the ship will be sent to the Sensor processor (5) and/or PLC.

  we will not forward the traffic from the Seafar PLC (3) to the Ship PLC (1) considering the operation in shadow mode.

Two vessels will be equipped with 5G-enabled teleoperation capabilities – the Tercofin II for demonstration at Port of Antwerp, and another vessel for demonstration at Zelzate. These vessels will be operated from remote stations at Seafar's Shore Control Centre (i.e. UC4.1's version of the TO Centre). These stations are equipped with 6 large displays for camera streams and a desk with joysticks, radio communication devices and smaller screens for additional camera views and ship status overviews.

3.1.1 Interfaces between Use Cases (WP4) and Enabling Functions (WP6)

There are no Enabling Functions deployed within use case UC4.1.

3.1.2 Interfaces between application layer (WP4/6) and 5G Network (WP5)

As discussed in section 2.3, slicing and NWDAF are the main concepts on the network layer that the applications should be aware off, and interact upon with the network. This interaction between the application layer components from WP4 (Use Cases) and WP6 (Enabling Functions) and the 5G network is performed using standardised interfaces from the 3GPP 5G architecture.

Slice selection in 5G is a two-stage process:

1. A customer needs to engage in a commercial relation with an MNO. As part of the onboarding, this customer need to agree on the slices available to him within this commercial agreement (subscription) and the performance parameters of each of these slices. These could be standardized slices (and parameters) or customized slices with a private set of parameter-values. Each slice is allocated a slice identifier. A mobile can use multiple slices simultaneously. As part of the subscription the customer receives one or more UICCs (5G SIMs).

2. When a mobile (UE) attaches to the network, the network sends the list of slices available to that UE (those agreed upon in the subscription). The applications on the UE need to recognize the identifiers. To this end the N1 interface is used.
    a. Applications on the UE can choose a slice from this list when they initiate a data flow towards an endpoint (an application on the internet).
    b. Applications on the internet are supposed to agree End-to-End with their counter-part on the UE about which slice to use. To this end the N6 interface is used. When possible, the UE selects this slice (or renegotiates a new one).
    c. Mid-session deviant behaviour can (as part of a subscription) be reported to an application on the internet via the NEF and CAPIF. The NEF and CAPIF uses an API with a HTTPS interface. This application then can request the application on the UE to select another slice (using the N6 interface). Deviant behaviour could be detected by an algorithm on the NWDAF.

3GPP has defined 2 models to avail Analytics services from NWDAF by any Network Function or Application Function

1. Subscription model - in case periodic Analytics information needed. For instance: Periodic Load information (current/predicted) of Network slice.

2. Request/Ad-Hoc model - if a one-time Analytics computation and information needed. For instance: Experience score of a newly deployed Application for a particular day/hour/region.

NWDAF is a novel feature of 5G, with which none of the 5G-Blueprint partners have hands on experience. Therefore it needs to be explored as part of the further 5G-Blueprint activities which of the above mentioned 2 avail models is most suitable. Similarly, first experience with NWDAF capabilities is needed to be able to assess which value can be expected from this function in practice. This way it can be determined which application layer components of the 5G-Blueprint IDA would benefit from using the analyses that NWDAF provides. Some examples currently being thought about in the project are:

- TO Interface: if the network will temporary degrade, it could take measures to keep the vehicle controllable such as reducing the video resolution.
- EDA feed: if the network will temporary degrade, it could warn the driver to slow down because the video resolution will degrade (and hence the driver will see less), or to even try to already stop and park the vehicle safely if the expected degradation is so severe that the initiation of an automated safety stop procedure is expected.
- 5G on board unit: in case of dual modem solution, information about a pending degradation could force the aggregator to change the primary modem (form of national roaming). But then these measures have to be synchronized with those of the TO interface and EDA feed, because the measures of the 5G on board unit might solve the network degradation in advance, and then those of the TO interface and EDA feed should actually not trigger.

However, these are only first thoughts, and it remains to be learned if indeed NWDAF would be able to support these IDA components, and how NWDAF could also be a valuable input for others. Those details will be presented in the next iteration of this IDA, which will be presented in Deliverable D7.3, “Final Architecture Revisited”, due at month 30 of the project.

3.2 UC4.2a – Automated teleoperator in-the-loop docking

Table 3 Key facts of UC4.2a.

