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5G BLUEPRINT

Next generation connectivity for enhanced, safe & efficient transport & logistics

D7.2: Platform Integration and Minimum Viable Platform

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Abstract

This deliverable describes the integration and piloting efforts which were executed in Work Package 7 (WP7) of the 5G-Blueprint project for the Minimum Viable Platform (MVP) phase. The MVP phase in general means that a subset of 5G-Blueprint components (use case and enabling functions) are integrated and tested over 5G network, while full set of integration and piloting is envisioned for the final platform deployment. This deliverable focuses on integrating all the components developed within the technical WPs (4, 5, and 6), towards creating an initial integrated pilot environment towards full end-to-end solutions for tele-operated driving using 5G network connectivity. It provides insights into i) what MVP means per use case, enabling function and 5G network, ii) Key Performance Indicators (KPIs) defined for performance evaluation, iii) results and performance evaluation of use cases and enabling functions over 5G during the MVP phase, and iv) outlook towards piloting activities planned for cross-border scenarios and the third year of the project.

Keywords: Minimum Viable Platform, Integration, Piloting, 5G

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Nature of the deliverable:	R	
Dissemination Level		
PU	Public, fully open, e.g. web	√
CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to 5G-Blueprint project and Commission Services	

* R: Document, report (excluding the periodic and final reports)
  DEM: Demonstrator, pilot, prototype, plan designs
  DEC: Websites, patents filing, press & media actions, videos, etc.
  OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

This deliverable describes the efforts which were executed in Work Package 7 (WP7) of the 5G-Blueprint project, and it focuses on integrating all the components developed within the technical WPs (4, 5, and 6), towards creating an initial integrated pilot environment towards full end-to-end solutions for tele-operated driving using 5G network connectivity. More specifically, this deliverable is documenting the development of so-called **Minimum Viable Platform (MVP)**, and it details on the MVP deployment and testing within two pilot sites, i.e., the Verbrugge Terminals at Vlissingen (The Netherlands) and Port of Antwerp Bruges (Belgium), combining the Use Case applications, 5G network connectivity, and Enabling functions whose role is to enhance the use case operations. Following the 5G network development and cross-border roaming mechanisms' enhancements in WP5, WP7 defines two main phases of integration and testing, i.e., i) MVP phase that includes the integration and testing activities of all use cases and a subset of enabling functions in the in-country pilot sites, i.e., Vlissingen (the Netherlands), and Antwerp (Belgium), which is the focus of this deliverable, and ii) final platform phase that includes the integration and testing of all use cases and enabling functions in all three pilot sites, with the special focus on the Zelzate pilot site and the impact of roaming procedures on the teleoperation performance.

At first instance, the deliverable introduces the overall 5G-Blueprint infrastructure, illustrating the all network and teleoperation system components from an end-to-end perspective, thereby spanning i) User Equipment (UE) that is including the variety of end users that are included in the project, such as trucks, skid steers, barges, and cars, ii) Radio Access Network (RAN) that consists of 5G Non Standalone (NSA) and Standalone (SA) base stations, i.e., gNodeBs, deployed within the designated pilot sites (Vlissingen, Antwerp, Zelzate), iii) transport network that connects RAN and 5G Core, iv) 5G Core for the 5G SA network deployment, including the extended roaming capabilities to support seamless connectivity when crossing the border between Belgium and the Netherlands, and finally v) the data network that provides cloud/edge services that support teleoperation through the deployment of use cases and enabling functions. Furthermore, Section 1 provides an overview of the three pilot sites, illustrating their scope in terms of use cases' and enabling functions' deployment, 5G network availability (release, frequency range), and their geographical locations.

From Section 2 onwards, the deliverable focuses on the MVP phase of the overall platform deployment. In Section 2, we describe what is considered as MVP on a Use Case level, 5G Network connectivity level, and Enabling Function level and how all of these MVP instances will be expanded towards the full pilot deployment (which will be reported in future deliverable D7.4). Furthermore, in Section 3, we present the methodology of defining Key Performance Indicators (KPIs) in the 5G-Blueprint project, thus, defining three levels: vertical KPIs (measuring performance of use cases), 5G KPIs (measuring performance of 5G NSA/SA network), and vertical enhancements' KPIs (measuring performance of enabling functions either as standalone or integrated components). Each of those KPI groups is being defined, with KPI target values and the testing time planning.

In Section 4, we further focus on the testing performed within the project. Before testing in the pilot sites, partners opted for the lab testing phase, which included testing of the teleoperation functionalities on their premises, and afterwards in Helmond area, which is a confined area with 5G SA coverage. In this deliverable, we only provide a brief overview of lessons learned from the initial lab testing, which provided helpful experience and input for the pilot testing. However, we focus more on the pilot testing activities, and the initial MVP results obtained in Vlissingen and

Antwerp. In particular, Section 4 describes the tests, including the test results of MVP for both pilot sites, documenting how the experimental measurements successfully met expected KPI target values. The deliverable is concluded with Section 5, where we provided an outlook on the pilot planning for the upcoming months, and until the end of the project. Finally, we conclude the document summarizing the main achievements from the MVP phase.

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ABBREVIATIONS

ACA	Active Collision Avoidance
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CCU	Central Control Unit
DENM	Decentralized Environmental Notification Message
E2E	End-to-End
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
ISY	I See You message
MEC	Multi-Access Edge Computing
MIoT	Massive Internet of Things
mMTC	massive Machine Type Communication
MQTT	Message Queuing Telemetry Transport
MVP	Minimum Viable Platform
NWDAF	Network Data Analytics Function
OBC	On-Board Computer
OBU	On-Board Unit
PLMN	Public Land Mobile Network
POV	Point-Of-View
PTC	Path Tracking Controller
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSCU	Remote Station Control Unit
SINR	Signal to Interference Noise Ratio
TO	Tele-operator
TOV	Tele-operated Vehicle

UC	WP4 Use-Case
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communication
VAM	VRU Awareness Message
V2X	Vehicle to Everything (communication)
VRU	Vulnerable Road User
WP	Work Package

1 INTRODUCTION

This deliverable is part of the documentation of the works on WP7, which is responsible for the integration of the effort developed in WP4 [1] [2] [3], WP5 [4] [5], WP6 [6] [7], and for managing the piloting activities. The goal of the document is to provide an insight into the development of the Minimal Viable Platform (MVP) and an integration effort executed in WP7 which should be used a basis for seamless evolution towards the final pilot. The list of all Use Cases (UCs) and Enabling Functions (EFs) is presented in Table 1 and Table 2. In addition, this deliverable is heavily based on the System Test Plan (STP), System Test Description (STD) and System Test Results (STR), being the living documents established in WP7. We use the latest snapshot of these documents with reference to the MVP phase of testing as a baseline for the deliverable.

In Section 2, this document provides a description of the MVP per Use Case (UC) defined by WP4, Enabling Function (EF) defined by WP6, and the Network defined by WP5. Furthermore, in Section 3, the Key Performance Indicators (KPI) are described for each UC, EF, and Network along with expected target values. In Section 4, we provide a high-level description of the tests that integrate specific networks and enabling functions into specific use cases according to the matrix shown in Table 3.

Table 1 List of Use Cases (UCs).

Use case ID	Full name
UC4.1	Automated barge control
UC4.2	Automated driver-in-the-loop docking
UC4.3	Cooperative Adaptive Cruise Control (CACC)-based platooning
UC4.4	Remote takeover

Table 2 List of Enabling Functions (EFs).

Enabling Function ID	Full name
EF1	Enhanced Awareness Dashboard
EF2	Vulnerable Road User (VRU) Interaction
EF3	Time Slot Reservation at Intersections
EF4	Distributed Perception
EF5	Active Collision Avoidance
EF6	Container ID Recognition
EF7	Estimated Time of Arrival (ETA) Sharing
EF8	Scene Analytics

Subsequently, the tests will be executed to obtain the data enabling quantification of KPI per UC, EF, and Network. In Section 4, we also present the test results obtained within the MVP setup, and we discuss if the targets of all measured KPIs were met.

In this section, we present the features of an initial technical blueprint for 5G-supported teleoperation of vehicles, trucks, barges, and skid steers, thus, detailing on the network architecture that is leveraging on 5G connectivity elements in both in-country and cross-border pilot sites. Such a blueprint is being tested and validated in the real-life environments, i.e., pilot sites that involve busy port areas such as Vlissingen and Antwerp, focusing also on the cross-border scenarios between Belgium and the Netherlands.

Table 3 Integration of 5G Network and Enabling Functions into Use Cases on the MVP level.

Integration	UC4.1	UC4.2	UC4.3	UC4.4
KPN 5G		X	X	X
Telenet 5G	X			
EF1			X	X
EF2				X
EF3				
EF4			X	X
EF5				X
EF6				
EF7		X	X	X
EF8				

1.1 5G-Blueprint Architecture

The high-level overview of the overall network architecture designed and leveraged upon in the 5G-Blueprint project is shown in Figure 1. Starting from the User Equipment (UE) side, we use either proof-of-concept or commercial cars, trucks, barges, skid steers, and reach stackers, depending on the use case and the testing scenario during the integration and piloting activities of teleoperation in both in-country and cross-border pilot sites. Such UEs are equipped with 5G communication capabilities (5G modem and necessary antennas), sensors, and Central Control Unit (CCU) that executes the commands sent by the tele-operator. As such, UEs produce the High Definition (HD) video and sensor data that needs to be processed by teleoperation cloud services and enabling functions (either running on the cloud or on the network edge), thereby requiring Ultra-Reliable Low-Latency (URLLC) and enhanced Mobile Broadband (eMBB) connectivity.

All the aforementioned data traffic is then transferred through 5G Radio Access Network (RAN) and transport, to the core network (via 3GPP N3 reference point). This activity leverages on the defined end-to-end network slices (both URLLC and eMBB). In the next step, the HD video feed and sensor data are processed by additional services running in the cloud, and then sent to the teleoperation center that remotely monitors data and further steers/controls the vehicle/barge remotely, thus, sending the control commands to the UE's Central Control Unit (CCU). The detailed network requirements for each of our use cases, considering both the uplink communication for transferring HD video data and the downlink one for control commands from the tele-operator to the tele-operated vehicle/barge, are presented in [8].

Concerning the roaming scenarios, to achieve session and service continuity across the border between Belgium and the Netherlands, we are taking various approaches on extending the roaming mechanisms, as well as the state-of-the-art 5G core components and their interaction between different mobile network operators. As this task is challenging, a more detailed overview of interaction between 5G SA core components, such as Access and Mobility Management Function (AMF), Session Management Function (SMF), User Plane Function (UPF), and Network Slice Selection Function (NSSF), between two domains, is part of our ongoing research and development activities, which will be presented in WP5 deliverables.

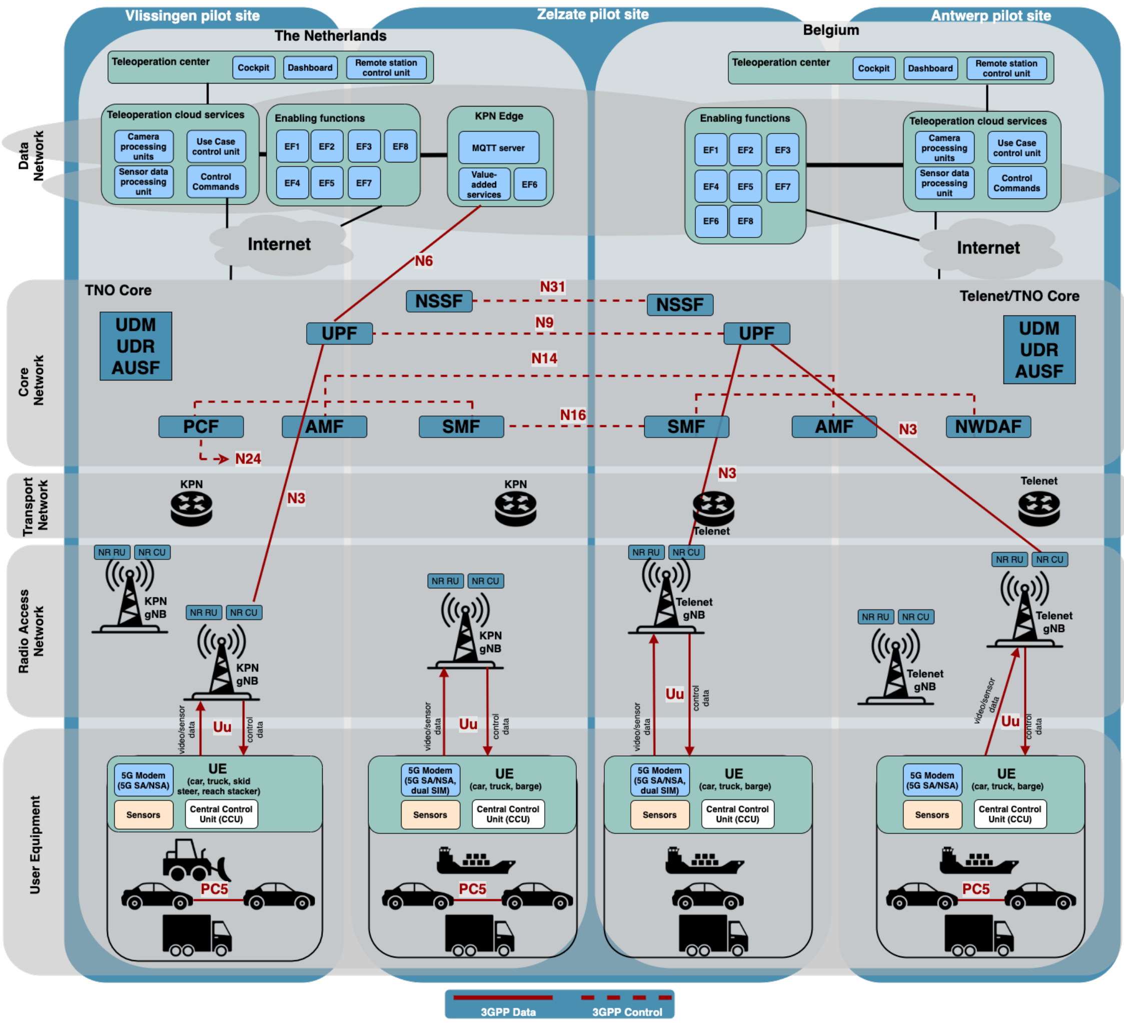

Figure 1 5G-Blueprint architecture.

1.2 5G-Blueprint pilot sites

In this section, we briefly introduce each of the three pilot sites designed and developed within the 5G-Blueprint project. The locations of all three pilot sites are presented in Figure 2, which shows the locations and the scope of each of the pilot site, i.e., the functionalities enabled in each of them.

1.2.1 Vlissingen pilot site (The Netherlands)

Vlissingen pilot site has network coverage for both 5G Non-Standalone (NSA), and Standalone (SA) test network, and as such, it is being extensively used for piloting Use Cases Automated driver-in-the-loop docking (4.2), CACC-based platooning (4.3), and Remote takeover (4.4). In particular, 5G NSA network is provided at 700MHz (anchored 1800MHz), while SA is at 3.5GHz, with four gNodeBs in total. The overview of this pilot site is presented in Figure 3. The pilot site consists of three locations.

First of them is the terminal of MSP onions at Nieuwdorp, which offers sufficient space and flexibility to deploy and test automated driver-in-loop docking. This test site contains a docking area with five docking stations, and a parking lot where trucks and cars can park or maneuver. Second is the Verbrugge Scaldia Terminal, where the teleoperation of cars, trucks, and skid steers, is being performed, while being isolated from the personnel at the terminal.

The driving tests for use case 4.3 are performed on the public road in the terminal area, as well as in the confined area within the terminal where a maximum speed of 25km/h is possible, due to the pedestrians and terminal vehicles randomly crossing the path of the teleoperated vehicles. Finally, the third site stretches the public road from the MSP Onions terminal to the Kloosterboer terminal, where the shadow-mode testing of use cases 4.3 and 4.4 is taking place.

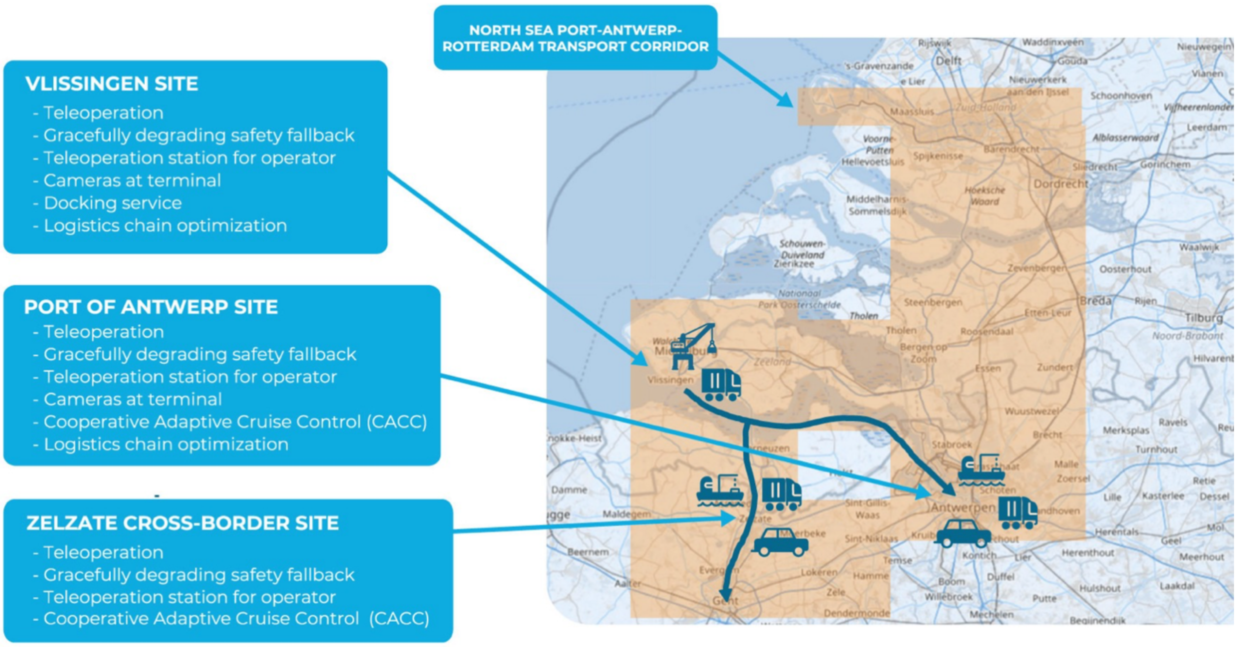

Figure 2 The overview of the pilot site locations and their scope.

1.2.2 Antwerp pilot site

Antwerp pilot site combines two locations with both 5G NSA and SA coverage. In particular, 5G NSA and SA are provided on the shared commercial infrastructure (four gNodeBs in total), SA at 3.5GHz, with NSA at 2.1GHz and 3.5GHz. The overview of locations is shown in Figure 4.

The first one refers to the Right bank of the Port of Antwerp Bruges, where the shadow-mode teleoperated navigation (UC4.1) is being performed on a commercial barge that sails from Liege to Antwerp on a weekly basis. The second location is the Transport Roosens Kallo site, which is a hub for picking up and dropping off containers from depots located at the MPET and Medrepair terminals on the Schelde's left bank at Port of Antwerp Bruges. On this location of the pilot site, both shadow-mode testing and real teleoperation on the closed roads is planned.

Figure 3 Vlissingen pilot site: MSP Onions docking states (left), and Scaldia Verbrugge Terminal (right).

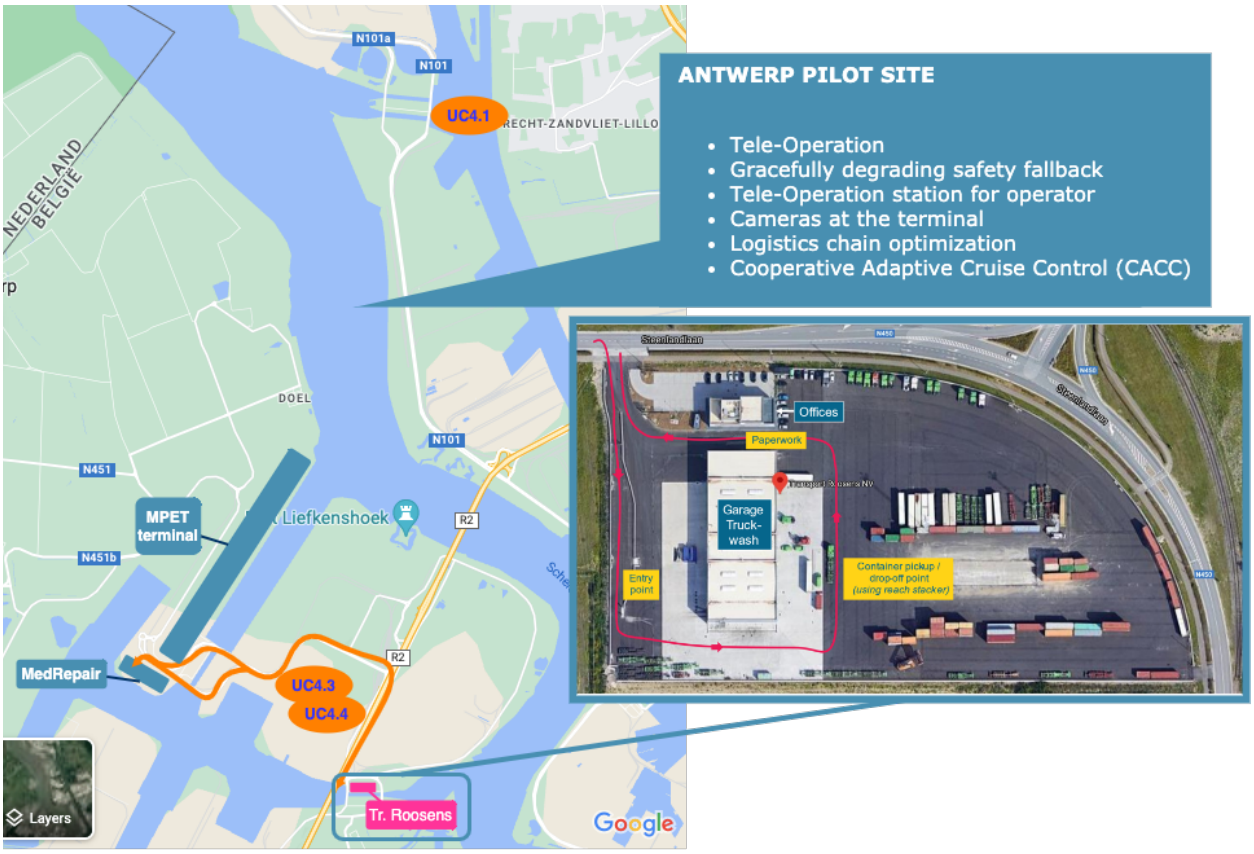

Figure 4 Antwerp pilot site: Transport Roosens Kallo site and the Right bank of the Port of Antwerp Bruges.