UC4.2a	Automated teleoperator in-the-loop docking
Description	UC4.2a revolves around the idea of a driver assistant system for docking articulated vehicles (i.e. vehicles with a pivot joint, such as trucks with trailers) within warehouses and distribution centres through the integration of 5G technology. The focus of UC4.2a is to develop a bi-directional controller to control the vehicle along the desired reference path. The controller will operate autonomously, with a teleoperator overseeing the operation and taking control if necessary.
Pilot sites	Vlissingen
EF's	2, 4, 5, 7
Partners	HAN, V-TRON, Roboauto, KPN, Imec, Locatienet, Be-Mobile

3.2.1 Application of IDA

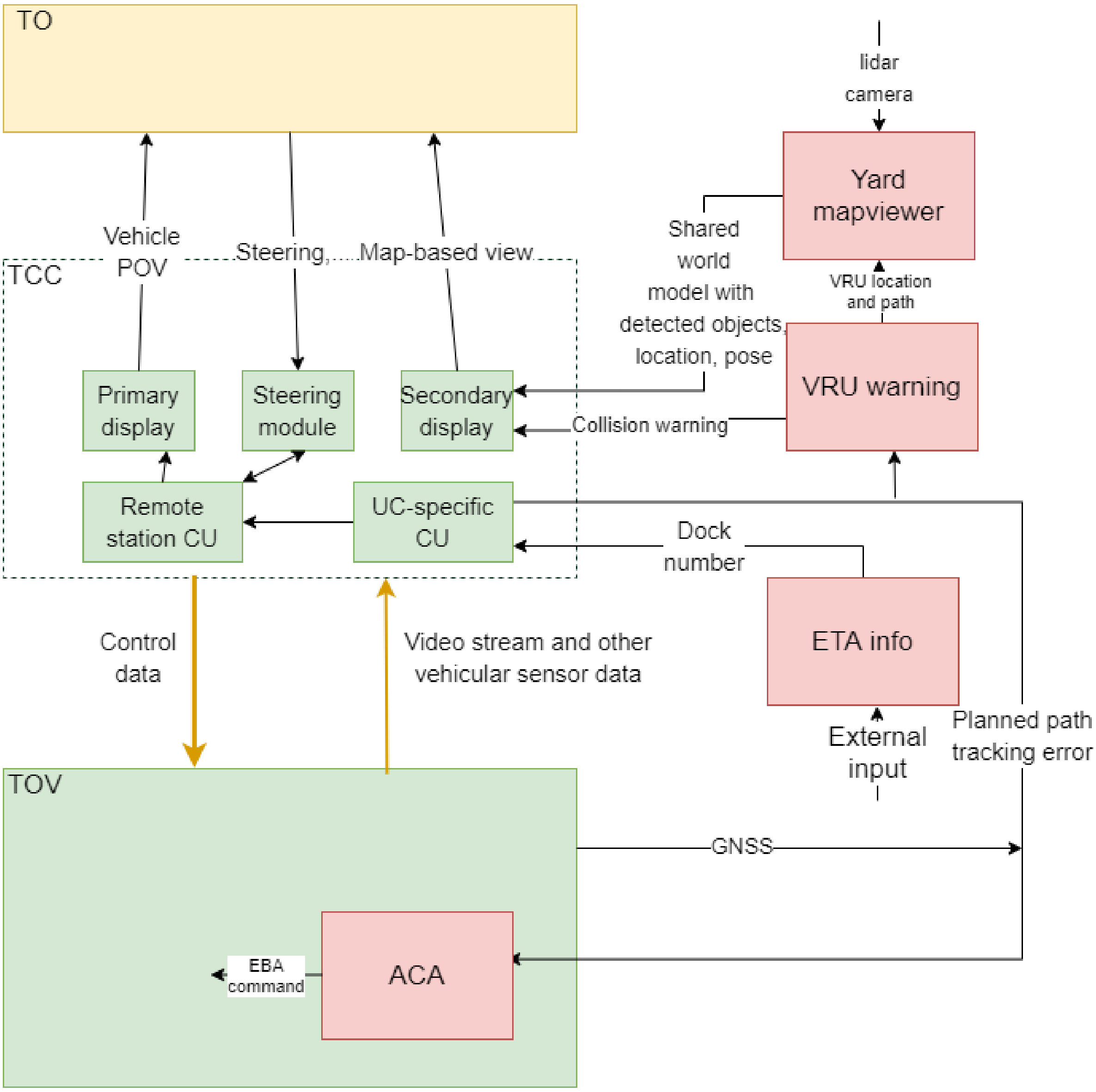

Figure 6 Application of IDA to UC4.2a.

The core of UC4.2a is the TO Centre which contains three interfaces towards the teleoperator: (i) the primary display which will show the teleoperator all (camera and other) feeds that she needs to operate the vehicle; (ii) the steering module which allows the teleoperator to operate the vehicle; and (iii) the secondary display which in this case will show a real-time dynamic map of the yard ("helicopter view") along with a textual warning feed. The teleoperation side is governed by the remote station CU which sends the control data to the TOV. The UC-specific CU takes care of elements specific to the UC such as the calculation of the planned path and the tracking error.

The enabling services used within this use-case are the following:

- **ACA (Active Collision Avoidance)**: This is a safety-critical part of the TOV's operation and as such completely embedded within the TOV component. ACA takes the planned path and the tracking error from the UC-specific CU as an input and provides EBA commands to the TOV.
- **ETA info**: This service will provide input on the ETA of the vehicle at the yard, as well as the docking gate to the UC-specific CU. This will allow the UC-specific CU to prepare for the docking. The information on the docking gate, and, more generally, the trigger to provide input toward the UC-specific CU will originate from an external source (e.g. the logistic planner which also sends requests to the TCC). The triggering is, however, out of scope of this project and will be emulated without implementing this element in the technical chain.
- **VRU warning**: On the basis of the planned (TOV) path coming from the UC-specific CU, the GNSS data from the TOV and VRU location data (coming from the LN VRU application), potential conflicts between VRUs and TOVs can be detected. If such a conflict is imminent a warning will be sent towards Be-Mobile which will then show it as a textual feed on the secondary display. At the same time, Locatienet will also make the location data of VRUs available to the yard mapviewer service of IMEC such that detected VRUs can also be displayed on the map.
- **Yard mapviewer**: On the basis of the Distributed Perception enabling function (EF4), and also of the VRU location data from LN, the GNSS data from the TOV, and the planned path and tracking error from the UC-specific CU, IMEC will provide a real-time dynamic map of the yard with detected objects, the location, pose, and tracking error of the TOV displayed. This map will be shown on the secondary screen available to the teleoperator.

3.2.2 Interfaces between Use Cases (WP4) and Enabling Functions (WP6)

The table below provides an overview of the various interfaces between WP4 and WP6 components, with details on the (technical) requirements of each interface and the communication protocol.

Table 4 UC4.2a interfaces between WP4 and WP6.

ID	Description	From	To	Requirements	Protocol
GNSS1	GNSS data from TOV to yard mapviewer	ROB	IMEC	Frequency of at least 10 Hz Json format WGS84 location coordinates with timestamp	ROB Public Gateway
GNSS2	GNSS data from TOV to VRU warning	ROB	LN	Frequency of at least 1Hz Accuracy of 5m (HDOP) WGS84 location coordinates with timestamp CAM format	ROB Public Gateway to LN MQTT Broker
PATH1	Planned path to VRU warning	HAN	LN	Set of WGS84 location coordinates with timestamp describing the path	MQTT Broker

				ETSI VAM format Frequency of at least 1Hz	
PATH3	Planned path and tracking error to ACA	HAN	ROB	Based on local coordinate system defined at the pilot site with a chosen origin Frequency of 30-50Hz NCOM format (proprietary format)	CAN at 1MBaud
DOCK1	Dock number and ETA to yard from ETA info to UC-specific CU	BEM	HAN	Json Sent at least 5 minutes (based on ETA) before arriving at yard, update frequency of 0.1Hz	MQTT Broker
VRU1	VRU location and path from VRU warning to yard mapviewer	LN	IMEC	Set of WGS84 location coordinates with timestamp describing the path ETSI VAM format Frequency of at least 1 Hz	LN MQTT Broker over TCP/IP
VRU2	Imminent collision warning from VRU warning to secondary display	LN	BEM	In DENM format, should contain TOV ID, VRU ID, timestamp and time to collision.	LN MQTT Broker over TCP/IP
SWM1	Map of the yard with detected objects, and location and pose of the TOV	IMEC	BEM	Frequency of at least 1Hz Geojson format	MQTT Broker

3.2.3 Interfaces between application layer (WP4/6) and 5G Network (WP5)

Similar to UC 4.1, the interface between the application layer and the network layer in UC 4.2a involves slicing and the usage of the NWDAF function. The corresponding details are the same as described for UC 4.1 in section 3.1.2.

3.3 UC4.2b – Teleoperated mobile harbour crane

Table 5 Key facts of UC4.2b.

UC4.2b	Teleoperated mobile harbour crane
Description	In UC4.2b a teleoperated mobile harbour crane will be deployed. The crane will be operated from a remote teleoperation control station.
Pilot sites	Vlissingen
EF's	EF6
Partners	HAN, Roboauto, KPN, Sentors, Room40

3.3.1 Application of IDA

The below diagram provides an overview of the application of the IDA to UC4.2b. Some elements have been omitted within each component for clarity. Details on the within-component architecture can be found in the deliverables of WP's 4 and 6.