1.2.3 Zelzate pilot site

Zelzate pilot site is the most challenging pilot site in terms of network connectivity tests as it spans two countries, i.e., the Netherlands and Belgium, and as such, it requires further extensions of the 5G Core network functionalities of both mobile network operators towards enabling session and service continuity when crossing the border. Currently, there is one gNodeB installed at the Dutch side of the border (SA @ 3.5GHz), and another one at the Belgian side (SA @ 3.5GHz). The scope and the diversity of piloting activities are illustrated in Figure 5.

For automated barge control operations, the barge will be sailing through the canal Gent-Terneuzen, which contains a bridge on the border between two countries. This bridge is an important obstacle in terms of connectivity due to which the piloting of Use Case 4.1 needs to switch from an automated mode to teleoperation. Furthermore, for piloting use cases 4.3 and 4.4, we defined a detailed cross-border trajectory that contains a significant variety in environmental conditions as for instance an urban center, a rural area/industrial area and a highway segment – all together frequented by personal cars, trucks, pedestrians and bikers.

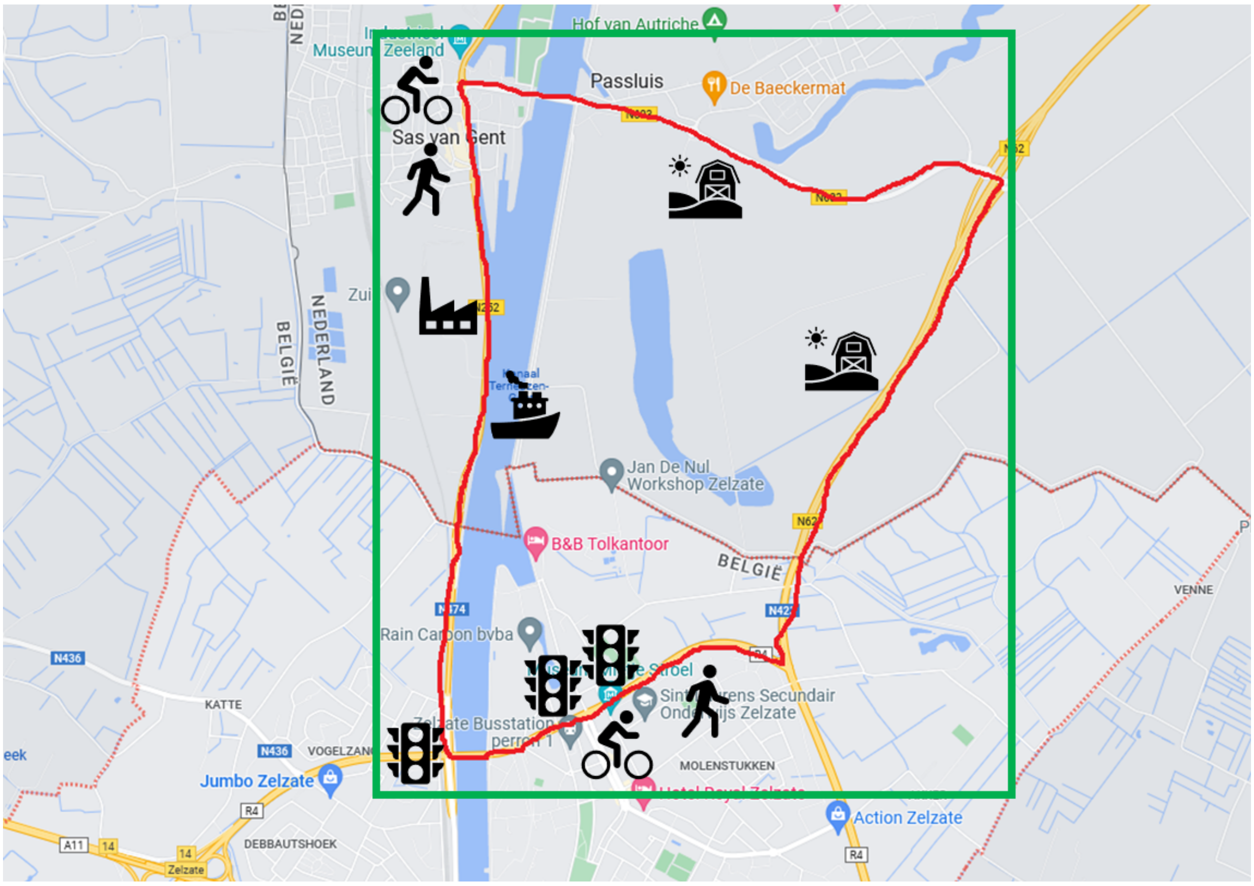

Figure 5 Zelzate pilot site.

2 DESCRIPTION OF THE MINIMUM VIABLE PLATFORM (MVP)

In this section, the description of the Minimal Viable Platform, i.e., MVP, will be provided on three different levels being the Use Case, the Enabling Function, and the Network. In Table 4, a brief description is given for all UCs and EFs along with the expected goals and explanation how the MVP will be extended towards the final deployment until the end of the project.

Table 4 MVP specification per component.

Component ID	MVP Specifications
UC4.1	***Description of MVP:*** MVP of the Automated Barge Control Use Case is to add the 5G capabilities to the current 4G design. The vessel is equipped with the Seafar remote control installation to control it from the Seafar Shore Control Center. This installation is extended with a 5G router to test the added value for security, border crossing, navigation and camera feed. The UC4.1 MVP is tested in the Antwerp pilot site. ***What are Goals of MVP:*** The goals of the MVP for UC4.1 are: i) to test the remote-controlled vessel with higher video quality to enhance the operational security by faster detection of dangerous situations, and ii) to validate the goals and the 5G solution by measuring the connection with the KPIs listed in Section 3. ***How to extend MVP towards the final platform:*** The following steps in the project are to keep monitoring the 5G solution and quality with different external factors like weather, a high vessel between the 5G router and the 5G antenna, substantial height of container stack on board own vessel, and lock-passage. Next to that, cross-border tests are planned to test the switch between providers without connection loss.
UC4.2a	**Description of MVP:** MVP of the Automated Driver-in-the-Loop Docking Use Case includes scaled vehicle combination of tractor and semitrailer (1:3). The vehicle combination is equipped with real time localization system and can be remotely operated in terms of longitudinal and lateral movement through traction motor, and steering angle actuator, respectively.

Figure 6 Scaled truck used in UC4.2a.

MVP further includes the Teleoperation Center (TOC), which is equipped with steering wheel, gas and brake pedals, number of screens and hardware ensuring the communication with vehicle combination. As a signal carrier 4G or 5G connection can be used provided by the network provider (KPN).

Figure 7 TOC for UC4.2a.

By this way, the actuation of vehicle can be done in two ways:

- open-loop engaging the driver, who controls the steering wheel and the pedals in the based on the visual input obtained in TOC (normal teleoperation)
- closed-loop engaging the Use Case dedicated control unit which is responsible for the planning of the reference path and subsequent path execution by controlling the speed and the steering angle of the scaled vehicle combination (automated teleoperation)

Given the size of real vehicle combination the MVP on the scaled level offers more flexibility when it comes to the testing activities and development of the functionalities for dedicated control unit. The UC4.2 MVP is tested in the Vlissingen pilot site.

What are Goals of MVP:

The goal of MVP of UC4.2a is to test technical KPIs defined and explained

	in the Section 3, during the tests described extensively in the System Test Plan. Successful completion of the KPIs on the scaled level provides a solid basis for implementation of EFs into UC on the full-scale level in the final platform. Additionally, the goal of MVP is to integrate EF7, which is in case of UC 4.2a responsible for providing the loading dock #id begin the final destination, where the semitrailer should be docked. During all the tests, 5G connectivity between TOC and the vehicle is established. ***How to extend MVP towards the final platform:*** All control-based hardware from the scaled truck, including the localization system must be transferred and re-integrated into the full-scale DAF tractor which is final platform for Use Case deployment. Furthermore, the Control Unit algorithms will be modified to the new dimensions of the vehicle combination and remaining Enabling Functions, namely EF1, EF2, EF4, and EF5, will be integrated.
UC4.3	***Description of MVP:*** For the MVP phase, Cooperative Adaptive Cruise Control-based platooning are demonstrated with test vehicles in a closed environment with no traffic. Both the lead and the following vehicle are equipped with C-V2X communication capabilities. Additionally, the following vehicle is equipped with sensors to measure the headway distance to the vehicle in front. The On-board unit in the lead vehicle acquires and communicates the acceleration and speed data through C-V2X to the following vehicle. The on-board unit in the following vehicles receives this data and sends it to the controller. Based on this received data and actual distance to the lead vehicle, the controller algorithm computes the required acceleration that the following vehicle should have, to maintain the desired headway distance to the lead vehicle. The UC4.3 MVP is tested in the Vlissingen pilot site. ***What are Goals of MVP:*** The main goal of the MVP is to test the functionality of the UC4.3 and V2V communication performance. The test is carried out with both WiFi-P and C-V2X communication. A comparison between the stock Adaptive Cruise Control (ACC) and the developed CACC system is performed to benchmark the results. In addition, the safety criteria is also be tested. ***How to extend MVP towards the final platform:*** For the MVP phase, the CACC based platooning demonstration is performed on a closed environment with no real traffic. Furthermore, the platooning speed is limited to 60 Kmph for safety measures, which will be increased to 90-100 Kmph in the next phase of testing. For the MVP only the longitudinal control will be tested, and the lateral control will be added for the final platform. Also, the cross-border

	demonstration (in real traffic condition) will be performed for the final platform.
UC4.4	***Description of MVP:*** MVP for the Remote Takeover Use case, i.e., teleoperation, revolves around operating a vehicle remotely– by setting up adequate steering, throttle and brake controls, and ensuring continuous connectivity required for life data feeds. The vehicle, equipped with teleoperation hardware, is remotely operated by a driver over 5G network. The remote driver is in control of the vehicle by means of a teleoperation rig, equipped with steering wheel, throttle and brake pedals; the video feed coming from the vehicle's on-board cameras is displayed on three screens placed in front of the remote driver. This setup allows for a realistic driving experience, with little need for adaptation on the remote driver's behalf. The remote station setup sends the control inputs over 5G network to a controller placed inside the vehicle, which elaborates it, and translates it to signals that are able to control the actuators in the vehicle. The safety driver, who is inside the driven vehicle at all times, has the ability to take back control of the vehicle by manually depressing a safety switch, which enables again complete control over the vehicle. The UC4.4 MVP is tested in the Vlissingen pilot site. ***What are Goals of MVP:*** The goals of the tests within MVP phase are to evaluate the remote drivability of the vehicle, as well as the stability of the 5G network. The tests assess the capability of the system in terms of reliability, robustness and safety. These tests are carried out by remotely connecting the vehicle to the remote station, and by checking that the steering, throttle and brake control work independently. Once it is established that the systems work as they should, the remote driver operates the vehicle in a closed circuit, as to determine the overall drivability. Very low latency and control accuracy are highly desired in order to retain a realistic driving experience. ***How to extend MVP towards the final platform:*** The final platform for the teleoperated passenger vehicle will be extended to work also in conjunction with the CACC system developed for UC4.3. This will enable a more integrated way of operating this type of vehicles, especially when paired to the associated EFs. The remote operation system developed for the passenger vehicle will be taken as a basis to be also applied on the DAF XF truck. The final platform for the teleoperated truck, also in conjunction with the autodocking system developed for UC 4.2a. This will enable a more integrated way of operating this type of vehicles, especially when paired to the associated EFs.

<table>
<tr><td>EF1</td><td>Description of MVP:
The Enhanced Awareness Dashboard (EAD), EF1, collects all relevant information and warning messages from other EFs (EF2, EF4, EF6, EF7, and EF8), and displays them on a Be-Mobile map. More precisely, the following information should be present on this map:
Basic GNSS data: current position, speed, and heading.
EF2: based on the VRU Awareness Message (VAM) messages from Locatienet, the predicted trajectory of all VRUs in the neighborhood of the TOV is regularly updated and all predicted collisions (in the DENM messages) are clearly shown
EF4: all detected obstacles (pedestrian, vehicle, car) are plotted in 3D on the map and regularly refreshed (<1s) such that the TO clearly sees where an obstacle has been detected. Yardview and detected objects are integrated in EAD, but still containing stimulated data in the MVP. Thus, the chain is tested, but not full functionality during MVP.
EF6: when the container id is detected by EF6, it is displayed on the EAD to inform the TO.
EF7: route information, turn-by-turn instructions, ETA and speed information (max + advice) are clearly visible and updated while driving.
EF8: When an anomaly is perceived by EF8 (or when no anomaly is present), the latest status of this anomaly is shown as an information message on the EAD. Moreover, live video stream is displayed on EAD.
The EF1 MVP is tested in both Antwerp and Vlissingen pilot sites.

What are Goals of MVP:
The goal is to test a subset of KPIs defined in Section 3, i.e., testing the efficiency of displaying the relevant information from different UCs and EFs2, as described above.
How to extend MVP towards the final platform:
No further developments will be done on the current EF, only deployment of EF3 on EF1. Further evaluation of EF1 will be performed, focusing on the set of KPIs identified and presented in Section 3.</td></tr>
<tr><td>EF2</td><td>Description of MVP:
The VRU Interaction, i.e., EF2 is fully functional in road, and as such it can be tested with emulated and live TOV data. Compared to the final platform, only the so-called “I See You (ISY)” message and integration with EF3 will not be included in the MVP.

The Vectordrive app on a 5G handset continuously reports its location, by using Cooperative Awareness Messages (CAMs) on the Message Queueing Telemetry Transport (MQTT) service in a quadtree structure. The app subscribes to path messages (VAM) of TOVs in nearby quad tiles. If it receives one or more path messages of TOVs, the app will calculate all possible paths of the VRU, select the most likely path, and post likely path</td></tr>
</table>

	messages (with 1Hz frequency) on the MQTT system. Depending on the path likelihood update, the app determines whether the likely path intersects, in space and time, with the paths of all nearby TOVs. In case a conflict is detected the site and time of the potential collision are published on the MQTT service as Decentralized Environmental Notification Message (DENM) (which are presented to the TO by EF1). The EF2 MVP is tested in the Vlissingen pilot site. ***What are Goals of MVP:*** ● Test core functionality of the app and cloud service ● Test integration with EF1 (and indirectly with UC4.4) ***How to extend MVP towards the final platform:*** ● No additional development is foreseen; the ISY and iTLC functionality have been dropped in favor of more elaborate 5G trials. ● More testing of this enabling function is planned, as defined in Section 5.
EF3	***Description of MVP:*** No MVP implementation of Time Slot Reservation at Intersections, i.e., EF3 has been tested in the pilot environment since the traffic lights hardware was not yet upgraded to the one needed to run the software of this EF. It has been developed and tested in the lab environment. Main features are: ● Test conflict-less crossing of intersection by teleoperated vehicles by providing a time slot for 'green-lighted passages', thereby reducing the likelihood of collisions and ensuring smooth navigation of the intersection by truck platoons. ● Test integration with EF7 Thus, EF3 will be fully utilized in the final implementation of the platform. ***How to extend MVP towards the final platform:*** ● No additional development is foreseen; Extension of the priority request will be tested to enable the iVRI to give an alternative time slot for an approaching platoon. ● More testing of this enabling function is planned, as defined in Section 5.
EF4	***Description of MVP:*** The MVP of Distributed Perception, i.e., EF4, aims to ensure that the system can work synchronously as a whole where point cloud data can be broadcasted from the vehicles in a relatively low size, and then fused to perform object detection. The EF4 MVP is tested in the Vlissingen pilot site. ***What are Goals of MVP:*** ● Deploy the hardware on the vehicles ● Integration with UC4.2, UC4.3, UC4.4 ● Validate the presentation of objects and class types as different colored bounding boxes on the dashboard

<table>
<tr><td></td><td>

Fuse data received from two vehicles
Examine the performance of the conversion of the point cloud to intermediate representation.
Each vehicle is able to transmit its data using KPN’s MQTT system.

How to extend MVP towards the final platform:

No further development is planned
Further tuning, validation for the fusion algorithm will be done, together with performance testing and validation, as indicated in Section 5
Perform the fusion on an on-board unit rather than the cloud.

</td></tr>
<tr><td>EF5</td><td>
Description of MVP:
The MVP for Active Collision Avoidance, i.e., EF5, aims to fully integrate Collision avoidance system on Toyota’s cars and DAF truck, where lidar is connected to the vehicle and based on their perception system tracks all obstacles in the actual path. Based on configuration and predefined time to collision parameter system emergency brakes when it is needed. The EF5 MVP is tested in the Vlissingen pilot site.
What are Goals of MVP:

Standalone system for emergency braking
Integration with cars and truck
Real-life tests

How to extend MVP towards the final platform:
For the MVP, no data exchange has been tested between standalone emergency systems and other EFs. In the final platform, Collision avoidance systems will test sharing the size, position and other parameters of obstacles detected by lidars.
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<tr><td>EF6</td><td>
Description of MVP:
The MVP of Container ID recognition, i.e., EF6, consists of a camera and 5G modem that is connected to a 5G SA network. The camera feed is routed to a server that is deployed within the telecom network. This is also known as Multi-Access Edge Computing (MEC). The server contains software that can recognize identification codes on containers and trains. Via this set-up, live footage from the camera is streamed to the software in order to recognize containers/trains in real-time. The EF6 MVP is tested in the Vlissingen pilot site.
What are Goals of MVP:
To test whether MEC processing on a 5G SA network is a viable alternative to on-premises processing. In this case, there is a “thin client” consisting of the camera with 5G modem, as opposed to outdoor computers that directly process the camera stream.
This has the advantage that less local hardware needs to be deployed and maintained, and opens the way for handling multiple thin clients with one software installation. This makes such deployments on (tele-operated) trucks and cranes more scalable.
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How to extend MVP towards the final platform:

The MVP was demonstrated in June 2022 on the site of Verbrugge using the 5G SA network from KPN and the Recognition software from Sentors. Obviously, a hard requirement is a stable connection with high upload bandwidth, otherwise container/trains are missed, because a thin client gives little to no option for local caching and processing when the connection is lost.

The MVP will therefore be extended with additional logging and the additional required hardware will be merged in an outdoor unit. This way the set-up can be tested for a longer period of time in an outdoor environment on an operational container/train terminal. The extension is focused on the real-life performance of 5G SA in the context of a container/train terminal, for two main reasons:

1) Container/train terminals are traditionally challenging for radio coverage, due to the container stacks (iron cages) and heavy machinery with dynamic locations during the operation. For this reason, some terminals have been rolling out private LTE networks, when WiFi and public 4G did not cover their needs.
2) This is an environment with heavy equipment that requires ruggedized hardware and ideally as little hardware as possible. When MEC Processing is realistic in such environments, including the upload capacity and service continuity, it opens up new ways of deployments and business models.

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<tr><td>EF7</td><td>

Description of MVP:

The Estimated Time of Arrival Sharing, i.e., EF7 is fully functional. All 5G-Blueprint partners who need to use ETA (EF7) in their own EF or use case, can easily request this information from the Be-Mobile 5G-Blueprint Platform. The EF7 MVP is tested in the Vlissingen pilot site.

The EF7 is sent to

- EF1: EAD
- EF2: VRU (ETAs to upcoming waypoints of anticipated path TOV)
- EF3: to calculate when priority needs to be provided at the iTLC
- EF8: to calculate when the drone needs to act and where. The drone collects the video for anomaly detection around the TOV
- HAN: ETA is sent to HAN to prepare the docking. The ETA is sent using emulated data

What are Goals of MVP:

Testing the feasibility of EF7 (ETA API) use by the other partners, i.e., UCs and EFs. In particular, EF7 is used in EF3, EF6, EF8 and in UC4.2a.