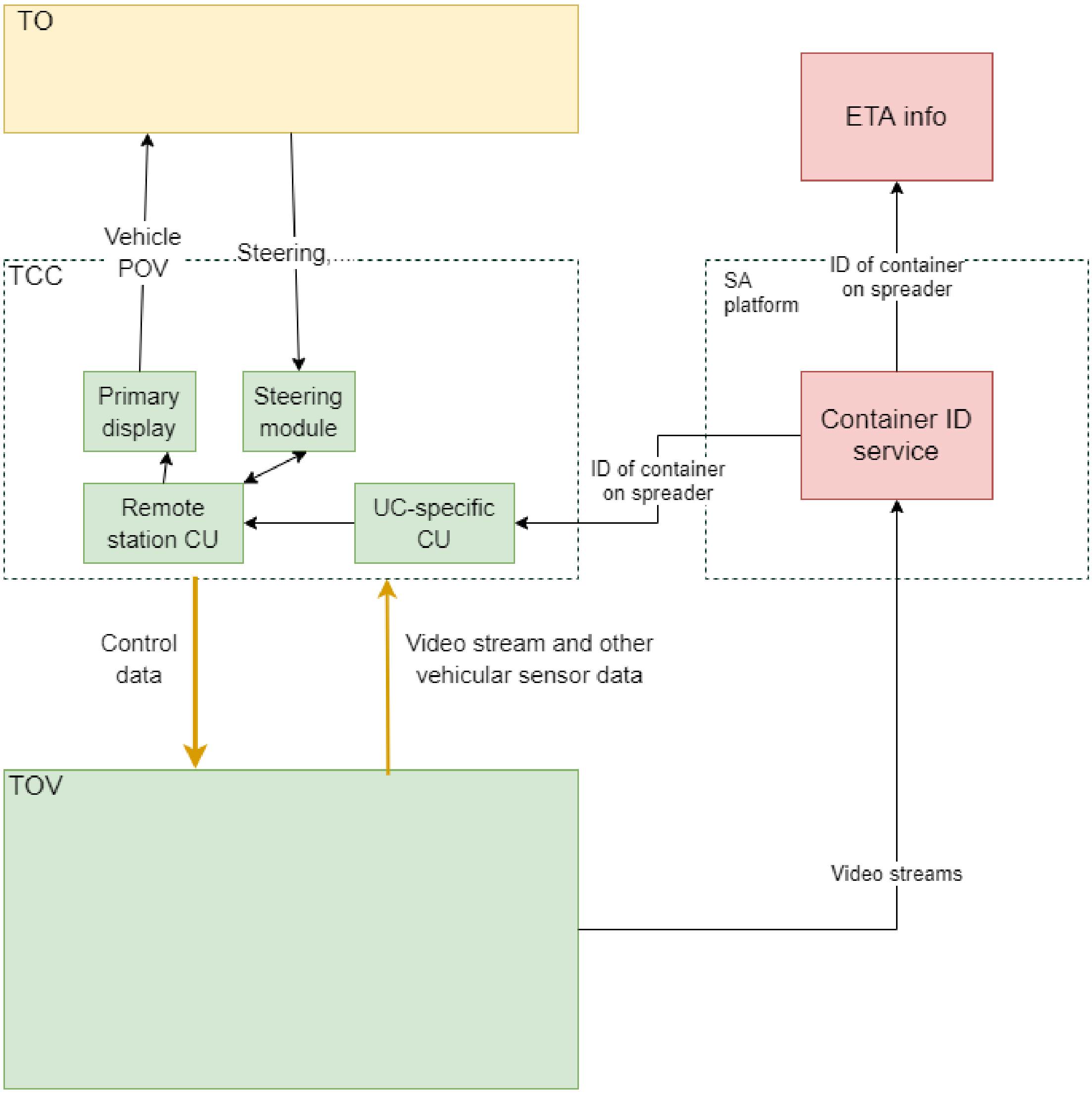

Figure 7 Application of IDA to UC4.2b.

The core of UC4.2b is the TO Centre. The teleoperator will have at her/his disposal (i) monitors to display different point of views required for the operation of the crane; (ii) controls to operate the crane (using similar input/output hardware that is available today in the non-teleoperated version of the crane); (iii) a set of speakers to ensure the teleoperator also receives the auditive feedback required to operate the crane; and (iv) a desktop station to handle and process data as required. The setup will as such be in line with the other UCs: there will be a primary display which will show the teleoperator all feeds that are needed to operate the crane; and the steering module which allows the teleoperator to operate the crane; the teleoperation side is governed by the remote station CU which sends the control data to the leading TOV. The flow of data is bidirectional between the teleoperator and the vehicle. On a discrete step level, the video feed is used by the operator as a first element of input using which he provides input the vehicle using the remote station. This loop repeats itself for every time where the vehicle is in operation. For the enabling function the video feed from the cameras used in the sensor suite of teleoperation will be used to provide the input to the container ID algorithm.

The enabling services used within this use-case are the following:

- **Container ID service**: This service will detect the ID of the container that is being attached to the spreader. The operator of the crane will as such be able to verify that the correct container is being picked up. The container ID service algorithms will run on Room40's

Scene Analytics platform. The information on the container ID can also be shared with other parties, such as the ETA info service.

3.3.2 Interfaces between Use Cases (WP4) and Enabling Functions (WP6)

The table below an overview of the various interfaces between WP4 and WP6 components, with details on the (technical) requirements of each interface and the communication protocol.

Table 6 UC4.2b interfaces between WP4 and WP6.

ID	Description	From	To	Requirements	Protocol
CAM1	Video streams from the crane to the SA platform	ROB	R40	Minimal resolution 960X1280 pixels in RGB color – sufficient to recognize the BIC code; the rule of thumb is that if a human can recognize the code, so can the software. Format: H.264	RTP (MUPEG RFC2435) over UDP
CID1	ID of container on spreader	SEN	ROB	Format: Json as per Datex II standard Update frequency: 1 sec	Websocket server
CID2	ID of container on spreader	SEN	BEM	Format: Json as per Datex II standard Update frequency: 1 sec	Websocket server

3.3.3 Interfaces between application layer (WP4/6) and 5G Network (WP5)

Similar to UC 4.1, the interface between the application layer and the network layer in UC 4.2b involves slicing and the usage of the NWDAF function. The corresponding details are the same as described for UC 4.1 in section 3.1.2.

3.4 UC4.3 – CACC-based platooning

Table 7 Key facts of UC4.3.

UC4.4	Remote takeover operation
Description	UC4.3 foresees deploying and demonstrating teleoperation in a CACC context. In this UC, a vehicle will follow from a short distance a teleoperated lead vehicle using camera and radar systems and vehicle-to-vehicle communication.
Pilot sites	Antwerp, Vlissingen, Zelzate
EF’s	1, 2, 3, 4, 5, 7
Partners	V-Tron, Roboauto, KPN, Telenet, Be-Mobile, SWARCO, Imec, Locatienet, Toyota

3.4.1 Application of IDA

The below diagram provides an overview of the application of the IDA to UC4.3. Some elements have been omitted within each component for clarity. Details on the within-component architecture can be found in the deliverables of WP’s 4 and 6.

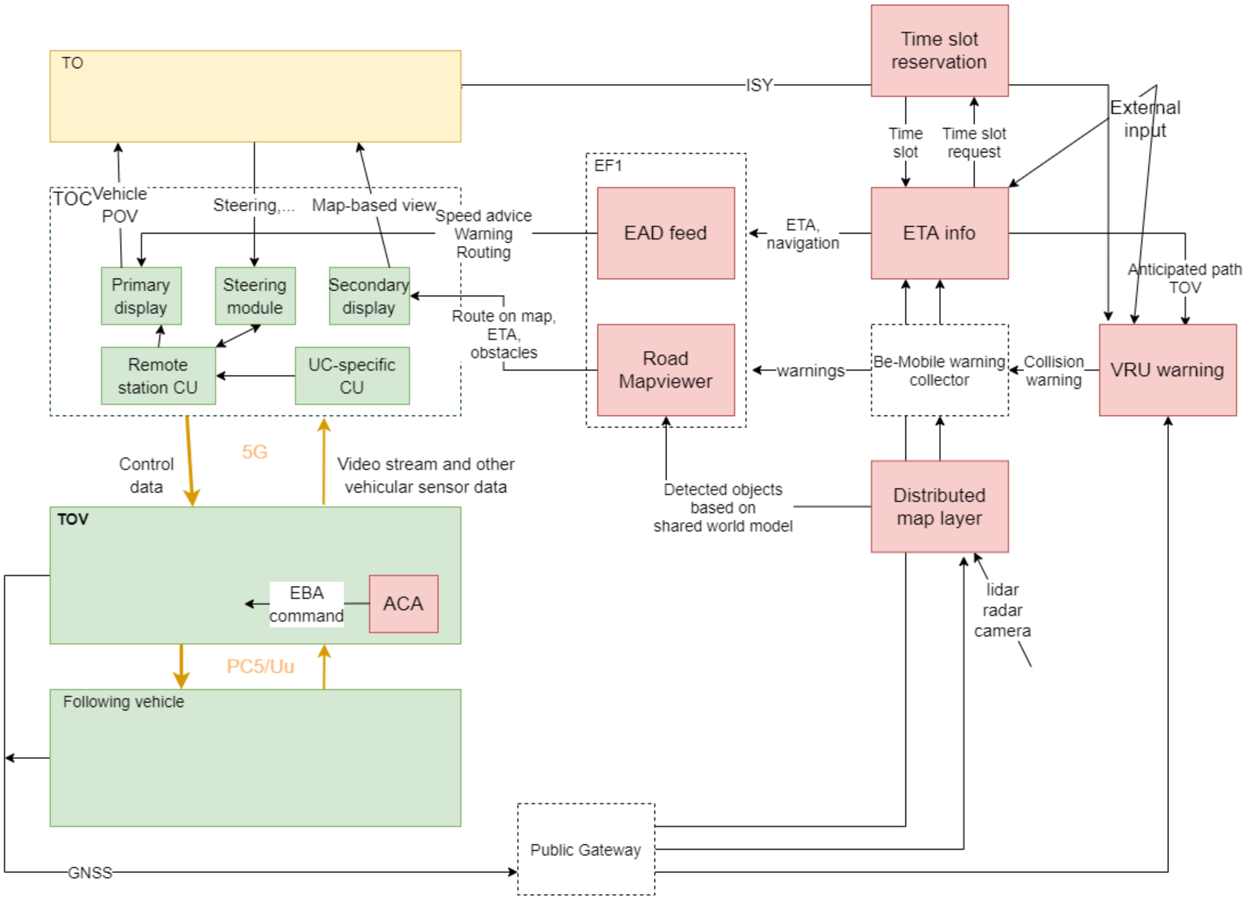

Figure 8 Application of IDA to UC4.3.