How to extend MVP towards the final platform:

Further integration of EF7 with EF3 is planned, as well as additional performance testing, as indicated in Section 5. In particular, the goal is to test the:

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	• service continuity (Uptime of the ETA calculation component, Uptime of the (internal) ETA data feed) • Throughput (Number of ETA calculations per hour) • Latency (Ingestion of real time warnings into ETA calculations (less than 1 sec), ETA calculations to EAD (less than 1 sec) • User Acceptance (% of driver that indicate that ETA provided in EAD is useful for operation of the TOV • Reliability: (ETA vs actual time of arrival)
EF8	***Description of MVP:*** The Scene Analytics, i.e., EF8, in the MVP setup is a functional system detecting anomalies and sending alerts in an open standard towards EFs and UCs requesting the information. The EF8 MVP is tested in the Antwerp pilot site. ***What are Goals of MVP:*** In the MVP phase, the development of EF8 took place, while its further integration and detailed performance testing is planned for the final platform. ***How to extend MVP towards the final platform:*** The MVP will ultimately meet the criteria to ensure that alert messages will be sent to EF7 in order to be shown to the teleoperator as well as other partners interested in monitoring the docking site and identify anomalies for various reasons (e.g., security). The timely delivery of both a heartbeat (to ensure handshake of systems regularly) as well as minimal time between detection and notifying EF7 will implicitly test the performance of the underlying 5G infrastructure between drone, Telecom tower, cameras, edge processor and the fallback cloud processing. This will drive and evolve the distributed application platform design further as a blueprint for application design on top of hybrid networks between private/public, cloud and edge as well as cellular (5G) and wired networks. Furthermore, performance evaluation is planned for the full platform, i.e., to test the technical performance by measuring: • Reliability and accuracy of detections: number of false positives and negatives • Service continuity (Uptime of the processing) • Latency: delays between processing and signaling, notably in case of multiple events • Security of drone operation: test the cloud to edge and edge to cloud failover not impacting the drone or anomaly processing capabilities (failover) including functional performance through testing Assistance to the Security of teleoperation, to ensure the safety of operation by confirming that the route to as well as the docking zone itself is clear and that the truck is safe

	to procced.
KPN 5G SA network	***Description of MVP:*** The SA network is designed to test slicing and coverage in a harbor environment. The solution is setup and tested in Vlissingen harbor. ***What are Goals of MVP:*** The main goal is to enable remote operations use cases in a reliable manner with a 5G network. The testing in Zelzate is planned for the year three of the project. ***How to extend MVP towards the final platform:*** The MVP will be reached in different steps: 1. As is 5G SA network with production like settings 2. 5G SA network including the different slices for the deployed services 3. Further seamless roaming mechanisms to enable service continuity across the border, as described in WP5 (D5.2 [5]).
KPN 5G NSA border network	***Description of MVP:*** The NSA border network is meant to test seamless handovers at the border. The main goal is to have vehicles cross the border without or minimal interruption. To achieve this an S1 handover between the bordering networks is implemented. However, testing of UCs and EFs in a cross-border setting is not planned for the MVP phase, whereas the detailed planning of activities is presented in Section 5. ***How to extend MVP towards the final platform:*** The MVP will be reached in different steps: 1. Home Public Land Mobile Network (PLMN) <-> Visiting PLMN (VPLMN) S1 handover with multiple vendors 2. VPLMN <-> VPLMN S1 handover with multiple vendors 3. VPLMN <-> VPLMN S1 handover with steering of roaming and multiple vendors VPLMN <-> VPLMN S1 handover with RAN data exchange
Telenet 5G SA network	***Description of MVP:*** The 5G SA network is built on top of the 5G NSA network with shared RAN and dedicated SA core. In Antwerp, multiple 5G SA cells are rolled out to enable as much coverage as possible for waterways and road networks. ***What are Goals of MVP:*** The goal is to provide continuous coverage and sliced network for use case trials. This is necessary for waterway use cases where routine is not fixed. ***How to extend MVP towards the final platform:*** As 5G SA & NSA share the RAN infrastructure, the network needs to: 1. Provide isolation between 5G NSA & SA network.

	2. E2E network slicing is implemented in a production practice which is feasible for further commercialization. 3. Deployed designed network slices according to use case requirement analysis.
Telenet 5G NSA network	***Description of MVP:*** Telenet NSA network is rolled out in both Antwerp and Zelzate. The network can provide high priority data service (gold) to project as performance benchmarking, while servicing as production network (gold, silver, bronze). In Zelzate the cell is upgraded to radiate across the border for 5G NSA roaming. ***What are Goals of MVP:*** In Antwerp, to provide best effort network performance benchmarking. In Zelzate, to provide coverage on the cross-border waterway and road and provide best possible signal strength during border crossing. However, the testing in Zelzate is planned for the year three of the project. ***How to extend MVP towards the final platform:*** The MVP will be extended in several steps. Note that step 3 and 4 can be in parallel or switched: 1. HPLMN <-> VPLMN S1 handover with multiple vendors 2. VPLMN <-> VPLMN S1 handover with multiple vendors 1. VPLMN <-> VPLMN S1 handover with simulated steering of roaming and multiple vendors VPLMN <-> VPLMN S1 handover with RAN data exchange

3 DEFINITION OF KEY PERFORMANCE INDICATORS

In this section, we recapitulate the Key Performance Indicators (KPI) identified and introduce the methodology of measuring these in the scope of 5G-Blueprint project.

Our methodology is illustrated in Figure 8, and it defines KPIs in three layers: i) Verticals, which is measuring performance of use cases, ii) Enhancements for verticals, measuring the performance of various enabling functions, and iii) Network performance, evaluating the performance of network regardless of the use case or enabling function.

Thus, in Sections 3.1, 3.3, and 3.3, we elaborate on KPIs for each of the aforementioned layers, respectively. For each KPI, we provide KPI description, define the method of measurement, the target value that is expected to be achieved during the MVP phase, as well as the measurement timing that indicates whether the KPI has been already measured during the MVP phase, or it is planned to be measured for the final deployment.

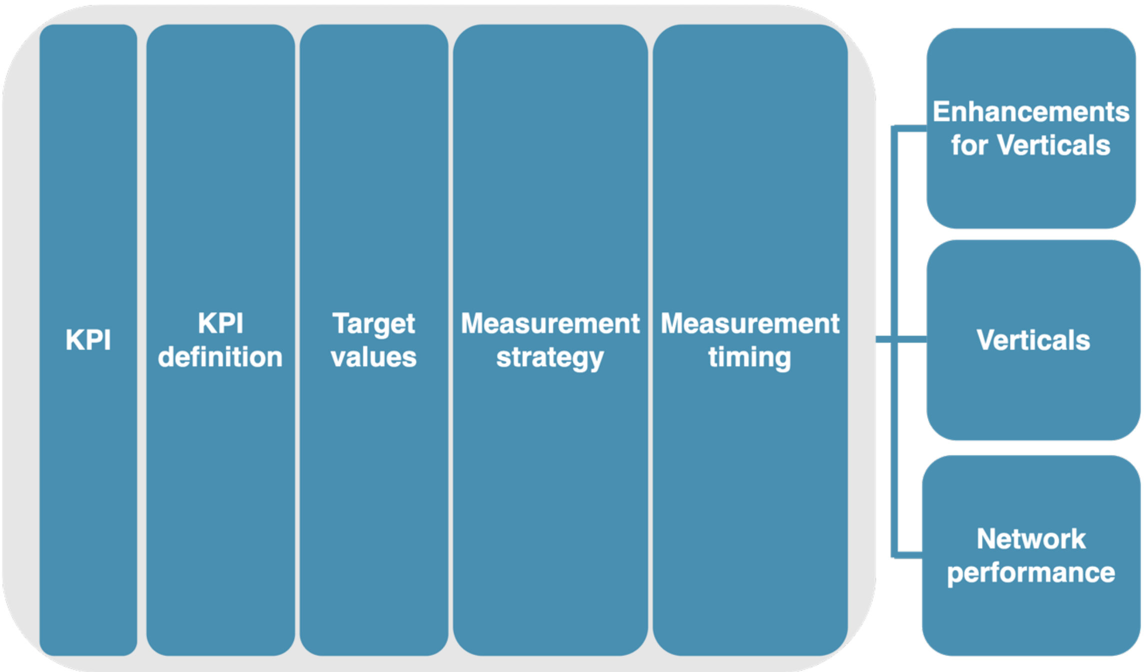
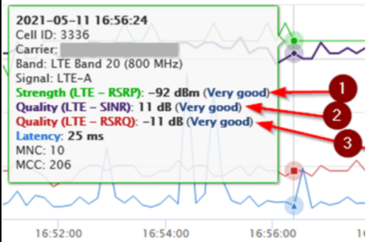


Figure 8 KPI methodology.

3.1 Description of KPIs for Verticals (Use cases)

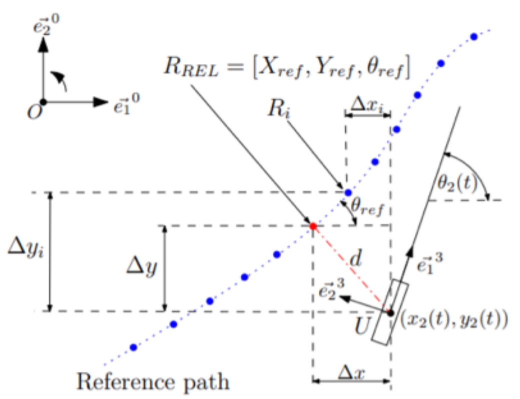
This section focuses on the KPIs for verticals, i.e., Use cases, and it provides the list of KPIs that are either already measured or will be measured until the end of the project in the context of four main use cases. Concerning the timing of the KPI measurement, the last column in all tables indicates the time of measuring particular KPI, and in case it is already measured, it provides the reference to the section in which the result is presented.

Table 5 KPIs defined for UC4.1: Automated barge control.

#	Name	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	Signal quality –RSRP	The average power received from a single reference signal.	between -101dB and -43dB	Continuous monitoring of all parameters through SF tooling. 	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final deployment)
2	Signal quality – SINR	The signal-to-noise ratio for the given signal.	between 4.5dB and 30dB	Continuous monitoring of all parameters through SF tooling.	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final deployment)
3	Signal quality – RSRQ	RSRQ is Reference Signal Received Quality.	between -15dB and -3dB	Continuous monitoring of all parameters through SF tooling.	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final deployment)
4	Latency / WAN node	The amount of time it takes for an IP packet to arrive to its destination per WAN node	40ms	Continuous ping testing of every WAN node (with SF tooling).	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final deployment)
5	Connection loss duration / WAN node	The total connection loss duration (down time) per WAN node	0ms	Measure the amount of time a WAN node was not connected (with SF tooling).	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final deployment)
6	VPN tunnel down time	The amount of time the entire VPN tunnel is down	0 downtimes of the tunnel	Measure the amount of time the VPN tunnel was not established (with SF tooling). Important to measure this KPI as all video feed (uplink) and control commands (downlink) are passing via Seafar VPN connection to the cloud. The same applies to KPIs 7 and 8.	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final deployment)
7	VPN IP packet drop / WAN node	The amount of IP packets that are lost per second	less than 5%	Continuous monitoring packet loss (with SF tooling).	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final deployment)
8	VPN maximum bandwidth	The maximum amount of data (Mb) that can go through the network per sec	20Mbps	Continuous testing the maximum bandwidth of the VPN tunnel with iperf3.	June 2022 (MVP): Section 4.3.1 December 2022 – June 2023 (final

					deployment)

Table 6 KPIs defined for UC4.2: Automated driver-in-the-loop docking.

#	KPI	Definition	Target value(s)	Measurement	Measurement timing
1	Path planning time	The time it takes the path planner to plan the desired path for docking	< 6 [s]	Measured by the controller with a (digital) stopwatch.	July 2022 (MVP): Section 4.3.2 December 2022-April 2023 (final deployment)
2	Tracking Error Real time	The lateral difference between the actual position of the truck and trailer and the generated reference path during maneuvering. The tracking error consists of: A) Lateral (Y) deviation, deviation of the axle of the trailing unit with respect to the generated path by the path planner.	The lateral deviation during maneuvering is < 0.25 [m] in terms of Maximum and Average Value	The docking controller works based on knowing the position of the turning point of the trailer (trailer axle). Therefore, the tracking error will be measured by comparing the trailer axle location with the desired location of the reference path. The actual trailer location will be measured by the RTK-GPS system (the measured sensor location should be translated to the axle position). The reference path is a set of discrete points (see Figure 9). So first it should be determined which of these points is most relevant to determine the tracking error at a certain moment in time. The relevant reference point RREL is selected based on the actual position of the trailer (Body U in Figure 9). RREL is determined by evaluating which point Ri of the reference path has the minimal absolute distance (d) towards the trailer. Based on the identified reference point RREL, the lateral error can be obtained in the local coordinate system of the trailer ($e^{\rightarrow 3}$) fixed to the controlled turn-point (axle) of the trailer. The lateral error reads: $e_{yU} = \Delta y cos\theta_2 - \Delta x sin\theta_2$  Figure 9 Determination of relevant reference path point which is used to determine the tracking	July 2022 (MVP): Section 4.3.2 December 2022-April 2023 (final deployment)

				error.	
3	Final Docking state error	The difference between the actual docking position and the planned docking position after the docking maneuver is performed. The Final Docking state error is divided into three parts: A) Lateral (Y) deviation, deviation of the trailer's end to the targeted docking position. B) Longitudinal (X) deviation, deviation of the trailer's end to the targeted docking position. C) Orientation angle (θ) of trailer, orientation of the trailer to the dock (should be straight in front of dock).	The lateral deviation after docking is < 0.10 [m] The longitudinal deviation after docking is < 10 [cm] The orientation angle of the trailer after docking is < 2 [o]	The deviation & orientation angle are calculated by comparing the measured position and heading with the designated docking position and heading. The lateral and longitudinal deviation can be compared with the actual on-site position (measured with laser or ruler) at the dock.	July 2022 (MVP): Section 4.3.2 December 2022-April 2023 (final deployment)
4	First time right rate	The ratio of the path tracking controller maneuvering the vehicle combination over the generated path first time with failures to the path tracking controller maneuvering the vehicle combination over the generated path first time without any failure.	The ratio should be < 0.5 [-]	Count the amount of initiated path tracking maneuvers that fail and the amount of path tracking maneuvers that succeed first time without any failure.	July 2022 (MVP): Section 4.3.2 December 2022-April 2023 (final deployment)
5*	Take Over Control (TOC) time	The time required for the handover of control between the automated systems and the	Minimum TOC time is 2 [s]	Measured with a stopwatch taking the average over multiple TOC's.	December 2022-April 2023 (final deployment)

		teleoperator (TO).			
6*	Control action delay	The amount of time between receiving the control action (can be both from the operator in the remote station or the controller) to actual actuation of truck	< 30 [ms]	Measured by the controller with a (digital) stopwatch. Overlaying logged actuation data vs movement data (GPS) over time?	December 2022-April 2023 (final deployment)
7	Elapsed time / total docking time	The time between the initial movement and the final stop of movement at the end position.	Maximum elapsed time of 200 [s]	The elapsed time will be measured by the controller with a (digital) stopwatch.	July 2022 (MVP): Section 4.3.2 December 2022-April 2023 (final deployment)
8	Static GPS Position tolerance	The tolerance in position of the truck and trailer in X and Y direction.	X position < 5 [cm] Y position < 5 [cm]	The tolerance will be measured with help of the position accuracy measured by the GPS system in [cm] together with physical laser measurements. These measurements will be done at standstill both at the start and end of the test.	July 2022 (MVP): Section 4.3.2 December 2022-April 2023 (final deployment)
9	Static GPS Heading tolerance	The tolerance in heading of the truck and trailer.	Heading tolerance < 0.5 [deg]	The tolerance will be measured with help of the heading accuracy measured by the GPS system in [deg] together with calculations using the vehicle dimensions and coupling. These measurements will be done at standstill both at the start and end of the test.	July 2022 (MVP): Section 4.3.2 December 2022-April 2023 (final deployment)

* KPI 5, 6 were not measured in the MVP phase as the autodocking was executed locally (on vehicle site) and not from the teleoperation center.

Table 7 KPIs defined for UC4.3: CACC-based platooning.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	Following distance	The minimum achievable headway to the lead vehicle	1 s	Headway time measured with sensors in (s)	July 2022: Section 4.3.3 December 2022-April 2023 (final deployment)
2	% Distance error	Percentage of difference between actual and desired distance	Less than 5% (in steady state condition)	Calculated based on the measured values with sensors	July 2022: Section 4.3.3 December 2022-April 2023 (final deployment)

3	Latency - V2V communication	Delay communicating the message from lead vehicle	Less than 10ms (for distance up to 60 m)	Calculated from the time stamp data measured in (ms)	July 2022: Section 4.3.3 December 2022-April 2023 (final deployment)
4	Max speed	Maximum achievable speed with CACC	80 Km/h	Can be measured from GPS / CAN bus in (Km/h)	July 2022: Section 4.3.3 December 2022-April 2023 (final deployment)
5	Max acceleration / deceleration	Rate of response of the following vehicle	2.5 to -3.5 m/s2	Can be measured from CAN bus in (m/s2)	July 2022: Section 4.3.3 December 2022-April 2023 (final deployment)
6	Overall system delay	End to end latency including all the delays (Communication & processing delay)	100ms	Will be computed from data post processing (ms)	July 2022: Section 4.3.3 December 2022-April 2023 (final deployment)
7	Number of human interventions	How many times does the driver / teleoperator needs to take control when driving under CACC	0 (in normal driving conditions)	Number can be measured during the maneuver	July 2022: Section 4.3.3 December 2022-April 2023 (final deployment)

Table 8 KPIs defined for UC4.4: Remote takeover.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	Steering Accuracy	The input given through the driving station should be the same on the teleoperated vehicle.	• Mean error < 0.1 [º] • Mean Absolute Error (MAE) <3.0 [º] • Root Mean Squared Error (RMSE) < 5.0 [º]	The steering wheel rotation is measured in degrees (º)	July 2022: Section 4.3.4 December 2022-April 2023 (final deployment)
2	Pedals Accuracy	The input given through the driving station should be the same on the teleoperated vehicle.	• Mean error <1.0 [%] • Mean Absolute Error (MAE) <4.0 [%] • Root Mean Squared Error (RMSE) < 6.0 [%]	The pedal travel, throttle and brake, are mapped to a percentage (0-100%)	July 2022: Section 4.3.4 December 2022-April 2023 (final deployment)

3	Overridability	The vehicle driver can instantly override all automated systems and completely revert to initial OEM status by pressing the manual override button.	• < 1 [ms]	System reaction time	July 2022: Section 4.3.4 December 2022-April 2023 (final deployment)
4	Maximum safe speed	Maximum possible speed for safe teleoperation.	25 [km/h]	Gathered teleoperator feedback	July 2022: Section 4.3.4 December 2022-April 2023 (final deployment)
5	Action time ratio	Ration of time required for task completion (teleoperation driver/onboard driver .)	90 [%]	Roboauto application logs driving mode, calculated from these logs	July 2022: Section 4.3.4 December 2022-April 2023 (final deployment)
6	Orientation time	Time required for teleoperator driver to obtain situational orientation in space.	8 [s]	Stopwatch is used to measure time from connecting to the vehicle to being able to start teleoperating	July 2022: Section 4.3.4 December 2022-April 2023 (final deployment)
7	Latency(video/commands)	Time taken to receive a response. The start and the end time for measurement of latency. (internal RBA latency measure)	mean < 20 [ms] max < 30 [ms]	Roboauto internal latency measuring algorithm, mean of means, mean of maxes	July 2022: Section 4.3.4 December 2022 (final deployment)
8	Bandwidth	% of network bandwidth used.	80 [%]	Calculated from Roboauto application log data and iperf3 measurements	July 2022: Section 4.3.4 December 2022 (final deployment)
9	Time to reconnect	Time required for teleoperation system to reconnect to vehicle. Time from system start after a crash to successful connection to vehicle	<5 [s]	Roboauto application log data	April and July 2022 (MVP): Section 4.3.4
10	System availability	% of the time when the system is available.	90%	Calculated from Roboauto application logs	December 2022-April 2023 (final deployment)

11	Stream quality	The quality of the video stream from the vehicle to the remote station.	<10 [points/minute]	A human spectator notes glitches in video stream quality and marks them based on their severity (fatal 3 points, medium 2 points, light 1 point).	December 2022-April 2023 (final deployment)

3.2 Definition of Network KPIs

The

Table 9 presents a list of network KPIs that will be considered during the network evaluation, which will be conducted as part of WP5. The KPIs may be subject to further changes, depending on the developments and deployments of the 5G network on the field, which is managed in WP5. Thus, the final list of networking KPIs and their evaluation will be presented in D5.4 at M37.

The target values for the listed KPIs are presented in the

Table 9 for the following KPIs: data rate and end-to-end latency. The indicated target values reflect on the type of use case and enabling functions, as described in D5.1 [4]. The target values for the remaining KPIs are currently being defined in WP5, and as such they will be presented in D5.4 and D7.4.
The deliverable D5.1 [4] provides a detailed analysis of the service requirements per use case and enabling function, and here we focus on the description of KPIs and the network evaluation planning, which is scheduled prior to testing use cases and enabling functions in the pilot sites, thereby making sure that 5G network is performing in a satisfactory manner.

Table 9 Network KPIs.

#	KPI	Definition	Target value(s) [unit]	Measurement		Measurement timing
				Procedure	Tools	
1	**User Experienced Downlink Data Rate**	Downlink data rate as perceived at the application layer. It corresponds to the amount of application data (bits) correctly sent within a certain time window (aka goodput)	Automated Barge Control (UC4.1): 2 Mbps Automated driver-in-the-loop docking (UC4.2): 2Mbps CACC-based platooning (UC4.3): 2Mbps Remote Takeover	Test will be setup where a known data stream will be sent from the Application Server (AS) to the UEs over 5G. This data stream can be a real application stream (e.g. video stream) an iPerf stream, ftp transfer. At the UEs, the data rate of the received data streams will be measured at the application over a small-time window (e.g. per second).	iperf, video streaming application, ftp transfer	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)

			(UC4.4): 2Mbps Time Slot Reservation at Intersections (EF3): 1 Mbps			
2	**User Experienced Uplink Data Rate**	Uplink data rate as perceived at the application layer. It corresponds to the amount of application data (bits) correctly received within a certain time window (aka goodput)	Automated Barge Control (UC4.1): > 50 Mbps < 250 Mbps Automated driver-in-the-loop docking (UC4.2): > 15 Mbps < 75Mbps CACC-based platooning (UC4.3): > 15Mbps < 75 Mbps Remote takeover (UC4.4): > 15Mbps < 75 Mbps VRU Interaction (EF2): 1Mbps Distributed perception (EF4): > 20Mbps < 100Mbps Active collision avoidance (EF5): < 1 Mbps	Test will be setup where a known data stream will be sent from the UE to the AS over 5G. This data stream can be a real application stream (e.g. video stream), an iPerf stream, or ftp transfer. At the UEs, the data rate of the received data streams will be measured at the application over a small-time window (e.g. per second).	iperf, video streaming application	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)

3	**Downlink throughput**	The instantaneous downlink data rate as perceived at the network layer between two selected end-points. The end points may belong to any segment of the overall network topology. It corresponds to the amount of data (bits) sent per time unit	NA	Test will be setup where a known data stream will be sent from the AS to the UEs over 5G. This data stream can be a real application stream (e.g. video stream) or an iPerf stream. At different network entities, the throughput of the bypassing data streams will be measured at the network layer over a small-time unit (e.g. bits per second).	iperf	June-July 2022 (initial results reported in D5.2 [5] for both Vlissingen and Antwerp) October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
	Uplink throughput	The instantaneous uplink data rate as perceived at the network layer between two selected end-points. The end points may belong to any segment of the overall network topology. It corresponds to the amount of data (bits) received per time unit	NA	Test will be setup where a known data stream will be sent from the UE to the ASs over 5G. This data stream can be a real application stream (e.g. video stream) or an iPerf stream. At different network entities, the throughput of the bypassing data streams will be measured at the network layer over a small-time unit (e.g. bits per second)	iperf	June-July 2022 (initial results reported in D5.2 [5] for both Vlissingen and Antwerp) October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
5	**Packet Delivery Ratio (PDR)**	Percentage value of the amount of sent network layer packets successfully delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets	NA	Test will be setup where a known data stream will be sent over 5G. The PDR will be calculated over a specified time window required by the targeted service. The measurement can be done both for uplink and downlink.	iperf, Wireshark, proprietary	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
6	**Packet Loss**	Percentage value of the amount of sent network layer packets failed to be delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets	NA	Test will be setup where a known data stream will be sent over 5G. The packet loss will be calculated over a specified time window required by the targeted service. The measurement can be done both for uplink and downlink.	iperf, Wireshark, proprietary	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)

7	**Guaranteed data rate from moving UE**	Minimum guaranteed throughput achievable by a UE moving in a tri-dimensional space with linear trajectory and fixed speed	NA	Measure the throughput during the life-span of an application and determine the minimum throughput that is observed over a specified time window reflecting the whole defined trajectory. Can be performed both in uplink and downlink.	iperf, Wireshark, proprietary	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
8	**E2E Latency**	The time required from the moment a data packet is transmitted by the source application, to the moment it is received by the destination application	Automated Barge Control (UC4.1): video < 22 ms (UL and DL), control (RTT) <35ms Automated driver-in-the-loop docking (UC4.2): video (UL) < 50ms, control (RTT) <35ms CACC-based platooning (UC4.3): video (UL) < 50ms, control (RTT) <35ms Remote Takeover (UC4.4): video (UL) < 50ms, control (RTT) <35ms VRU Interaction (EF2): UL < 500ms Time slot reservation at Intersections (EF3): DL < 200ms Distributed perception (EF4): UL < 100ms (LIDAR), <200ms (RSU) Active collision	Per data packet that is transferred the difference between the timestamp upon sending and the timestamp upon arrival is calculated. Can be performed both in uplink and downlink.	ping, proprietary	June-July 2022 (initial results reported in D5.2 [5] for both Vlissingen and Antwerp) October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)

			avoidance (EF5): UL < 100ms			
9	**Guaranteed Maximum E2E Latency**	The guaranteed maximum time required from the moment a data packet is transmitted by the source application, to the moment it is received by the destination application	NA	E2E latency is measured over the life-span of the application and then the max value is observed. Can be performed both in uplink and downlink.	ping, proprietary	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
10	**Jitter**	The variation in the latency on a packet flow between two systems. Jitter can be caused by network congestion, timing drift and route changes	NA	The variation of the E2E latency will be measured on a traffic flow that is setup between the UE and the AS. Can be performed both in uplink and downlink.	iperf	June-July 2022 (initial results reported in D5.2 [5] for Antwerp) October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
11	**Reliability**	The amount of application layer messages or network layer packets (depending on the measurement level) successfully delivered to a given system node within the time constraint required by the targeted service, divided by the total number of sent messages or packets	NA	A data flow will be setup between the UE and the AS and the measurement will be performed over a specified time window required by the targeted service. Can be performed both in uplink and downlink.	iperf, proprietary	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
12	**Network Coverage**	The geographic area within which the Mobile Network Operator voice/data services can be accessed and used by the subscriber	NA	Drive test measurements l where the network coverage will be measured at different locations.	drive test tools	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)
13	**Communication Range**	Communication range is the maximum distance between a transmitter and its intended receiver allowing communication with a targeted Latency, and Reliability	NA	Drive test measurements where the communication range will be measured at different locations.	iperf, drive test tools	October – November 2022 (Vlissingen, Antwerp), March 2023 (Zelzate)

14	**Handover Mobility Interruption Time**	The time it takes for the UE to complete the handover procedure during handover at the border	NA	Driving tests where the UE will perform a handover at the border. The handover procedure time will be measured at the network.	Measured in the 5G network with specific network tools	March 2023 (Zelzate)
15	**E2E Roaming Mobility Interruption Time**	The time duration between the transmission (or reception) of the last IP packet through the old connection and the transmission (or reception) of the first packet through the new connection during roaming at the border	NA	Driving test where the interruption time at IP level will be measured while doing an international handover at the border.	proprietary	March 2023 (Zelzate)
16	**International Roaming Latency**	E2E latency due to roaming at the border	NA	Driving test where the E2E latency between the UE and AS will be measured while doing an international handover at the border.	ping, proprietary	March 2023 (Zelzate)

3.3 Description of KPIs for Enhancements for Verticals

This section focuses on the KPIs for enhancements for verticals, i.e., Enabling Functions, and it provides the list of KPIs that are either already measured or will be measured until the end of the project in the context of eight main enabling functions. Same as for the case of use cases in Section 3.1, Measurement timing indicates the time of measuring particular KPI, and in case it is already measured, it provides the reference to the section in which the result is presented.

Table 10 KPIs defined for EF1: Enhanced Awareness Dashboard.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
	Availability of current position, speed and heading of the TOV	Basic GNSS data (coming from MQTT of Roboauto): current position, speed and heading.	100% available	Visual confirmation of route information on EAD.	June 2022 (MVP): Section 4.3.4
1	Availability of route information on EAD	Display Route information on EAD, Display Route information for specified start and end GPS position	100% available	Visual confirmation of route information on EAD.	June 2022 (MVP): Section 4.3.4
2	Efficiency of displaying EF2 (Vulnerable Road User Interaction) on EF1	Display the location and the predicted path of the VRU and the location of potential collision on the EAD	100% available	Visual confirmation correctly showing the information of the VAM/DENM messages, i.e., location and predicted path VRU and location of and time to collision. This information should also real-time update.	June 2022 (MVP): Section 4.3.4
3	Efficiency of displaying feedback from EF3 (Timeslot Reservation at Intersections) on EF1	EAD Display result of requested priority of EF3 on	100% available	Visual confirmation that when we approach intersection, priority is requested and result is displayed.	November 2022 - June 2023 (final deployment)
4	Efficiency of displaying results from EF4 (Distributed perception) on EF1	Display critical detected object for teleoperator on EF1	100% available	Visual confirmation that all transmitted objects are shown in 3D on the road map view.	June 2022 (MVP): Section 4.3.4)
5	Efficiency of displaying results from EF6 (Container ID recognition) on EF1	Display the detected container id on EF1	100% available	Visual confirmation that the correct container ID is shown.	June 2022 (MVP): Section 4.3.4
6	Efficiency of displaying results from EF7 (Estimated Time of Arrival Sharing) on EF1	Display and real-time update of ETA, turn-by-turn instructions, and speed information	100% available	Visual confirmation that ETA and next turn instruction update when the TOV progresses along the route. Moreover, the max speed and speed advice must be corrected with respect to the	June 2022 (MVP): Section 4.3.4

				current position of the TOV.	
7	Efficiency of displaying results from EF8 (Scene analytics) on EF1	(1) Display anomalies on EF1 (2) display video of the anomaly on the EF1	100% available	Visual confirmation that all detected anomalies are shown on EAD and that the video of the anomaly can be played when available.	June 2022 (MVP): Section 4.3.4
8	Frequency	Calculation of speed advice and integration into EAD	1 Hz	Based on metrics	November 2022 - June 2023 (final deployment)
9	Latency	EF2/EF6/EF8 ingestion of warnings into warning collector and integration into EAD	less than 1 s	Based on metrics and tracing in code + processing time in response	November 2022 - June 2023 (final deployment)
10	Latency	EF4: Integration of map builder into EAD	less than 1 s	Based on metrics and tracing in code + processing time in response	November 2022 - June 2023 (final deployment)
11	User Acceptance	Validate the driving experience of the TO with all information streams visible on the EAD, % of time that driver abides by speed advice % of driver that indicate that EAD is useful for the operation of the TOV	100%	Survey	November 2022 - June 2023 (final deployment)
12	Reliability of the EAD	Driver indicates that the information provided in the EAD is accurate.	100%	Survey	November 2022 - June 2023 (final deployment)

Table 11 KPIs defined for EF2: Vulnerable Road User (VRU) interaction.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	Service Continuity	Percentage of time during which smartphone apps were operational during each field test.	98%	crash monitoring tool	June 2023
2	Service Continuity	Percentage of time during which MQTT service was operational	98%	Server log file	June 2023
	Service Continuity	Network awareness: % of times apps correctly warned VRU for network degradation	98%	Network monitoring log and app event log	June 2023
	Throughput	Number of messages made available via MQTT Broker with position of VRU, and potentially warning, per hour	3600 * 9 (# Quad tiles in detection zone)	Server log file	June 2023
	Latency	Time between detection and warning to TO	<500ms	Detection time: DENM.	June 2023

				Warning time: server log file.	

Table 12 KPIs defined for EF3 - Timeslot reservation.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	Latency	the total loop time end to end between ToV and iTLC processing is given by the requirement of the government.	<70ms	Analysis of the broadcasting times of ToV and iTLC in message chain (SSM, SRM answering sequence)	February 2023 in Vlissingen, June 2023 Zelzate (final deployment)
2	Latency	to compare 4G QoS vs 5G we need to know the difference between both channel, we measure the time between RSU and UDAP/TLEX (broker)	<15ms	Latency test on duration 7 days 4G and 7 days 5G	February 2023 in Vlissingen, June 2023 Zelzate (final deployment)
	Availability	the traffic engineering application is operational as a cloud service in an online situation.	System availability >99,9%	Measuring uptime and downtime ITS cloud and RIS application over an operational period of time (min. month)	February 2023 in Vlissingen, June 2023 Zelzate (final deployment)

Table 13 KPIs defined for EF4: Distributed perception.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	Fusion algorithm computation time	Time required to transform and fuse the point clouds	200-400ms	Based on metrics and tracing in code + processing time in response	June 2022 (MVP): Section 4.3.3
2	Object detection average precision and accuracy	Object's available being successfully detected by the algorithm	Visual comparison between available objects and detected ones	Visual	June 2022 (MVP): Section 4.3.3
	Bandwidth	Amount of data that is transmitted per second.	Data of about ~3Mbs should be transmitted successfully in real time	Frequency of point clouds data received at the edge node	June 2022 (MVP): Section 4.3.3

Table 14 KPIs defined for EF5: Active collision avoidance.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	False negative rate	Failure to activate with obstacle present	<5 [%]	A series of test using a dummy will be performed and the results will be recorded.	May 2022 (MVP): Section 4.3.4 March 2023 (final deployment)
2	False positive	Erroneous activation without obstacle present	<3 [#/hour]	ACA will be active during teleoperated driving, erroneous situations will be manually noted.	May 2022 (MVP): Section 4.3.4 March 2023 (final deployment)

Table 15 KPIs defined for EF6: Container ID recognition.

#	KPI	Definition	Target value(s)	Measurement	Measurement timing
1	Service continuity	Uptime of 5G SA network and Edge node	40 ms	Logging of timestamps of connectivity loss by the modem, and a regular ping from the edge to the camera. The goal to achieve 25 frames per second.	November 2022 - March 2023 (final deployment)
2	Frame drop	The number of camera frames that are not received at the edge node	maximum 1 out of 25fps (frames per second)	Frame drop as provided by video encoder, and logging of packet loss.	November 2022 - March 2023 (final deployment)
3	Bandwidth	Amount of data that is transmitted per second.	Upload for 1 continuous camera stream e.g. >10mbit.	Data received at the edge node.	November 2022 - March 2023 (final deployment)
4	API delivery time	The time it takes before a container/train is recognized and received at EF1 (end-to-end, from camera to edge to EF1 via the internet)	<1s	Logging of frame time, the time when the edge node has pushed a container/train code message, and the received time at EF1, all synchronized via NTP.	November 2022 - March 2023 (final deployment)

Table 16 KPIs defined for EF7: ETA sharing.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	Service continuity	Uptime of the ETA calculation component Uptime of the (internal) ETA data feed	100% available	number of errors when ETA is requested = 0	November 2022 - March 2023 (final deployment)
2	Throughput ETA computations	To have an accurate and no outdated ETA, the Number of ETA calculations per hour must be sufficiently large	at least 10/min per vehicle	Based on metrics and tracing in code	November 2022 - March 2023 (final deployment)
3	Process time of ETA request on ETA api	time it takes before eta is returned when asked for via the eta-api	less than 100ms	Based on metrics and tracing in code	November 2022 - March 2023 (final deployment)
4	Visual confirmation of correctness.	When driving, verify if the quality of the route information is correct	Correctness of ETA/route/turn-by turn information	Visual	November 2022 - March 2023 (final deployment)

Table 17 KPIs defined for EF8: Scene analytics.

#	KPI	Definition	Target value(s) [unit]	Measurement	Measurement timing
1	False negative rate	Failure to detect anomaly	<5 [%]	The platform will be continuously processing video streams. Logs will be reviewed and matched with reality.	January – April 2023 (final deployment)
2	False positive	Wrongful anomaly detection	<3 [#/hour]	The platform will be continuously processing video streams. Logs will be reviewed and matched with reality.	January – April 2023 (final deployment)
3	Latency	Delay between detection and alert	<1[second]	Delay will appear in logs.	January – April 2023 (final deployment)

4 MVP TESTS AND RESULTS

4.1 Testing methodology

The overall teleoperation testing and validation process is performed in the two main stages. During the first stage, the System Under Test (SUT) for each of the use cases is being integrated in a lab environment, thereby performing the integration of components developed by different partners in each of their respective labs. In this section, we first provide a brief overview of the lab testing that has been performed prior to the piloting. Afterwards, the focus is shifted to the second stage and the piloting activities, i.e., on the validation of use cases and enabling functions, and their performance while using 5G network connectivity in the pilot sites.

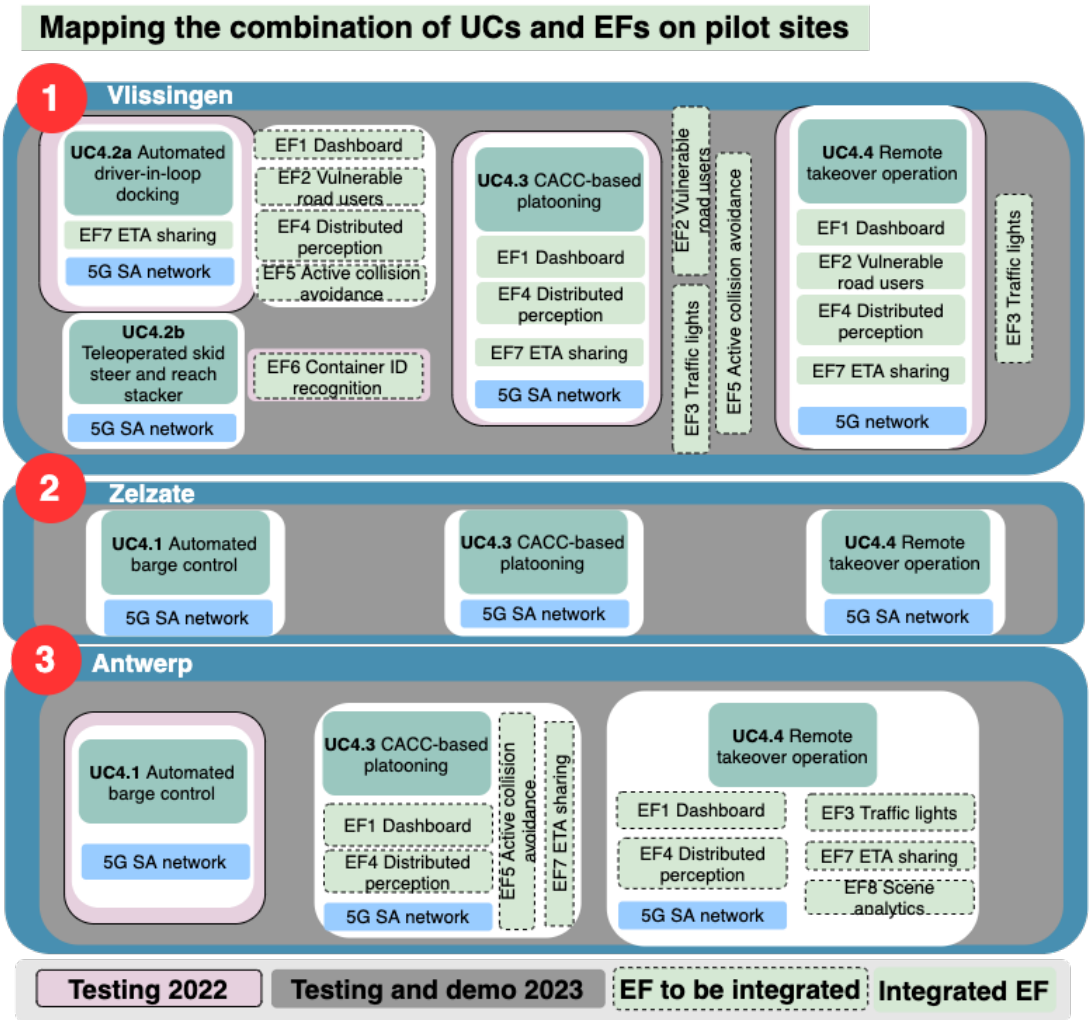


Figure 10 Mapping the combination of UCs and EFs on pilot sites.

Thus, in the second stage, the validation is being performed in the three different pilot sites, i.e., Vlissingen (NL), Antwerp (BE), and Zelzate (cross-border area NL-BE). For each of the tests, specific trajectories have been defined, combining confined areas (e.g., parking lots) and public roads with 5G coverage. In case of testing on the public road, in regular traffic conditions, some specific exemptions are required, and thus, various permits need to be obtained from both the

Dutch and Belgian public authorities. To mitigate such challenges, in the 5G-Blueprint project, we organize the testing in the pilot site as a combination of the two following testing modes:

- **Shadow-mode teleoperation** means that the control commands sent from the tele-operator via 5G network to the vehicle/barge are not directly translated to the local commands, thus, being disabled by the drive-by-wire system of the vehicle. This mode means human-in-the-loop approach, where a person in the vehicle/vessel is driving based on the commands received from the teleoperation, and as such it is being extensively used when testing on the public roads in the pilot sites.

- **Real teleoperation** happens in the confined areas such as parking lots within 5G-covered pilot sites, or on the closed public roads. As for this type of testing on the public roads a particular permit is required, we focus on testing in confined areas and the shadow-mode testing on the public roads to collect a sufficient amount of results and learnings before performing the same test with a more stable teleoperation, leveraging on a mixed traffic public roads environment.

The integration activities involve i) interfacing of different use case components and the relevant enabling functions, and ii) the testing and validation of the performance of these interfaced components using 5G network deployed in the pilot sites, and in particular the network slices (e.g., URLLC and eMBB). For that purpose, in Figure 10 we present a high-level overview of our current planning of the integration and pilot testing for each of the use cases, and their mapping to each of the pilot sites. In particular, after performing an initial lab testing (first testing stage) in the first half of 2022, we have started with the extensive testing in the pilot sites (second stage). As it can be seen in Figure 10, all four use cases have been tested either in Vlissingen or in Antwerp pilot site (Testing 2022), together with their respective integrated enabling functions. The main focus was mostly on the Vlissingen pilot site, given the timely availability of both 5G SA and NSA in both confined areas and the public roads. One of the ongoing activities in 2022 is to transfer the learnings from the Vlissingen pilot site and proceed with the testing of use cases 4.3 and 4.4 on the Antwerp pilot site as well.