The core of UC4.3 is the TO Centre which contains three interfaces towards the teleoperator: (i) the primary display which will show the teleoperator all (camera and other) feeds that she needs to operate the vehicle; (ii) the steering module which allows the teleoperator to operate the vehicle; and (iii) the secondary display which in this case will show a real-time dynamic map of the route along with a textual warning feed. The teleoperation side is governed by the remote station CU which sends the control data to the leading TOV. The UC-specific CU takes care of elements specific to the UC such as taking in the acceleration, braking, and steering data from the other vehicle. The flow of information between the teleoperator and the vehicle remains the same as that described in the UC4.2b. Additionally in UC 4.3 the GNSS data of the vehicle is shared over the public gateway to other enabling functions. The GNSS data in combination with the data from the LIDAR, RADAR and camera on the vehicle is used to provide the roadmap viewer with 3D objects detected which are shown on the EAD. The GNSS data is also used by the ETA info system and the time slot reservation system for traffic lights and the VRU detection system.

The enabling services used within this use-case are the following:

- **ACA**: This is a safety-critical part of the TOV's operation and as such completely embedded within the TOV component. ACA provides EBA commands to the TOV.
- **EAD feed**: This service will provide a feed containing speed advice, warnings, and turn-by-turn navigation advice to the primary display, where it will be shown on a heads-up-display (to be taken care of by Roboauto). The inputs for this service are the ETA, navigation information from the ETA info service (on which basis the speed advice is calculated), and the warnings provided through the Be-Mobile warning collector.
- **Road Mapviewer**: This service will provide a real-time dynamic map of the road network in the immediate vicinity of the TOV's and of the route ahead. The map will be built by using inputs from ETA info, the warning collector, and the Distributed Map layer service.

This map will be shown on the secondary screen available to the teleoperator.

- **ETA info**: This service will provide input on the ETA of the vehicles toward their destination and relevant waypoints, as well as turn-by-turn navigation. The ETA will be determined based on warnings for obstacles ahead of the route (from the distributed map layer and the VRU warning), as well as the iTLC time slot.
- **Time slot reservation**: On the basis of a request made through the ETA info service (and the position and ETA's of the platoon), this service will provide a time slot reservation for greenlighted passage over an intersection. The time slot will be an input for the ETA info service, who will use it to calculate ETA's at relevant waypoints (and within EF1 to calculate speed advice which will allow the platoon to make the time slot).
- **Distributed map layer:** Based on lidar and camera images from the TOV and other vehicles part of the platoon, and also based on the GNSS data from the TOV, IMEC will provide a shared world model with detected objects in the vicinity of the TOV. These detected objects will be shared with the Road Mapviewer service for display on the real-time dynamic map. This map will be shown on the secondary screen available to the teleoperator. The objects will also provide an input for the Be-Mobile warning collector.
- **VRU warning**: Based on the anticipated path of the TOV (coming from the ETA info), the GNSS data from the TOVs and VRU location data (coming from the LN VRU application), potential conflicts between VRU's and TOV's can be detected. If such a conflict is imminent a warning will be sent towards Be-Mobile's warning collector.

3.4.2 Interfaces between Use Cases (WP4) and Enabling Functions (WP6)

The table below provides an overview of the various interfaces between WP4 and WP6 components, with details on the (technical) requirements of each interface and the communication protocol.

Table 8 UC4.3 interfaces between WP4 and WP6.

ID	Description	From	To	Requirements	Protocol
GNSS1	GNSS data from TOVs to ETA info	ROB	BEM	Frequency of at least 1 Hz WGS84 location coordinates with timestamp, one set for each vehicle in the platoon.	ROB Public Gateway
GNSS2	GNSS data from TOV to VRU warning	ROB	LN	Frequency of at least 1Hz Accuracy of 5m (HDOP) WGS84 location coordinates with timestamp for first vehicle in the platoon CAM format	ROB Public Gateway to LN MQTT Broker
GNSS3	GNSS data from TOV to Distributed map layer	ROB	IMEC	Frequency of at least 10 Hz Json format WGS84 location coordinates with timestamp	ROB Public Gateway
EAD1	EAD feed with speed advice, warning and routing from EAD feed to primary display	BEM	ROB	Format: Json as per Datex II standard Update frequency: 1 sec	Websocket server
MAP1	Mapviewer from Road mapviewer to Secondary display	BEM	BEM	Waypoints and metadata & turn by turn Format: Mapbox Update frequency: less than 1 minute	Websocket server
ISY1	ISY message from Teleoperator to VRU warning	ROB	LN	ETSI CPM message	LN MQTT Broker over TCP/IP

3.4.3 Interfaces between application layer (WP4/6) and 5G Network (WP5)

Similar to UC 4.1, the interface between the application layer and the network layer in UC 4.3 involves slicing and the usage of the NWDAF function. The corresponding details are the same as described for UC 4.1 in section 3.1.2.