4.2 Lessons learned from Lab testing

In the beginning of May 2022, a testing in KPN field lab (Figure 11) took place. The main goal was to learn about the compatibility of acquired modems with 5G SA network in connection with the different use cases.

Figure 11 KPN field lab (Vaarle parking lot near Helmond, The Netherlands).

Lessons Learned can be summarized as follows:

- 4G vs 5G SA; 5G SA can achieve very low latency:
  - Driver inputs sent from the remote station reached the vehicle with an average latency of 10ms. In contrast, during initial tests over 4G at V-tron premises and at the HAN's at IPKW, the average latency was around 30ms.
- 5G SA is very coverage dependent:
  - In the testing area (parking lot) the signal would almost completely cut off at the extremes and deteriorate next to foliage.
- Low latency means higher driving speeds:
  - With the latency of the 5G SA network, it was possible to safely achieve speeds of 60 km/h given the testing space, retaining full control of the vehicle. In contrast 20-30km/h was the limit on 4G, not for space but rather for confidence of having safe control of the vehicle by the remote operator.
- Latency remained low when the vehicle was remote driven from Roboauto's headquarters in Brno:
  - Latency remained very low, however the video stream was not optimal due to bandwidth limitations between the test network and the production network.
- Vehicle velocity and depth are hard to perceive from the remote station:
  - Only with the speedometer it is possible to be aware of the actual vehicle speed, the video feed alone is not sufficient to grasp small changes in velocity.
  - The teleoperator's view is not always optimal when driving close or next to cones and lane lines.
- Different 5G modems tested:
  - Digi TX64 and Sierra Wireless XR90. Only the Digi modem could be used in Helmond as it was discovered that the Sierra was not ready to work reliably out of the box, and a software update was required to function correctly.

4.3 Pilot tests and results

In this section, we steer the focus towards the tests that have been performed in the pilot sites during the MVP phase of the platform. Thus, in each of the following sections we describe the testing procedures for various use cases and their supporting enabling functions, and afterwards, we present the results obtained by measuring a subset of KPIs that is presented in Section 3.

It is important to note that the content of the following sections is prepared in the format of the System Test Description (STD) document that has been extensively used as a living document in WP7, to describe and to thoroughly prepare for the testing phase.

The names of the tests (Antw-4.1, Vlis-4.2a, etc.), indicate the location, i.e., the pilot site where the testing has been performed, as well as the main use case that is tested either standalone or with the EFs. In particular, Antw-4.1 refers to the UC4.1 tests performed in the Antwerp pilot site.

4.3.1 Antw-4.1: Test and results

Short description

This section focuses on the tests performed within the scope of UC4.1, i.e., Automated barge control, in the Antwerp pilot site area. For this testing, it is important to demonstrate that the use of 5G is in place, and that the KPIs can be measured using the Seafar shore control in Antwerp, while sending command signals to the vessel which is navigating in the Belgian waterways. All the results presented in this section are obtained while performing the use case in the Antwerp pilot site, thus, using 5G deployment as described in Section 1.2.2.

The vessel is commercially navigating, and at the moment, Seafar is working closely with the Port of Antwerp Bruges to obtain the permission to navigate the vessel from a distance by assuring the safety of operation and environment. Given that, it is decided that this testing will be performed without making the control commands effective onboard, i.e., by applying shadow-mode testing that has been already defined in Section 4.1. Therefore, all commands are sent to the vessel but held in our processor aboard the ship. During the test, performance of the 5G network infrastructure is monitored and recorded for future analysis.

Pre-conditions

- Seafar sensors and control systems
- Seafar network system presented in Figure 12
    - 5G SIM card is delivered by Telenet
    - 5G equipment is configured
    - 5G antenna installed onboard the ship, in addition to 4G

In Figure 12, the high-level overview of the Seafar connection between the vessel, cloud, and Shore control center, is presented.

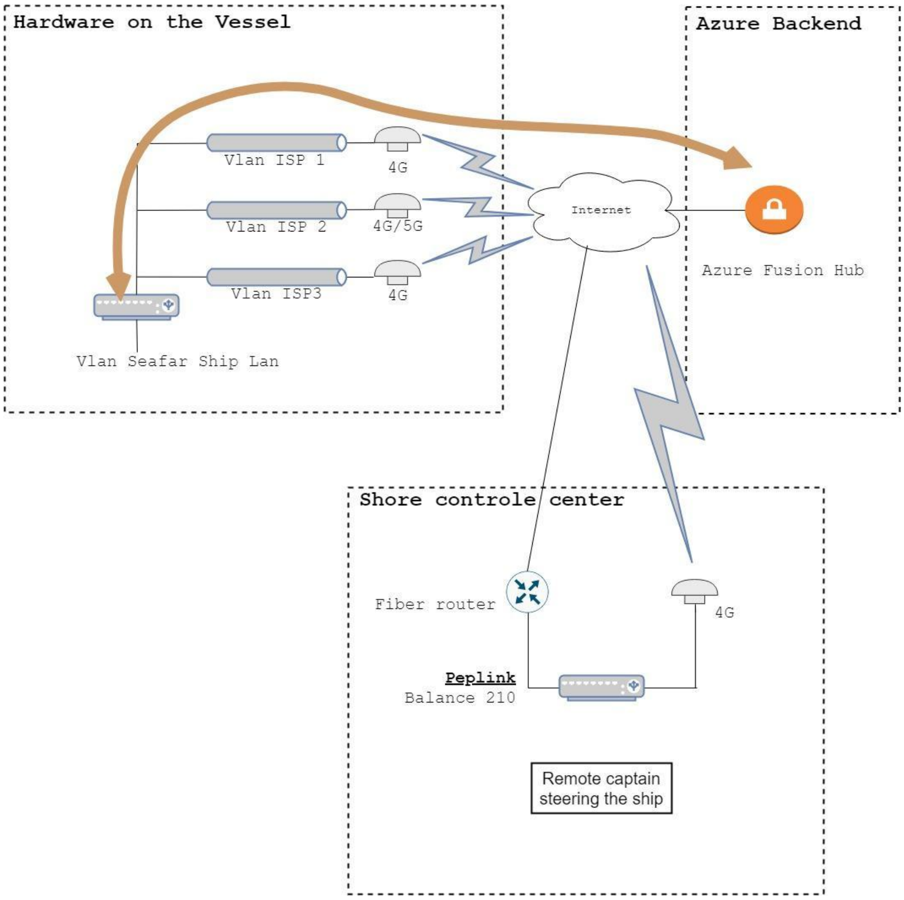


Figure 12 Overview of UC4.1 solution.

Network installation by Telenet

The tests performed in MVP phase are executed on the Telenet NSA network. In Figure 13, the design of the Telenet network in Antwerp pilot site can be seen.

Test inputs

All local GPS and vehicle data is used to simulate the remote control of the vessel.

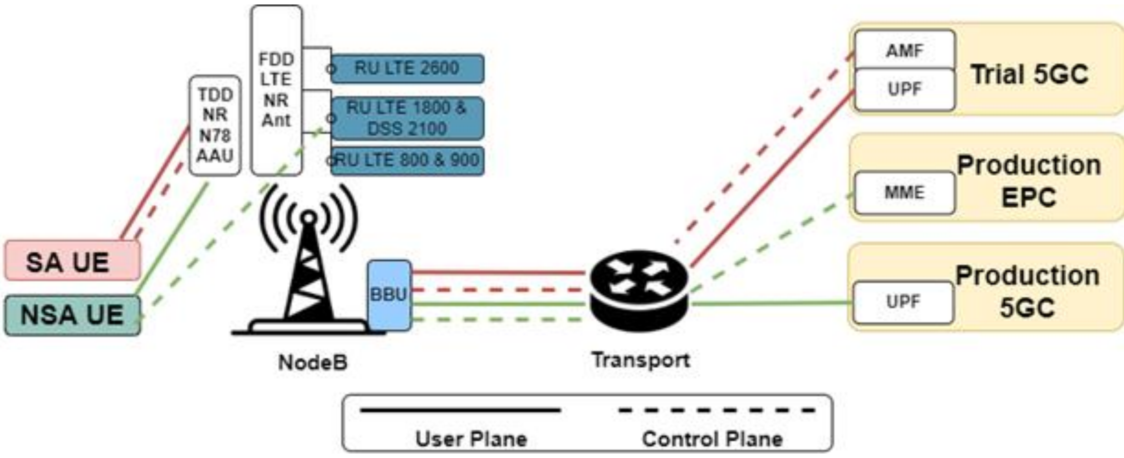


Figure 13 Telenet 5G network configuration in the Antwerp pilot site.

Test procedure

In order to minimize the risk to the operation, as the vehicle under the test is a commercial ship, it is decided to perform shadow-mode testing. To do so, all commands from the shore control center are sent to the Seafar control system onboard the ship via Seafar and Telenet cloud over 4G and 5G, but as such they are not sent to the ship controller and PLC (illustrated in Figure 14). The measurements are performed considering three measurement setups, as described in Table 18.

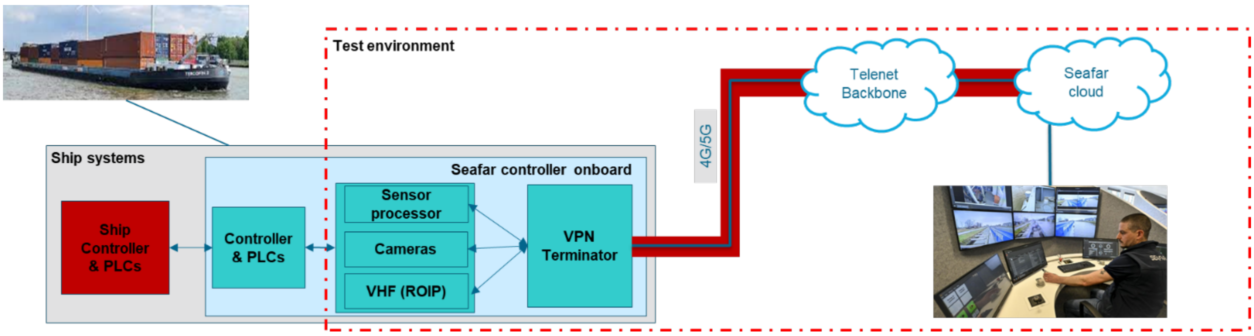


Figure 14 The overview of UC4.1 shadow-mode testing.

Table 18 UC4.1 Measurement setups.

Environment	KPIs
5G/4G antenna	- The signal quality - Total bandwidth used
Between Ship and Seafar Cloud	- latency
Between Ship and Shore control center	- Total latency - Message flows - Operational Quality

Results

The tests described in this section were done in the window of two weeks, as the ship's planning was to navigate the trajectory once per week. Therefore, there are two shadow mode testing results available. In both rounds of the test, all the tests mentioned in the tables below are performed by the network engineer and the shore control center captain. The KPIs are measured per test.

In the first round of tests, KPIs are measured in the 5G environment to make sure we can test in the new network setup. In the second round, a specific operation setup was created so that the tests can be done on 4G and 5G environments, in a sequence to make a comparison. The results are sorted based on KPIs, as shown in the tables below. The indications of signal quality intervals are defined in Table 19. For RSRP, the indications of *poor* and *very poor* are not acceptable. For SINR, only the indications of *excellent* and *very good* are acceptable. Furthermore, for the signal quality, three sets of data were assessed, i.e., Reference Signal Received Power (RSRP), Signal to Interference Noise Ratio (SINR), Reference Signal Received Quality (RSRQ), as presented in Table 19.

Table 19 UC 4.1 Indications of signal quality intervals.

Level	Measurement RSRP	Measurement SINR	Measurement RSRQ
excellent	Between -85dB and -43dB	Between 13dB and 30dB	Between -9dB and -3dB
very_good	Between -95dB and -85dB	Between 4.5dB and 13dB	Between -11dB and -9dB
good	Between -101dB and -95dB	Between 2dB and 4.5dB'	Between -13dB and -11dB
fair	Between -108dB and -101dB	Between 0 and 2dB	Between -15dB and -13 dB
poor	Between -115dB and -108dB	Between -3dB and 0dB	Between -17dB and -15dB
very_poor	Between -140dB and -115dB	Between -20dB and -3dB	Between -19.5dB and -17dB'

Table 20 UC 4.1 test results.

#	Name	Definition	Result- 4G	Result round 1 – 5G	Result round 2- 5G
1	Signal strength – RSRP	The average power received from a single reference signal.	The RSRP strength is between -48dB and –89dB. This is excellent.	The RSRP strength is between -63dB and –98dB for the 5G bands. This is between excellent and good. For the reused 4G bands we see some values with a lower quality.	The RSRP strength is between -63dB and -92dB. This is between excellent and good. For the reused 4G bands we see values with a lower quality.

2	Signal quality – SINR	The signal-to-noise ratio for the given signal.	The SINR quality was between -20 and 29. The average is 1.3. This is fair and poor.	The SINR quality was between 6 and 29. It is excellent and very good. The average is 17.8 and still excellent.	The SINR quality during the full test was between 11 and 28. It is excellent and very good. The average is 19 and still excellent.
3	Signal quality – RSRQ	RSRQ is Reference Signal Received Quality.	The RSRQ quality is between -6 and -20. The average is -11, which is considered good.	The RSRQ quality is between -11 and -13. This is a good result and sufficient for the operations but less than the other quality measurements.	The RSRQ quality is for the full operational test -11 and -12. This is a good result.
4	Latency / WAN node	The amount of time it takes for an IP packet to arrive at its destination per WAN node	Latency was between 11 and 49ms with spikes above 200ms. The average was 28ms.	Latency was between 10 and 40ms with some spikes above 80ms. The average was 26ms.	Latency was between 9 and 35ms with some spikes to 55ms. The average was 15ms. During the load test, we had line saturation and ping loss.
5	Connection loss duration / WAN node	The total connection loss duration (down time) per WAN node	We had a short link saturation with connection loss to the camera feed. This saturation was during the load testing	There was no connection loss.	We had a short link saturation with connection loss to the camera feed. This saturation was during the load testing
6	VPN tunnel downtime	The amount of time the entire VPN tunnel is down	The VPN tunnel was up during the full test window. It stayed up during the link saturation.	The VPN tunnel was up during the full test window.	The VPN tunnel was up during the full test window. It stayed up during the link saturation.
7	VPN IP packet drop / WAN node	The amount of IP packets that are lost per second	No drops were noticed.	No drops were noticed.	No drops were noticed.
8	VPN maximum bandwidth	The maximum amount of data (Mb) that can go through the network per second	Speed up to 24Mbps, could be reached.	Speed between 22 and 29 Mbps, could be reached.	Speed up to 36Mbps, could be reached. In the VPN.

The WAN quality map shown in Table 20 illustrates the strength and the quality of signals during the testing phase. The WAN quality on the map is colored in three circles depending on the values of latency, signal strength and signal quality (more details shown in Figure 15).

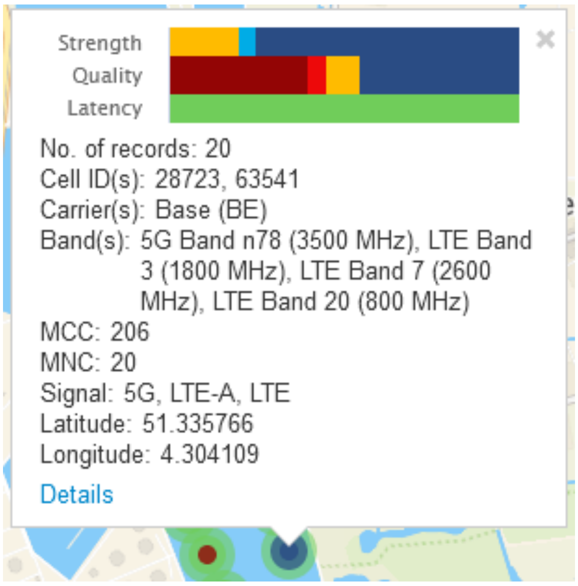
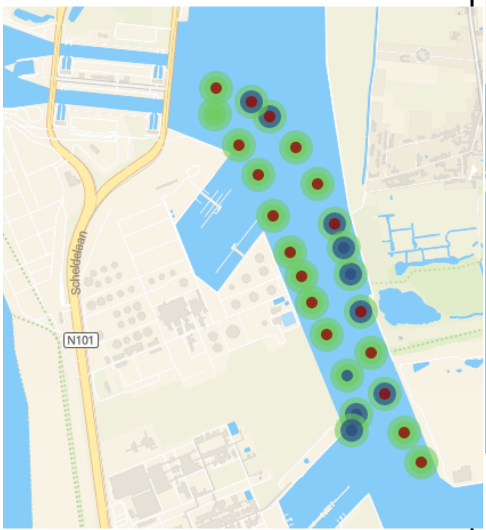
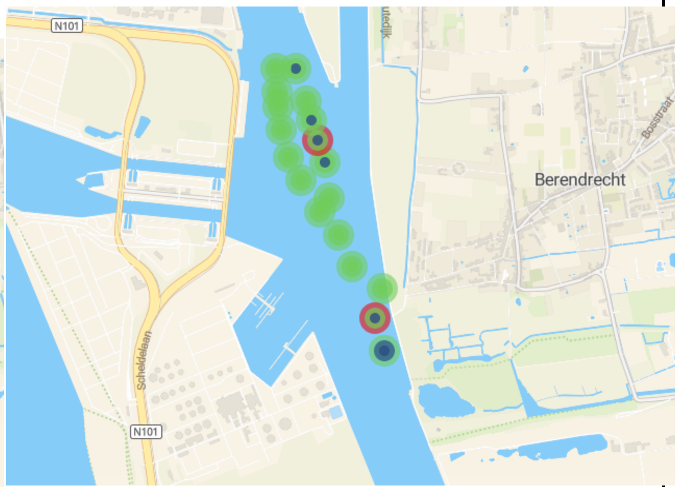
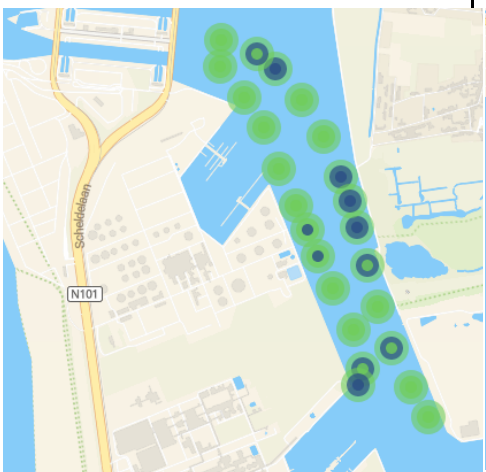
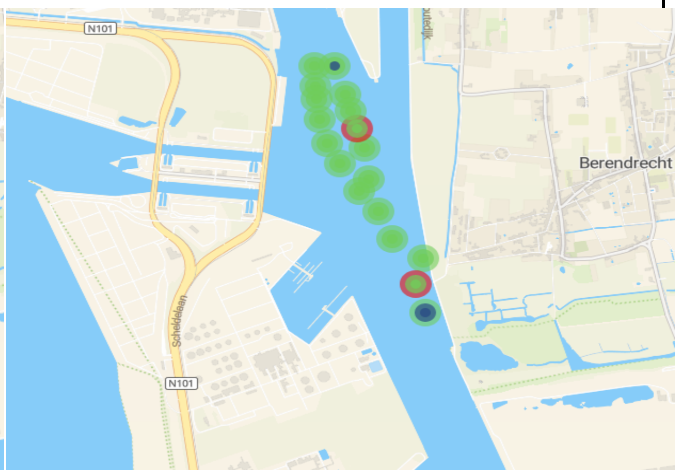


Figure 15 A detailed example of one dot on the WAN quality map.

Table 21 UC 4.1 Wan Quality map legend.

Color	Outer circle Latency	Middle circle Signal strength	Outer circle Signal Quality SINR	Outer circle Signal Quality RSRQ
Green	Lower than threshold <100ms	Excellent Between -85dB and -43dB	Excellent Between 13dB and 30dB	Excellent Between -9dB and -3dB
Dark Blue	N/A	Very Good Between -95dB and -85dB	Very Good Between 4.5dB and 13dB	Very Good Between -11dB and -9dB
Light blue	N/A	Good Between -101dB and -95dB	Good Between 2dB and 45dB	Good Between -13dB and -11dB
Orange	N/A	Fair Between -108dB and -101dB	Fair Between 0dB and 2dB	Fair Between -15dB and -13dB
Red	Higher than threshold >100ms	Poor Between -115dB and -108dB	Poor Between -3dB and 0dB	Poor Between -17dB and -15dB
Dark Red	N/A	Very Poor Between -140dB and -115dB	Very Poor Between -20dB and -3dB	Very Poor Between -19.5dB and -17dB

Table 22 UC 4.1 Wan Quality map.

KPI	5G test round 1	5G test round 2
SINR		
RSRQ		

From the results presented in this section, we can conclude that the overall quality of the signal is better on 5G compared to 4G. The values are improved, and the signal is much more stable on 5G then on the 4G test. The Latency is very stable and better on 5G than on the 4G testing. The gain in latency achieved by 5G compared to 4G is evident, where the average latency of 26.62ms is achieved using 4G, and 15.06ms with 5G. The values of jitter for both 4G and 5G can be considered as negligible, since the achieved values are 2.34ms, and 3.57ms, respectively. There was only a connection loss during a short moment of link saturation as a result of the load testing, and this was an expected behavior. Taking into account the UC4.1 network requirements presented in D5.1 [4], the performance over 4G might not be sufficient for the uplink traffic (<22ms), i.e., HD camera feeds transferred from the barge to the control services on the cloud. It could be reasonably expected that such performance could be even more hindered when more barges are simultaneously connected to the remote cloud services. On the other side, both 4G and 5G results comply with the requirements on the ship control interface (<35ms).

Concerning the bandwidth, our measurements show that up to 24Mbps could be achieved over 4G connectivity, and up to 36Mbps over 5G. The VPN was up all the time and there were no drops registered during the test window. The bandwidth for the VPN traffic was up to 36Mbps, and this is double of the current used bandwidth, and as such it will give us the chance to work on a better video quality and increase the security.

Although both results suffice the bandwidth requirements, the testing included only simple Iperf measurements, whereas more tests need to be performed to evaluate the bandwidth improvements with e.g., 10 HD camera streams on the uplink and 6 video screens per operator.

During the first 5G test, we see a big difference in signal quality between the first and the second half of the test. The reason for this difference could be the location of the wheelhouse which is between the 5G antenna and the mast during the first part of the test. We will relocate the second antenna to confirm this is the reason. During the second 5G test we have been navigating more to the North and due to this, we experienced a better 5G quality.

4.3.2 Vlis-4.2: Test and results

Short description

This section focuses on the tests performed within the scope of UC4.2, i.e., Automated driver-in-the-loop docking, in the Vlissingen pilot site area. This test combines UC4.2 with Estimated Time of Arrival (ETA, EF7) info enabling service on scaled setup using 5G NSA. All the results presented in this section are obtained while performing the use case in the Vlissingen pilot site, thus, using 5G deployment as described in Section 1.2.1.

Figure 16 Scaled truck (1:3) used in UC4.2.

Pre-conditions

- HAN and Be-Mobile have agreed on a format to share ETA and dock information over HTTP

For the Path Planner

- The path planner is installed in the control PC.
- The path planner is an A* algorithm-based path planner with motion primitives.
- Contains the motion primitives designed for scaled model.
- Contains a map of the static variables.
- Communicates with the controller as an input.
- Communicates with the localization system to take initial pose input.
- Final dock position is received from ETA (Be Mobile).
- The path planner and the path following controller are installed in a single control PC.
- The MATLAB code is executed containing the path planner

For the Path Tracking Controller (PTC)

- The Path tracking controller is installed in the control PC.
- Controller is formed by the combination of a Pure Pursuit Controller (PPC) and inverse kinematics to calculate the steer angle of the tractor
- PPC with the following parameters:
    - Lookahead distance is set to 2 [m]
    - Desired linear velocity is set to 1 [m/s]
    - Maximum angular velocity is set to 0.1 [rad/sec]
- Controller runs on MATLAB Simulink on a Windows PC running
- CAN communication is enabled within Simulink to send and receive data
- MATLAB code controls the start and stop of Simulink, where the path segment is executed
- Inputs to the PPC:
    - Planned path from the path planner
    - Localized position of the semitrailer's pose (centre axle position and orientation angle from RTK-GPS)
- PPC outputs:
    - Angle that the semitrailer needs to execute to stay on planned path
- Inverse Kinematics:
    - Calculates the steer angle of the tractor's steer axle based on PPC output
- Controller outputs:
    - Tractor steer angle in [deg]
    - Speed based on direction of motion, 1 for forward and -1 for reverse.
    - Real time tracking error and yaw rate of tractor and semitrailer (scaled setup) in int16 format to be shared with other EF via MQTT server (not achieved yet at the time of testing).
- The MATLAB code is executed containing the path following controller.

For the Teleoperation:

- The remote station with necessary hard- & software (as recommended by Robotauto)
- KPN static IP SIM card for the remote station + Network connection to the Truck
- Remote operator is present at the remote station.
- Remote take-over is activated by the remote station

- Autodocking is activated by the remote operator at the remote station (not achieved at the time of testing)

<u>For the Localization:</u>

- The RT1003 RTK system should be installed on the Truck (including RT-XLAN)
- The RT3000 v3 RTK system should be installed on the Trailer (including RT-XLAN)
- Both RT systems should be installed according to the manual, considering the most preferable settings to receive highest accuracy (max length between antennas, etc.)
- The Base Station should be set-up in the test area, with clear connection to the sky and no (or very limited) buildings around it + setting-up pole for radio antenna.
- Configuration of the entire system according to the manual
- Calibration of the entire system according to the manual.
- The pose of the scaled setup and longitudinal speed are transmitted via CAN signals after converting to the format int32 and int16 respectively.
- The vehicle signals can be tapped by supporting EF via the MQTT server (not achieved at the time of testing).

<u>For the 1:3 Scaled Truck Trailer Combination:</u>

- The 1:3 scaled Truck equipped with the HAN drive-by-wire system, attached to:
    - DC steering motor (lateral)
    - Dyno motor controller (longitudinal)
    - Roboauto DBW Hardware via CAN bus
    - Control PC (path planner & controller) via CAN bus
- Steering calibration before remote takeover or automated docking
- Both Truck & Trailer should be equipped with the RTK GPS systems
- The truck equipped is equipped with Roboauto teleoperation hardware with 4G or 5G routers. Including the KPN sim cards for the 4G and/or 5G Network connection.
- Operator present at the truck (near the kill switch)
- Tests will be performed at initially slow speeds of ±5 km/h.
- The test site area should be approximately 25 x 25m and isolated with limited traffic / other participants. The weather conditions should be ideal (clear sky, no rain, etc.)
- Datalogger configured to log vehicle and teleoperation signals to monitor performance. Signals include throttle, brake and steering inputs received from the remote station; throttle signals (% throttle and forward or reverse) and steering inputs received from the path (following) controller; actual throttle signals and steering angle of the vehicle.

<u>Test inputs</u>

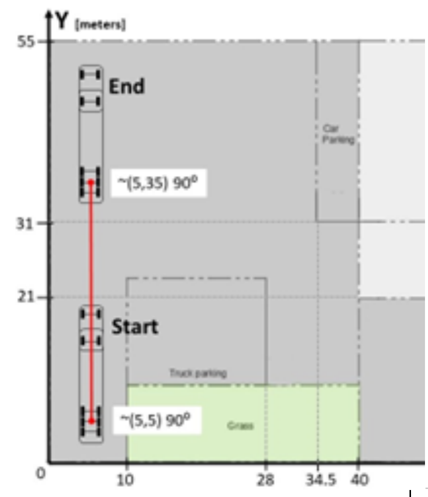
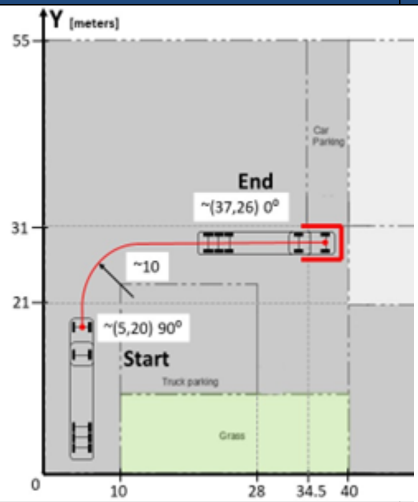
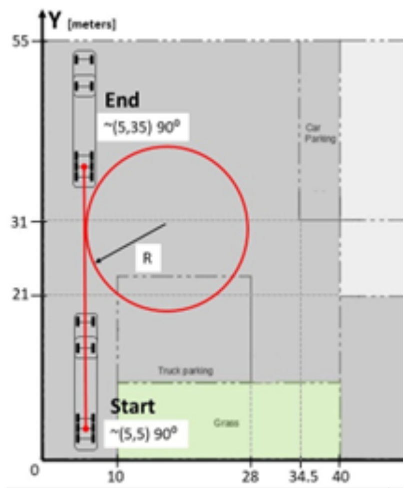
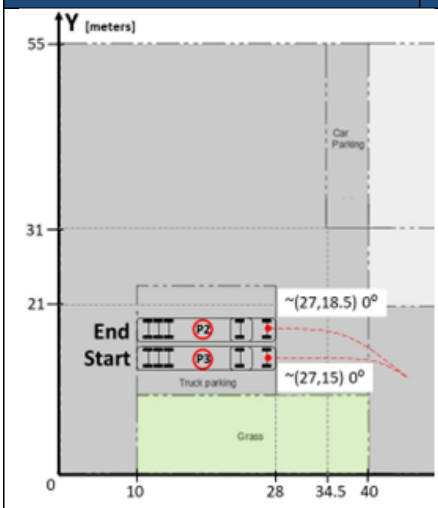
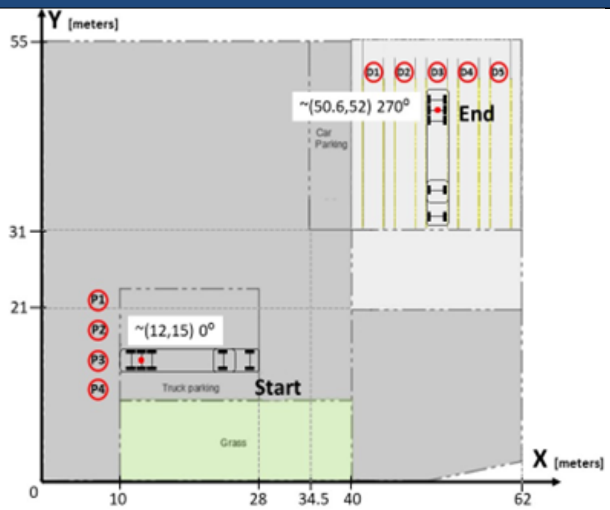
GPS trace is needed as input to emulate outdoor trajectory when performing this test case in a lab setting.

To perform the Automated driver in the loop docking functionality the inputs required are:

- Calibration of wheels/steering mechanism. From the operator (TC) to truck
- Initiating the Automated driver in the loop docking. From the operator (TC) to truck
- The throttle %, forward or reverse motion and the steering angle. From PTC to truck
- Vehicle video feed and status (odometry). From truck to the operator / remote station.
- Actual position (X, Y) and heading of the Truck-Trailer. From GPS to the Control PC
- Final pose is received from ETA (to be emulated in the MVP phase, yet respecting agreed formats to be used also in full scale deployment).

All other necessary inputs are obtained from different sensors installed by the HAN (or V-tron).

Table 23 The description of test maneuvers in UC4.2 deployed in Vlissingen.

<table>
<tr><th>Straight line (forward & reverse)</th><th>90°trun (left & right + forward & revere)</th><th>360° circle (forward & reverse)</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Driving a straight line for 10 meters. One forward path and one reverse path.</td><td>Driving a 90 degree turn. Forward left, forward right, reverse left and revere right</td><td>Driving a 360 circle with start & end being a straight line. One forward path and one reverse path.</td></tr>
<tr><th>Parallel Parking Maneuver</th><th colspan="2">Auto-docking Maneuver</th></tr>
<tr><td>
</td><td colspan="2">
</td></tr>
<tr><td>Driving from one “parking spot” to the one next to it. Forward & Reverse paths</td><td colspan="2">Driving from a random position to a specific dock which is being provided by EF7 -ETA. First driving a forward path, then a reverse path</td></tr>
</table>

Results

The RTK GPS sensors were accurate up to 2.4 [cm] on the day of the test. Before the auto-docking test is performed, the dock number is received from Be-Mobile through EF7. The example of initial and final positions of the vehicle are shown in the Paths figure, i.e., Figure 17. The path that was planned for the docking maneuver is depicted in the figure as 'Reference path', which holds for the semitrailer middle axle. The reference path involves a forward maneuver followed by a reverse into the dock position.

Once the path is planned, the path tracking controller performs the maneuver with the steering angles as shown in the figure on the right-hand side. The trajectories of the tractor and the semitrailer are overlapped in the Paths graph, and it can be seen that the semitrailer path follows very well. Hence, the path tracking error is visualized in the figure on the right. The error is less than 0.1 [m] throughout the entire maneuver, with the forward path being exceptionally good with an average error of 0.004 [m], whereas the reverse shows an average error of 0.04 [m]. The lateral end position error is 0.062 [m]. The entire docking sequence took 90.1 [s] in total.

Quantitatively comparable results were obtained also for other test maneuvers specified in Table 23. The worst-case performances of all KPIs are then summarized in Table 24, showing the targets were met.

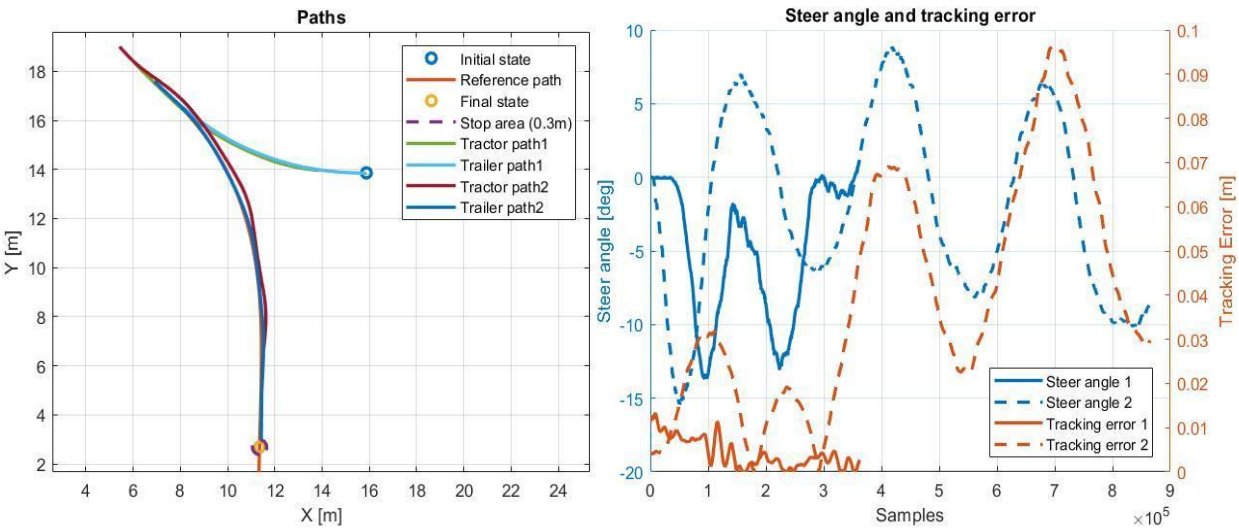


Figure 17 Auto-docking, left: Top view of the vehicle positions during docking, right: Steer angle applied by the controller along with the tracking error of the maneuver.

Table 24 KPIs obtained for UC4.2: Automated driver-in-the-loop docking.

#	KPI	Definition	Target value(s)	Measurement	Vlissingen result
1	Path planning time	The time it takes the path planner to plan the desired path for docking	< 6 [s]	Measured by the controller with a (digital) clock.	Average 1.7 [s] and maximum 5.1 [s]
2	Tracking Error Real time	The lateral difference between the actual position of the truck and trailer and the generated	The lateral deviation during maneuvering is < 0.25 [m] in terms of Maximum and Average Value	Measured by comparing the trailer axle location with the desired location of the reference path. The actual trailer location is measured by the RTK-GPS system (the measured sensor location should	Average 0.03 [m] and maximum 0.22 [m]

		reference path during maneuvering.		be translated to the axle position).	
3	Final Docking state error	The difference between the actual docking position and the planned docking position after the docking maneuver is performed.	The lateral deviation after docking is < 0.10 [m] The longitudinal deviation after docking is < 0.10 [m] The orientation angle of the trailer after docking is < 2 [o]	The deviation & orientation angle are calculated by comparing the measured position and heading with the designated docking position and heading. The lateral and longitudinal deviation can be compared with the actual on-site position (measured with laser or ruler) at the dock.	Lateral: Average 0.05 [m] Longitudinal: Average 0.01 [m] Orientation: Average 0.9 [o]
4	First time right rate	The ratio of the path tracking controller maneuvering the vehicle combination over the generated path first time with failures to the path tracking controller maneuvering the vehicle combination over the generated path first time without any failure.	The ratio should be < 0.5 [-]	Count the amount of initiated path tracking maneuvers that fail and the amount of path tracking maneuvers that succeed first time without any failure.	0 All maneuvers were successful
7	Elapsed time / total docking time	The time between the initial movement and the final stop of movement at the end position.	Maximum elapsed time of 200 [s]	The elapsed time is measured by the controller with a (digital) clock.	Maximum 110 [s]
8	Static GPS Position tolerance	The tolerance in position of the truck and trailer in X and Y direction.	X position < 5 [cm] Y position < 5 [cm]	The tolerance is measured with help of the position accuracy measured by the GPS system in [cm].	X position 2.4 [cm] and Y position 2.4 [cm]
9	Static GPS Heading tolerance	The tolerance in heading of the truck and trailer.	Heading tolerance < 0.5 [deg]	The tolerance is measured with help of the heading accuracy measured by the GPS system in [deg.	Heading 0.5 [deg]

ETA (EF7) was correctly integrated into UC 4.2, with all ETA requests handled within the time limit of 30ms. The complete performance measurement of EF 7 will be conducted in the next phase of the project.

4.3.3 Vlis-4.3: Test and results

Short description

This section focuses on the tests performed within the scope of UC4.3, i.e., CACC-based platooning, in the Vlissingen pilot site area. This test combines UC4.3 with Distributed perception (EF4) using 5G NSA. All the results presented in this section are obtained while performing the use case in the Vlissingen pilot site, thus, using 5G deployment as described in Section 1.2.1.

Figure 18 Vehicles used in Use cases 4.3 and 4.4.

Pre-conditions

- Safety systems test and CACC activation tests
- V2V communication tests
- Both the vehicles equipped with OBU for V2V communication via PC5 mode 4
- Acceleration and speed of the following vehicle is measured from the vehicle CAN bus
- Acceleration and speed of the lead vehicle is measured via the vehicle CAN bus and sent via the OBU to the following vehicle
- Following vehicle equipped with V-Tron vision system to measure relative speed and distance
- Following vehicle equipped with the necessary CACC hardware/software
    - Hardware: V-Tron CANBox
    - Software: Controller to compute the required acceleration to maintain the target following distance
    - Target acceleration forwarding via CAN to the vehicle
- Safety drivers present in vehicle for monitoring longitudinal motion and to provide lateral control as the MVP version is limited to longitudinal control
- Minimum road segment length must be greater than 200 meters
- Test performed in isolated road with no traffic

Test inputs

- CACC system manually activated by the driver
- Steering inputs to control lateral motion
- Acceleration and speed values from lead vehicle over V2V and relative speeds from vision sensor on board the following vehicle
- Acceleration and deceleration inputs to following vehicle from CACC controller via vehicle CAN bus

Test procedure

- The lead vehicle driven at low speeds (40-60 Kmph)
- CACC activated when the vehicles reach a stable target speed (45 kmph in Vlissingen tests)
- The following vehicle equipped with CACC system on-board follows the lead vehicle with a desired headway time
- Three main scenarios for testing CACC
  - Gap closing: The acceleration of the lead vehicle will be increased gradually, and the behavior of the following vehicle will be monitored and logged. The following vehicle is expected to close the gap created because of the acceleration.
  - Following: The lead vehicle will be driven at a constant speed (zero acceleration), and the behavior of the following vehicle will be monitored and logged. The following vehicle is expected to follow the current following distance (without large variations)
  - Collision avoidance: The lead vehicle will be decelerated aggressively (to a complete stop), and the behavior of the following vehicle will be monitored and logged. The following vehicle is expected to react and decelerate instantly and avoid a collision.
- The delay or packet loss in communication will be logged for analysis
- For safety reasons, the driver can deactivate the CACC system at any given time and manually take control of the vehicle (when the communication is lost or during safety critical situations) by just pressing the brake pedal.
- Vehicle ACC will take over (fallback) when there is loss in communication

Results

A comparison was made between the stock ACC, CACC with WiFi-P, i.e., ITS-G5 communication and CACC with C-V2X communication. The test was performed in a closed environment with lead vehicle driving at approximately 45 Kmph and then the speed was increased to 60 Kmph and then reduced back to 45 Kmph before coming to a complete stop. The following vehicle was able to follow the lead vehicle in all the cases and the difference in the performance is shown in the plots above.

The comparison between the stock ACC and CACC system is made to show that the developed CACC system is capable of performing the similar characteristics of ACC, but with reduced head way time (following closely). The overall reaction time is reduced when using CACC as the current state of the lead vehicle is always communicated to following vehicle, whereas with ACC the sensor needs to measure the state of the lead vehicle. With this the following vehicle reacts faster in case of acceleration or deceleration, which allows to follow with shorter inter vehicular gaps while ensuring safety. The activation and the basic functioning of CACC is kept similar to that of stock ACC system to minimize the complexity and to ensure safe operation. Furthermore, during the tests carried out in Vlissingen, the measurements were taken with regards to the KPIs, and they are presented in Table 25.