3.5 UC4.4 – Remote takeover operation

Table 9 Key facts of UC4.4.

UC4.4	Remote takeover operation
Description	UC4.4 foresees the takeover (from standstill) of a vehicle's operations by a teleoperator. The vehicle's, equipped with a 'teleoperation' plugin, are controlled from remote stations by teleoperators at the TO Centre.
Pilot sites	Antwerp, Vlissingen, Zelzate
EF's	1, 2, 3, 4, 5, 7, 8
Partners	V-Tron, Roboauto, KPN, Telenet, Be-Mobile, SWARCO, Imec, Locatienet, Room40, Eurofiber

3.5.1 Application of IDA

The below diagram provides an overview of the application of the IDA to UC4.4. Some elements have been omitted within each component for clarity. Details on the within-component architecture can be found in the deliverables of WP's 4 and 6.

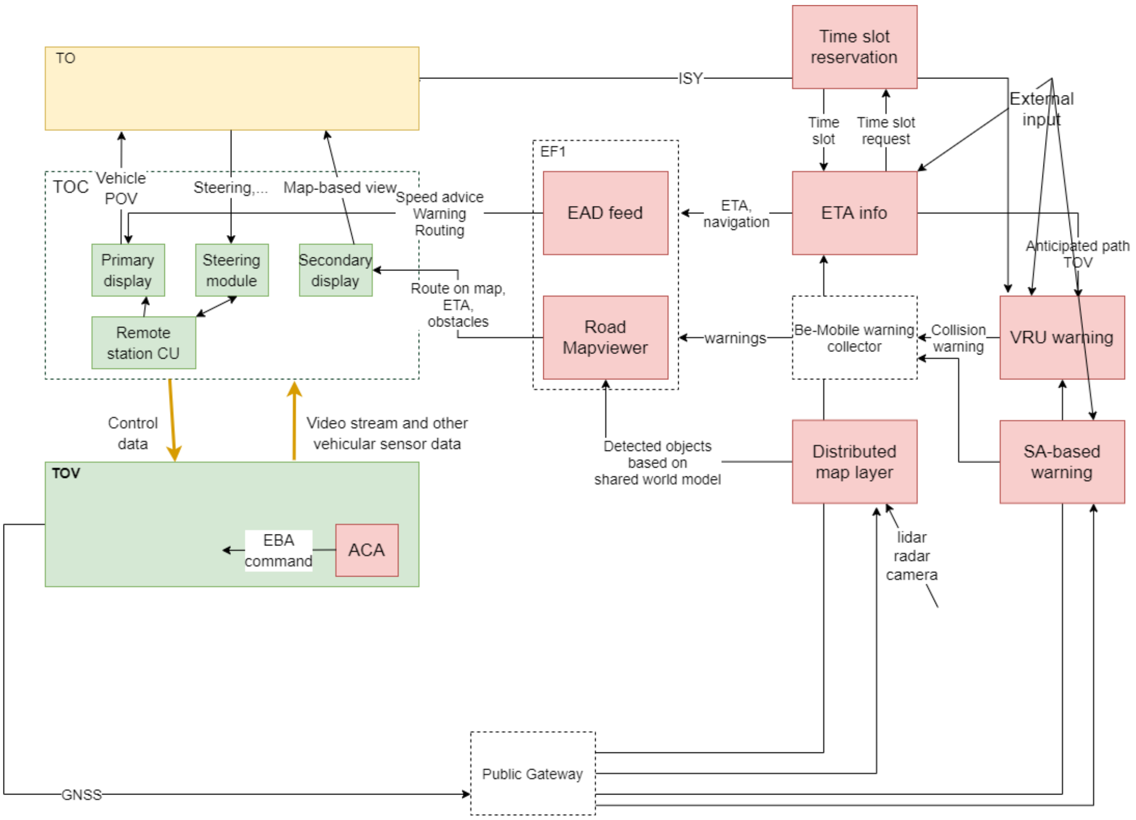

Figure 9 Application of IDA to UC4.4.

The core of UC4.4 is the TO Centre which contains three interfaces towards the teleoperator: (i) the primary display which will show the teleoperator all (camera and other) feeds that she needs to operate the vehicle; (ii) the steering module which allows the teleoperator to operate the vehicle; and (iii) the secondary display which in this case will show a real-time dynamic map of the route along with a textual warning feed. The teleoperation side is governed by the remote station CU which sends the control data to the TO Vehicle. The flow of data remains identical to that described in UC 4.3 section 3.4.1.