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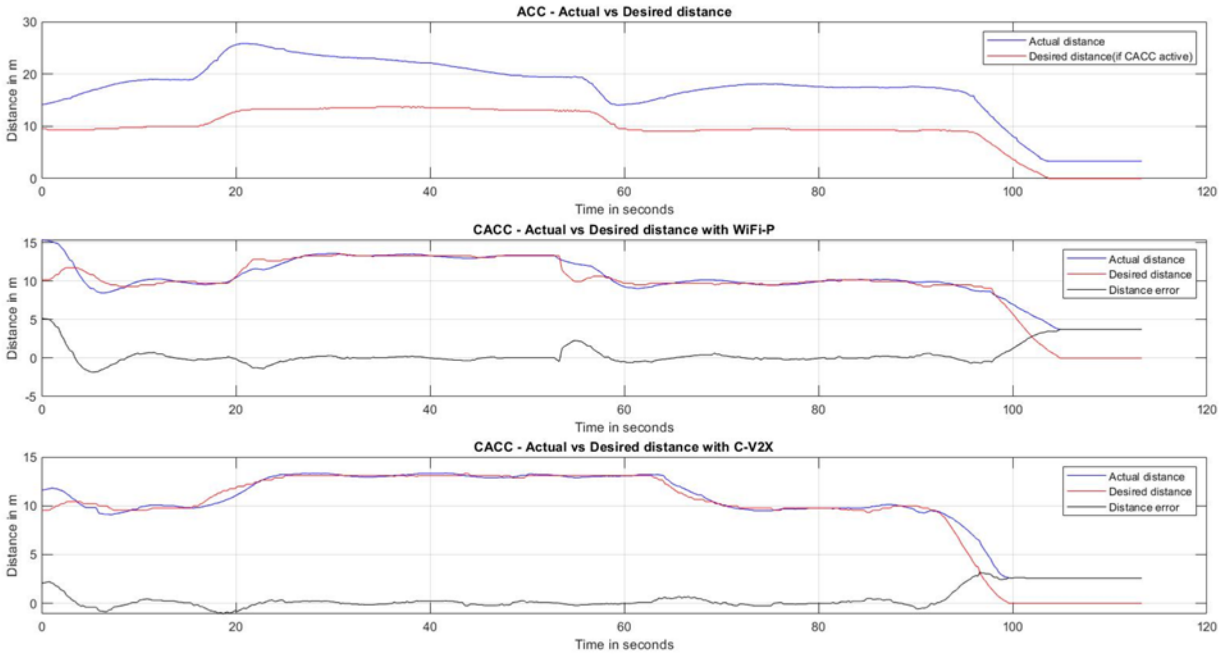

Figure 19 CACC Distance Plots.

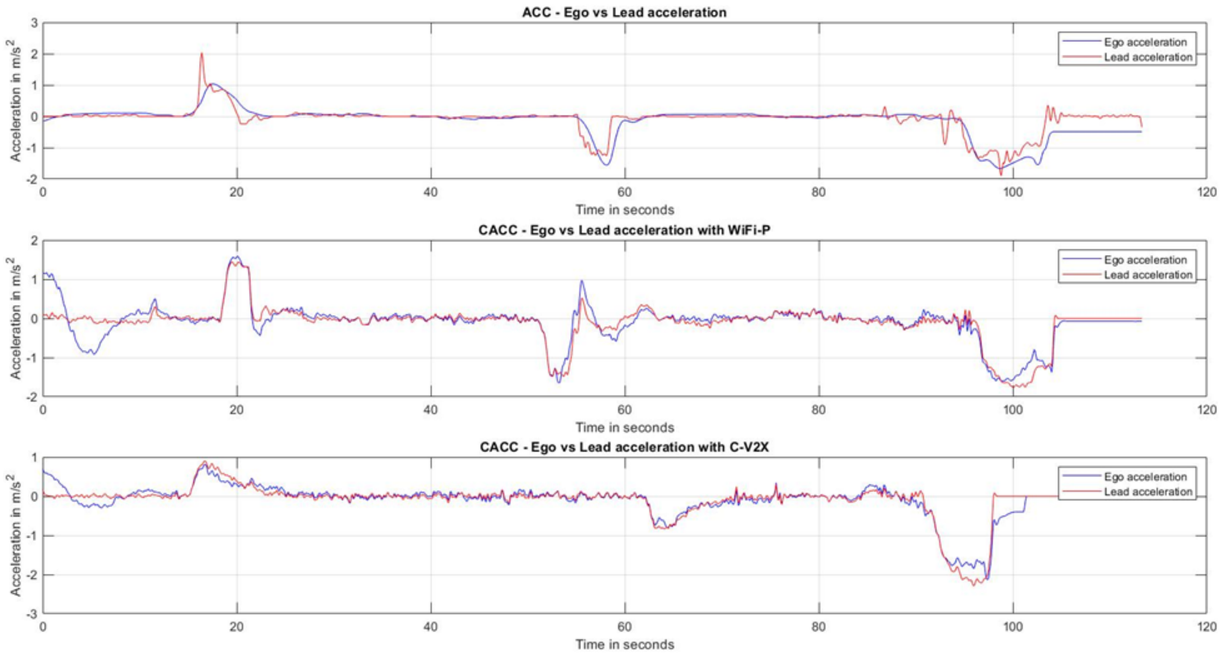

Figure 20 CACC Acceleration Plots.

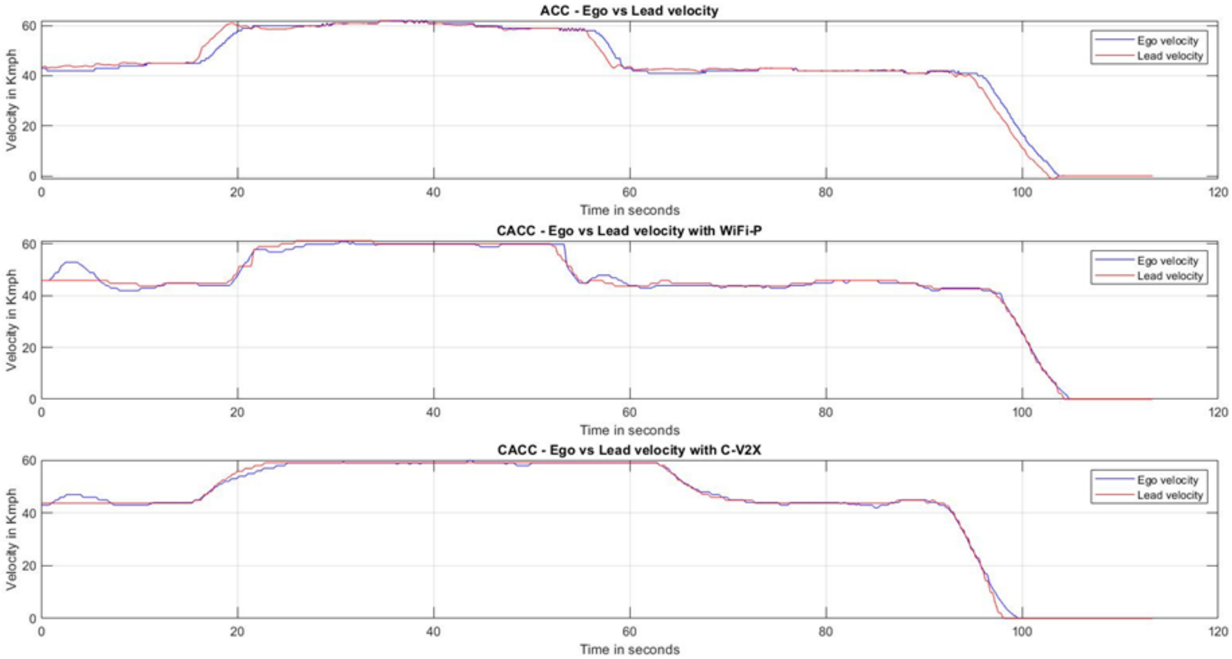

Figure 21 Velocity Plots.

Table 25 KPIs obtained for UC4.3: CACC based platooning.

#	Name	Definition	Measurability	Target value [units]	Results Vlissingen
1	Following distance	The minimum achievable headway to the lead vehicle	Headway time measured with sensors in (s)	1 s	0.8s
2	% Distance error	Percentage of difference between actual and desired distance	Calculated based on the measured values with sensors	Less than 5% (in steady state condition)	<5%
3	Latency - V2V communication	Delay communicating the message from lead vehicle	Calculated from the time stamp data measured in (ms)	Less than 10 ms (for distance up to 60 m)	20 – 25 ms
4	Max speed	Maximum achievable speed with CACC	Can be measured from GPS / CAN bus in (Kmph)	80 Km/h	90 Km/h
5	Max acceleration/ deceleration	Rate of response of the following vehicle	Can be measured from CAN bus in (m/s^2)	2.5 to -3.5 m/s^2	Values are within the maximum limits
6	Overall system delay	End to end latency including all the delays (Communication & processing delay)	Will be computed from data post processing (ms)	100 ms	120-150 ms
7	Number of human interventions	How many times does the driver / teleoperator needs to take control when driving under CACC	Number can be measured during the manoeuvre	0 (in normal driving conditions)	0

Table 26 KPIs obtained for EF4: Distributed perception.

#	Name	Definition	Measurability	Target value [units]	Results Vlissingen
1	LiDAR pointclouds broadcasted	The the time required to publish and receive the point clouds after the snapshot	Measuring the time between the LiDAR's snapshot, processing, publishing, then receiving it. The point clouds should be received no later then 80ms from the time of the snapshot	50-70ms	The point clouds were received after 50-90ms after the snapshot depending on the signal strength in the location of the vehicles.
2	Fusion algorithm computation time	Time required to transform and fuse the point clouds	Point clouds transformed and fused in a maximum of 500ms	less than 400ms	The fusion took around 300miliseconds to fuse both point clouds

3	Object detection average precision and accuracy	Object's available being successfully detected by the algorithm	Visual comparison between objects seen by eye can be detected.	Visual assessment, comparing what can be seen by eyes and what is detected	In many cases the objects were detected correctly. However, some further validation work needs to be implemented to ensure higher accuracies in complex scenarios.

4.3.4 Vlis-4.4: Test and results

Short description

This test included performance evaluation of Remote takeover, i.e., UC4.4, including supporting enabling functions. All the results presented in this section are obtained while performing the use case in the Vlissingen pilot site, thus, using 5G deployment as described in Section 1.2.1.

Pre-conditions

For Remote Takeover (UC4.4):

- Network Setup should be completed on the remote station side and the vehicle side
- Safety Systems Tests
- Brake Responsiveness Tests
- Steering Responsiveness Tests
- Throttle Responsiveness Tests
- Driving Accuracy Tests
- Data Sharing Test
- MQTT Server Test
- Collision avoidance test and optimization
- Overall Teleoperation Functionality Tests

For Enhanced Awareness Dashboard (EF1):

- Be-Mobile: EAD web tool visible on secondary screen
- Be-Mobile: Widget on EAD where vehicle id can be selected
- Be-Mobile: Connection to back-end Be-Mobile
- Roboauto: GNSS data (with vehicle-id) from Roboauto
- TO: correct vehicle id must be selected on the secondary screen and route destination is entered in EAD

For Vulnerable Road User Interaction (EF2):

- 5G connectivity
    a. KPN provides a 5G SIM to LN
    b. LN installs SIM in 5G smartphone

c. LN confirms that the smartphone is connected through the 5G test network of KPN to the MQTT service of EF2 (EF2-MQTT). Should this not be the case then LN resolves this with KPN.

- TOV operational and publishing vehicle path
  a. The teleoperated V-Tron vehicle publishes GNSS data in real-time.
  b. Based on the GNSS data, Be-Mobile (EF1) continuously produces VAM messages and publishes these to the MQTT service of EF2.
  c. LN confirms that TOV-VAM messages are published on the EF2-MQTT.
- App operational
  a. The Vectordrive app is installed on the 5G smartphone
  b. LN confirms that the app publishes CAM or VAM messages on the EF2-MQTT
  c. Smartphone screen recording is turned on
- Dashboard EF1 operational
  a. The dashboard is operational and shown to the TO
  b. Screen recording is turned on during the tests

For ETA Sharing (EF7):

- Roboauto: MQTT connection is operational and GNSS data is available
- TO: Correct vehicle id must be selected on the secondary screen and route destination is entered in EAD. Moreover, the TO should follow the proposed route.
- Routeplanner of BEM is operational

Test inputs

For Remote Takeover (UC4.4):

- Logging setup online
- Steering, brake and throttle input
- Data sharing via MQTT

For Enhanced Awareness Dashboard (EF1):

- Map data from Be-Mobile needs to be available
- Traffic information Be-Mobile needs to be available
- Vehicle id must be known

For Vulnerable Road User Interaction (EF2):

- Log file listing messages published on the MQTT
- Screen recording per test run of smartphone app
- Screen recording per test run of EF1-dashboard

For ETA Sharing (EF7):

- Roboauto: GNSS data (with vehicle-id) from Roboauto
- TO: correct vehicle id must be selected on the secondary screen and route destination is entered in EAD

Test Procedure for Remote takeover, i.e., UC4.4

- **Safety Systems Test Procedure:** This test should be executed with the vehicle travelling at very low speeds (< 5 km/h). In order to avoid any kind of injuries resulting from harsh braking. The test is to be carried out both from the remote station and from inside the vehicle as follows:
  - **From the remote station**: i) the remote station is put in neutral (drive is deactivated); on the vehicle, this should result in: Brake signal fully applied (100%), Throttle is not applied (0%) and steering angle is 0°, ii) the connection between the remote station and the vehicle is lost; on the vehicle, this should result in: Brake signal fully applied (100%), Throttle is not applied (0%) and steering angle is 0°.
  - **Inside the vehicle**: The safety driver presses the manual steering override button; this should immediately give manual steering capabilities to the driver.
- **Steering Responsiveness Test Procedure:** Once the connection between the remote station and the vehicle is established, the remote operator turns the steering wheel in the desired direction; the vehicle's steering wheel should match the requested steering angle with minimal delay. By keeping the remote station steering wheel in a fixed position, the vehicle's steering wheel should keep the requested angle in a stable manner; this should be true of the steering angle transitions as well.
- **Brake Responsiveness Test Procedure:** Once the connection between the remote station and the vehicle is established, the remote operator depresses the brake pedal by a certain percentage; the vehicle's braking power should match the requested one with minimal delay. By keeping the remote station brake pedal in a fixed position, the vehicle's brake force should keep the requested percentage in a stable manner. The behavior of the brake pedal should result predictable and natural, unwanted jerking should be minimal.
- **Throttle Responsiveness Test Procedure:** Once the connection between the remote station and the vehicle is established, the remote operator depresses the accelerator pedal by a certain percentage; the vehicle's acceleration should match the requested one with minimal delay. By keeping the remote station throttle pedal in a fixed position, the vehicle's acceleration should keep the requested percentage in a stable manner. The behavior of the vehicle's acceleration should result predictable and natural, unwanted jerking should be minimal.
- **Driving Accuracy Test Procedure:** In order to evaluate the accuracy and possible delays of the driving experience, the incoming messages to the vehicle will be logged. The physical actuation of the vehicle will be logged as well, and by comparing the output graphs, the delay will be evaluated. Little delay will indicate a good accuracy of the actuators and an overall perception of good accuracy.
- **Slow Speed Maneuvering Test Procedure:** The vehicle needs to be connected to the remote station, and the previous tests need to have a satisfactory result before carrying this one out. The vehicle will be remotely operated, with the presence of the safety driver, at low speeds. This will simulate a parking maneuver, thus the steering angles will be large, and the speeds low. The result of this test will further validate the correct functioning of the actuators, their tuning and the network stability.

- **Regular Speed Maneuvering Test Procedure:** The vehicle needs to be connected to the remote station, and the previous tests need to have a satisfactory result before carrying this one out. The vehicle will be remotely operated, with the presence of the safety driver, at higher speeds, compared to the previous test. This will simulate an everyday driving experience; thus, the steering angles will be small, and the speeds will be close to the legal limit. The result of this test will further validate the correct functioning of the actuators, their tuning, and the network stability.

The Enabling Functions tests are done in the framework of this use case UC4.4, i.e., Remote Takeover, and below we define the testing procedure from the perspective of the integrated enabling functions.

Test for Enhanced Awareness Dashboard (EF1): For this test, EF1 demonstrates that alerts from enabling functions are instantly received and offered on a secondary display to the TO. This is crucial to drive the TOV as safely as possible. The display standard contains the Be-Mobile map with the ETA (EF7) based on Be-Mobile data only (Traffic Data, events, such as roadworks and traffic lights). It is enhanced with widgets per enabling function offering instant alerts. Moreover, the predicted path of pedestrians and cyclists and the location of potential collision with those pedestrians are offered by Locatienet (EF2) by means of VAM (location and heading and predicted path) and DENM (location of potential collision and time to collision) messages. When the TOV performs some actions or some information is received, we expect something on the secondary display. Thus, the steps below do not have to be necessarily executed in a chronological manner.

Test for Vulnerable Road User Interaction (EF2): The test demonstrates that Vectordrive smartphone app, developed by Locatienet (LN) as Enabling Function EF2, detects potential collisions with a probe vehicle and that this collision is presented in the EF1 dashboard developed by BeMobile, to the TO.

Test for ETA Sharing (EF7): Initially, a route request is processed resulting in a route, turn-by-turn instructions and speed information. Moreover, the test demonstrates that Estimated Time of Arrival (EF7) is continuous recalculated based on the GNNS data coming from the TOV (Roboauto), in combination with the Be-Mobile data only (Traffic Data, events, such as roadworks).

Results

The graphs shown in Figure 22, the comparison between the behavior of the vehicle as requested by the remote operator and the one accomplished by the vehicle. This was done to show relevant data regarding the reactivity of the system with respect to steering angle, throttle position and brake position. During the period of 30 seconds, the speed of the vehicle greatly varies, starting from a standstill, up until 15 km/h.

It can be seen how the graphs are very closely related, with only minor error. This can be further implemented, but there is an inherent error factor which cannot be nullified, primarily due to the physical actuation of the system.

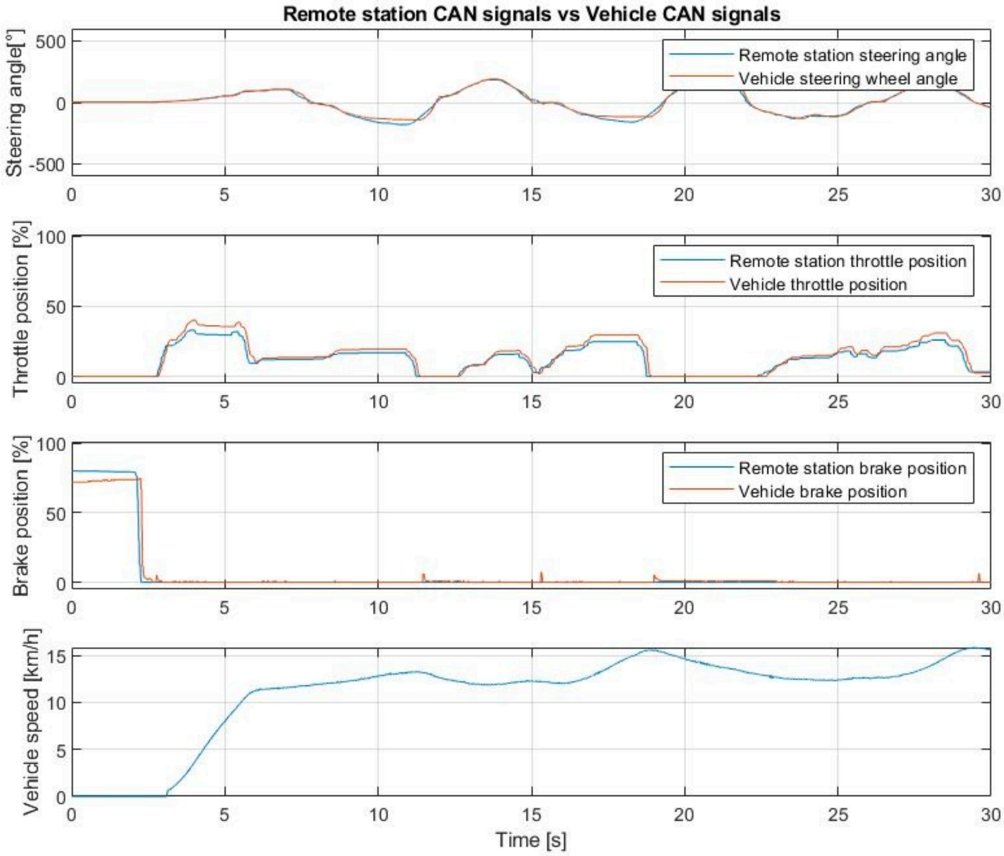

Figure 22 Teleoperation Plots.

Table 27 KPIs obtained for UC4.4: Remote takeover.