The enabling services used within this use-case are the following:

- **ACA**: This is a safety-critical part of the TO Vehicle's operation and as such completely embedded within the TO Vehicle component. ACA provides EBA commands to the TO Vehicle.
- **EAD feed**: This service will provide a feed containing speed advice, warnings and turn-by-turn navigation advice to the primary display, where it will be shown on a heads-up-display. The inputs for this service are the ETA, navigation information from the ETA info service (on which basis the speed advice is calculated), and the warnings provided through the Be-Mobile warning collector.
- **Road Mapviewer**: This service will provide a real-time dynamic map of the road network in the immediate vicinity of the TO Vehicles and of the route ahead. The map will be built by using inputs from ETA info, the warning collector and the Distributed Map layer service. This map will be shown on the secondary screen available to the teleoperator.
- **ETA info**: This service will provide input on the ETA of the TO Vehicle towards its destination and relevant waypoints, as well as turn-by-turn navigation. The ETA will be determined on the basis of warnings for obstacles ahead of the route (from the distributed map layer and the VRU warning), as well as the iTLC time slot.
- **Time slot reservation**: On the basis of a request made through the ETA info service (and the position and ETAs of the TO Vehicle), this service will provide a time slot reservation for greenlighted passage over an intersection. The time slot will be an input for the ETA info service, who will use it to calculate ETAs at relevant waypoints (and within EF1 to calculate speed advice which will allow the platoon to make the time slot).
- **Distributed map layer**: Based on lidar and camera images from the TO Vehicle and other vehicles, and also based on the GNSS data from the TOV, IMEC will provide a shared world model with detected objects in the vicinity of the TOV. These detected objects will be shared with the Road Mapviewer service for display on the real-time dynamic map. This map will be shown on the secondary screen available to the teleoperator. The objects will also provide an input for the Be-Mobile warning collector.
- **VRU warning**: On the basis of the anticipated path of the TOV (coming from the ETA info), the GNSS data from the TOVs and VRU location data (coming from the LN VRU application), potential conflicts between VRUs and TOVs can be detected. If such a conflict is imminent a warning will be sent towards Be-Mobile's warning collector.
- **SA-based warnings:** On the basis of Scene Analytics which takes CCTV, sound data and other sensors as input, along with TOV streams and GNSS data, real-time incident warnings will be created, which will then be sent to Be-Mobile's warning collector.

3.5.2 Interfaces between Use cases (WP4) and Enabling Functions (WP6)

The table below provides an overview of the various interfaces between WP4 and WP6 components, with details on the (technical) requirements of each interface and the communication protocol.

Table 10 UC4.4 interfaces between WP4 and WP6.

ID	Description	From	To	Requirements	Protocol
GNSS1	GNSS data from TOVs to ETA info	ROB	BEM	Frequency of at least 1 Hz WGS84 location coordinates with timestamp, one set for each vehicle in the platoon.	ROB Public Gateway
GNSS2	GNSS data from TOV to VRU warning	ROB	LN	Frequency of at least 1Hz Accuracy of 5m (HDOP) WGS84 location coordinates with timestamp for first vehicle in the platoon CAM format	ROB Public Gateway to LN MQTT Broker
GNSS3	GNSS data from TOV to Distributed map layer	ROB	IMEC	Frequency of at least 10 Hz Json format WGS84 location coordinates with timestamp	ROB Public Gateway
GNSS4	GNSS data from TOV to SA-based warnings	ROB	R40	Frequency of at least 1 Hz WGS84 location coordinates with timestamp, one set for each vehicle in the platoon.	ROB Public Gateway
EAD1	EAD feed with speed advice, warning and routing from EAD feed to primary display	BEM	ROB	Format: Json as per Datex II standard Update frequency: 1 sec	Websocket server
MAP1	Mapviewer from Road mapviewer to Secondary display	BEM	BEM	Waypoints and metadata & turn by turn Format: Mapbox Update frequency: less than 1 minute	Websocket server

3.5.3 Interfaces between application layer (WP4/6) and 5G Network (WP5)

Similar to UC 4.1, the interface between the application layer and the network layer in UC 4.4 involves slicing and the usage of the NWDAF function. The corresponding details are the same as described for UC 4.1 in section 3.1.2.

4 CONCLUSION

This document describes the first version of our systems architecture. It is meant to be further improved in D7.3. Here, we have presented the initial defined architecture, where we mapped the building blocks according to the use cases and the enabling services. We have presented the diagrams according to each use case, where we can see the enabling services supporting the use cases.

The next steps in the Work Package 7 are to integrate the blocks presented in the architecture so that they are ready to be deployed for the minimum viable platform (MVP). In addition, we will also analyse how these integrated blocks in the architecture are applicable on the pilot sites, which is in line with the work on task T7.3 of the project. This work will be documented in the deliverable D7.2. On the other hand, the refined architecture will take the lessons learned and will be presented in D7.3.

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