#	KPI	Definition	Target value(s) [unit]	Measurement	Results Vlissingen
1	Steering Accuracy	The input given through the driving station should be the same on the teleoperated vehicle.	Mean error < 0.1 [º] Mean Absolute Error (MAE) < 3.0 [º] Root Mean Squared Error (RMSE) < 5.0 [º]	The steering wheel rotation is measured in degrees (º)	N/A
2	Pedals Accuracy	The input given through the driving station should be the same on the teleoperated vehicle.	Mean error < 1.0 [%] Mean Absolute Error (MAE) < 4.0 [%] Root Mean Squared Error (RMSE) < 6.0 [%]	The pedal travel, throttle and brake, are mapped to a percentage (0-100%)	N/A

3	Overridability	The vehicle driver can instantly override all automated systems and completely revert to initial OEM status by pressing the manual override button.	< 1 [ms]	System reaction time	N/A
4	Maximum safe speed	Maximum possible speed for safe teleoperation.	25 [km/h]	Gathered teleoperator feedback	>30km/h
5	Action time ratio	Ration of time required for task completion (teleoperation driver/onboard driver .)	90 [%]	Roboauto application logs driving mode, calculated from these logs	100%
6	Orientation time	Time required for teleoperator driver to obtain situational orientation in space.	8 [s]	Stopwatch is used to measure time from connecting to the vehicle to being able to start teleoperating	5s
7	Latency(video/commands)	Time taken to receive a response. The start and the end time for measurement of latency. (internal RBA latency measure)	mean < 20 [ms] max < 30 [ms]	Roboauto internal latency measuring algorithm, mean of means, mean of maxes	NSA: mean 18.4ms max 31.4ms SA: mean 11.38ms max 19.8ms
8	Bandwidth	% of network bandwidth used.	80 [%]	Calculated from Roboauto application log data and iperf3 measurements	SA: 35% upload NSA: 90% upload
9	Time to reconnect	Time required for teleoperation system to reconnect to vehicle. Time from system start after a crash to successful connection to vehicle	<5 [s]	Roboauto application log data	2.3s

Although the lists of KPIs are presented in Section 3.3, the performance evaluation of enabling functions EF1 and EF7 that supported UC4.4 is presented as work-in-progress for the MVP phase, whereas most of the KPIs need to be evaluated and studied in the final deployment of the 5G-Blueprint platform. Thus, the following figures (Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, Figure 28, Figure 31, Figure 29) illustrate the integration success between different enabling functions and UC4.4, while in D7.4 the detailed evaluation of EF performance will be presented.

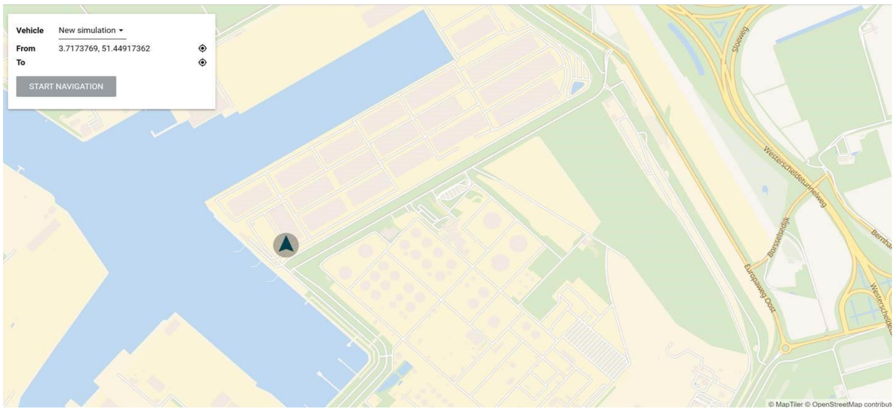

Figure 23 Availability of current position, speed and heading of the TOV for EF1: Location of vehicle received from MQTT server on the EF1.

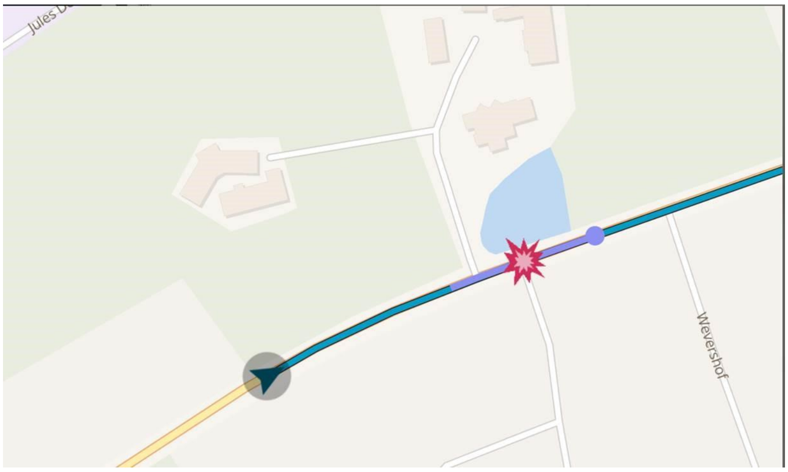

Figure 24 Efficiency of displaying VRU information on EF1: (1) VAM (location and heading, expected path) of TOV (blue arrow) and VRU (blue bullet) on EF1, (2) DENM (location and time of potential collision between TOV and VRU - Red star).

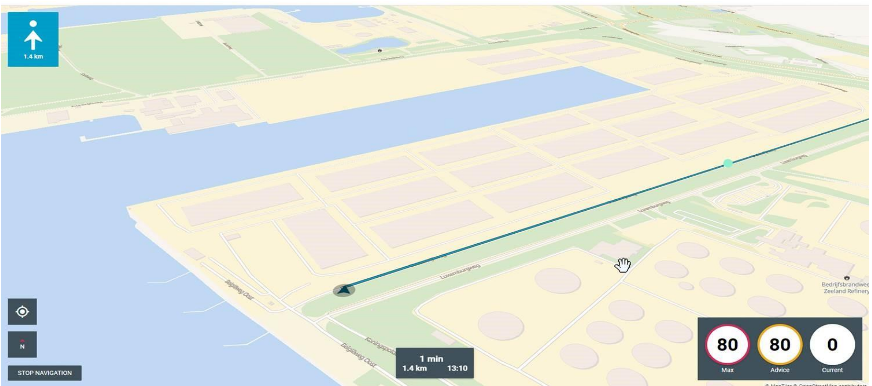

Figure 25 Availability of route information on EAD (EF1) and Efficiency of displaying results from EF7

(Estimated Time of Arrival Sharing) on EF1: Route and Estimated Time of Arrival (EF7) of TOV on the Enhanced Awareness Dashboard (EF1) offered to the TO.

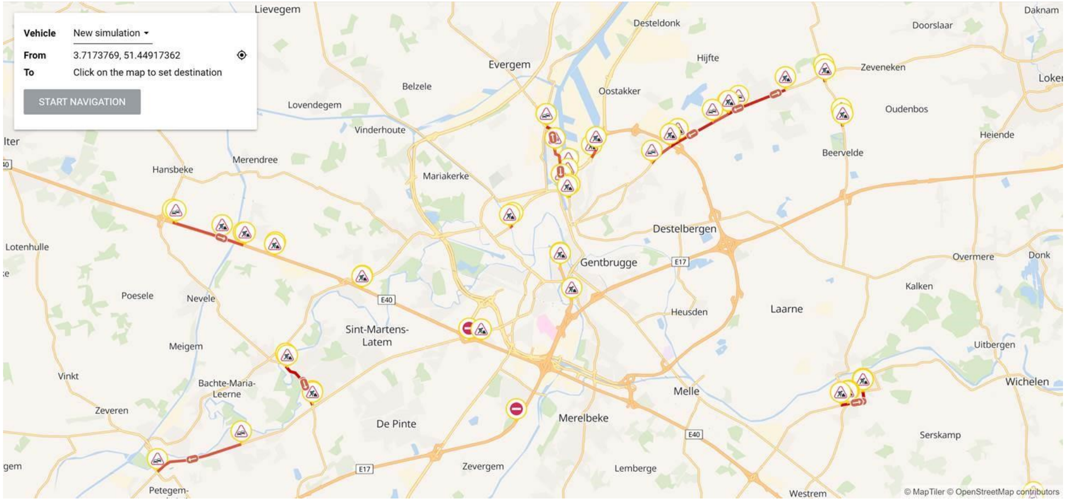

Figure 26 Availability of route information on EAD (EF1) and Efficiency of displaying results from EF7 (Estimated Time of Arrival Sharing) on EF1 (2): Traffic Data of Be-Mobile taking into account in the route and EF7 calculation for the TOV, offered to the TO.

Figure 27 Efficiency of displaying results from EF4 (Distributed perception) on EF1 (1): Critical objects (red cuboid) for the TOV, detected by EF4 are displayed on the EF1 for the TO.

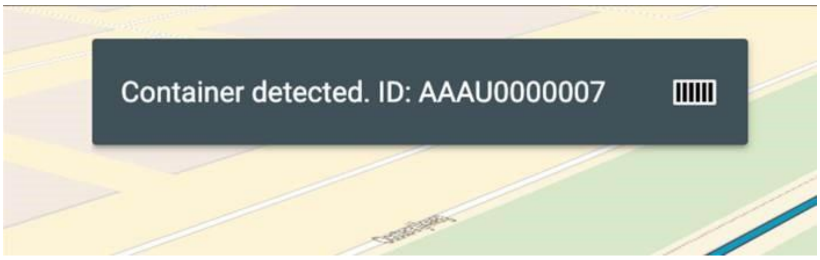

Figure 28 Efficiency of displaying results from Container ID recognition (EF6) on EAD (EF1): Container ID of the TOV, recognized by EF6 is displayed on the EF1 to the TO.

Furthermore, for Active Collision Avoidance, i.e., EF5, more results are presented in Table 28 and Figure 29. Figure 29 shows the visualization of obstacle detection captured during Vlissingen tests. During the tests, there were many more false positives than planned, but after analysis the problem was solved based on better configuration of the system. On records from tests, we achieved two false positives per hour.

Table 28 KPIs obtained for EF5: Active collision avoidance.

#	KPI	Definition	Target value(s) [unit]	Measurement	Result Vlissingen
1	False negative rate	Failure to activate with obstacle present	<5 [%]	A series of tests using a dummy will be performed and the results will be recorded.	2%
2	False positive rate	Erroneous activation without obstacle present	<3 [#/hour]	ACA will be active during teleoperated driving, erroneous situations will be manually noted.	5/hour

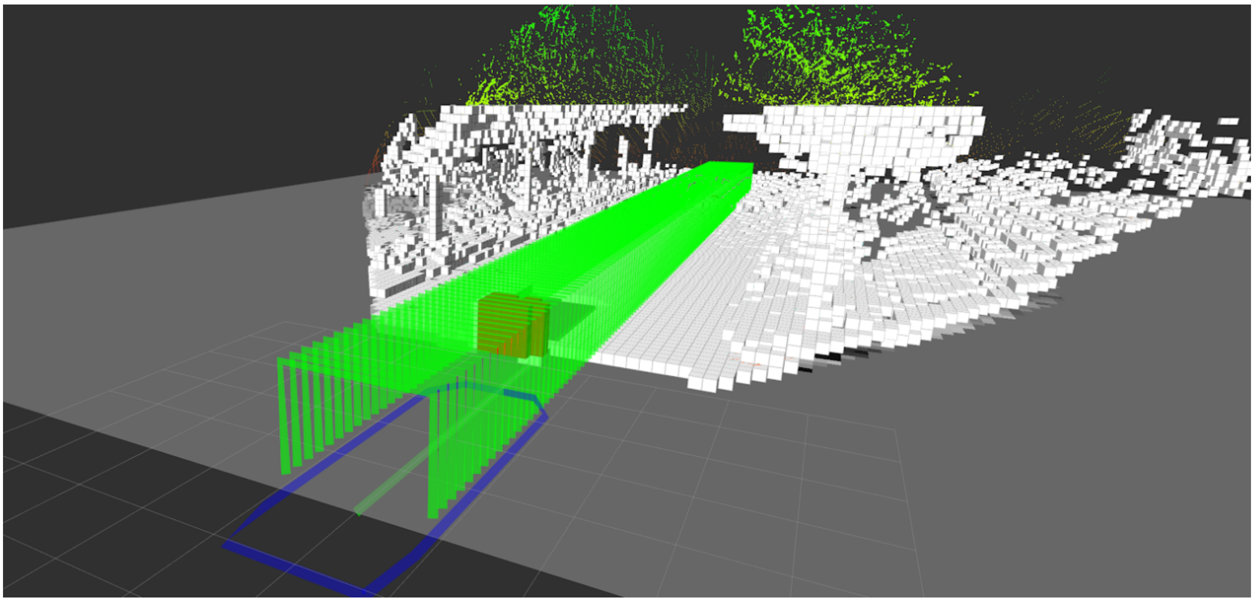

Figure 29 Visualization of obstacle detection.

In case of Container ID recognition (EF6), Figure 30 shows the working prototype that was tested in June 2022. This set-up was tested outdoors with random containers. In the indoor environment, a demo was given with three different container boards that could be shown before the camera and their codes were recognized in real-time.

The test has demonstrated an end-to-end working prototype of a 5G SA-connected camera. This camera is connected to the 5G SA network with a modem and the video stream is routed to an edge node in the KPN network where the software runs. This software recognizes the container codes and the results are submitted via an API push on the internet to EF1.

Figure 30 The working prototype of Container ID recognition (EF6).

4.3.5 Antw-EF8: Test and results

Short description

The aim of this test was to trial the environmental anomaly detection through enabling function Scene Analytics (EF8) to enable safe remote takeover operation. Video streams from on-site video surveillance cameras as well as a drone are processed in order to identify unusual situations that could present risks for the operation of the truck. Alerts are then transmitted through EF1 and EF7 so that the remote operator can take appropriate action. Testing was conducted in conjunction with EF1 and EF7 in the Antwerp pilot site, thus, using 5G deployment as described in Section 1.2.2. Further testing will be conducted in Q2 2023 to validate the network performance of the 5G infrastructure.

Pre-conditions

- An established 5G connection. WiFi and 4G are used as fallback.
- An operational drone, that offers video and location to Room40.
- The communication between Room40 and Be-Mobile needs to be in place

Test inputs

- Testing was done with a virtual truck.
- In the absence of live location data, simulated truck data was produced by Be-Mobile.
- Location and video feed was streamed from a drone provided by Room40.
- The test start location was designed as 5 minutes away from the Roosens site in Antwerp (provided by Room 40 in advance to Be-Mobile).

- The coordinates of the destination site in Antwerp were provided by Room 40 in advance to Be-Mobile.
- The input live location data of the simulated truck (no needed from location in Antwerp) with interval were provided by Be-Mobile.

Results

Same as in the case of other enabling functions within UC4.4, a detailed performance evaluation of EF8 is planned for the final platform, while for the MVP phase, a work-in-progress overview is illustrated in Figure 31.

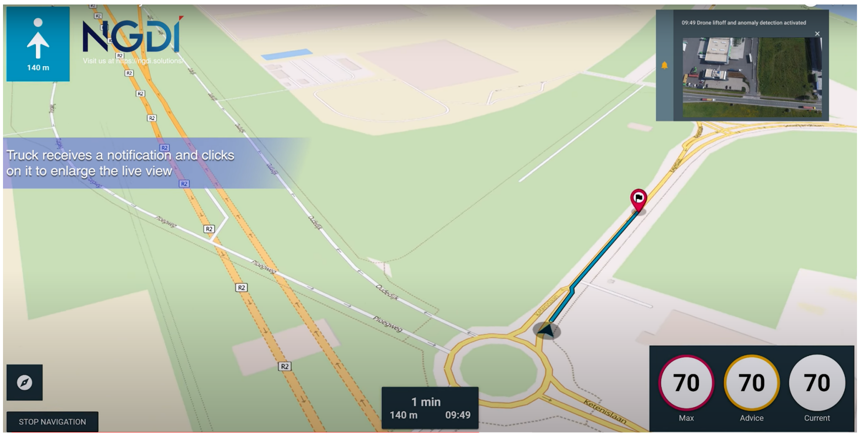

Figure 31 Efficiency of displaying results from Scene Analytics (EF8) on EAD (EF1): Info message and video of critical anomaly for TOV is offered on the EAD to the TO.

5 PILOT PLANNING FOR THE THIRD YEAR OF THE PROJECT

In this section, the overview of the pilot planning for the third year of the 5G-Blueprint project is presented. In particular, Figure 32 reflects a snapshot of the current status of the pilot planning, while Figure 33provides further explanation of the color codes used for indicating the status of particular activities.

				M25	M26	M27	M28	M29	M30	M31	M32	M33	M34
Pilot site	Test activities (functional)	Test activities (5G angle)	Info in note?	September '22	October '22	November '22	December '22	January '23	February '23	March '23	April '23	May '23	June '23
Vlissingen	5G deployment												
	5G network evaluation												
	24/7 5G connectivity measurements												
	UCs from cluster B	URLLC + eMBB cross-border, PC5											
	EF6 (container ID)	MEC, bandwidth/reliability terminal											
	EF3 (iTLC) (+EF7 ETA)	Fixed wireless access											
Antwerp	5G deployment												
	5G network evaluation												
	24/7 5G connectivity measurements												
	UCs from Cluster A	URLLC + eMBB cross-border											
	UCs from Cluster B (no UC4.2)	URLLC + eMBB cross-border, PC5											
	EF4 (distr. percept.)	Network awareness											
	EF8 (scene analyt.) (+EF7 ETA + container pickup)	"5G femto cell" with RAN and MEC											
Zelzate	Development of 5G SA seamless roaming												
	5G network evaluation												
	TNO testing												
	24/7 connectivity measurements												
	UCs from Cluster A	URLLC + eMBB cross-border											
	UCs from Cluster B (no UC4.2)	URLLC + eMBB cross-border, PC5											
	EF2 (VRU)	Multiple slices same UE											
	EF3 (iTLC) (+EF7 ETA)	Fixed wireless access critical infra, + EF7											

Figure 32 Pilot planning for the third year of the project.

Cluster A (water): UC4.1 **Cluster B** (wheels): UC4.2a (docking), EF7, UC4.2b (skid steer), UC4.3 (CACC), UC4.4 (+EF5)	Planned	Implementation ready & test cases written	Tests ongoing
	Tests done but still analysing results	Analysis done	

Figure 33 Legend for the pilot planning shown in Figure 32.

In all three pilot sites, thorough testing of 5G SA network is ongoing, providing the data for performance assessment in light of effective testing/ validation of the planned piloting activities of use cases and enabling functions. Thus, as it can be seen in Figure 32, 5G deployment activity refers to some remaining configuration of 5G network slices at different pilot sites (red box for Vlissingen means that configuration of slices is still ongoing and is not finalized in September 2022), while network evaluation includes thorough testing and compilation of a meaningful set of results.

The piloting activities for use cases and enabling functions in the cross-border pilot site, i.e., Zelzate, will start once the seamless roaming mechanisms are developed and tested (TNO Cores; currently planned for the period of September '22 until end of February '23). In the meantime, we are fully focused on the other two pilot sites, i.e., Vlissingen and Antwerp, where further network configuration and testing are currently ongoing. Thus, in March 2023, the network performance evaluation in the cross-border area will start, and once successful, the use cases and enabling functions are planned to proceed with piloting activities from April until the end of June next year. Afterwards, additional two months are planned for reporting on the tests performed during all testing phases.

During the testing phase in all three pilot sites, more shadow-mode testing is foreseen for the practical reasons, as it is not possible to close the public roads for a long period of time. To facilitate the testing procedure, we defined two clusters of use cases. In particular, Cluster A contains only UC4.1, i.e., testing of barge tele-operation in the waterways. On the other hand, Cluster B groups all other use cases that involve testing on the roadways, including several enabling functions that are closely integrated with the use cases in the previous phase of testing (June/July 2022). The remaining enabling functions will be thoroughly tested over 5G SA network as standalone elements, and as such, a subset of the enabling functions will be further integrated with the use cases in light of the final demo.

This overview presents a high-level planning that is being maintained and closely monitored by WP7, while partners responsible for testing are applying the WP7 living documents (such as STD) to plan and document their testing procedures and all related details important for everyone involved in the piloting activity. Apart from the monitoring of planning and testing progress/status, WP7 also monitors the status of KPIs that have been defined in Section 3, for network, use cases, and enabling functions. As indicated in Section 3, all KPIs that were not measured during the MVP phase, will be measured and presented in D7.4, due at M37.

6 CONCLUSION AND OUTLOOK

This deliverable provides insights into the work performed within WP7, focusing on i) 5G-Blueprint architecture, and description of pilot sites where piloting activities are being performed, ii) integration of activities performed in technical work packages WP4-6 to produce the MVP level on two pilot sites, i.e., Vlissingen and Antwerp, ii) test results obtained during the MVP pilot testing in the aforementioned pilot sites. The results are quantified through the KPIs which were established following a three-layer methodology, i.e., Verticals (Use cases), Enhancements for Verticals (Enabling Functions), and Network performance.

As presented in Section 4, the MVP phase of piloting activities mainly resulted in performance evaluation of Use Cases while using 5G network. On the other hand, the initial results on the integrated enabling functions prove the success of integration with a subset of use cases, but a detailed performance evaluation in terms of measuring and studying the defined KPIs (Section 3) will take place in the upcoming months (as indicated in Section 5), and as such, it will be presented in D7.4. The Use Cases are presented in this document, leveraging on the shadow-mode testing of barge control, automated docking, CACC platooning, and remote takeover.

In Section 4.3, we provided a set of performance validation results for 5G-enhanced teleoperation in real-life environments, i.e., Vlissingen and Antwerp pilot sites, thereby testing the feasibility of 5G NSA and SA in real-life harbor and surrounding environments. To reflect first on the results obtained in the Vlissingen pilot site, the results show enhancements of the network performance (latency, throughput), as well as teleoperation key performance indicators, such as accuracy in steering angles, throttle positions, brake positions, and the distance between lead and ego vehicles in CACC-based platooning scenarios. In particular, test Vlis-4.2 UC4.2 and ETA Sharing enabling function (EF7) have been integrated and tested over 5G network, whereas the setup included a scaled truck trailer combination equipped with the HAN drive-by-wire system. The results show the maximum value of tracking error is 1.3cm, with the average of 0.4cm, which is a promising result as it meets the requirements of less than 2.5cm.

Furthermore, test Vlis-4.3 included 5G-enhanced CACC-based platooning integrated with the Enhanced Awareness Dashboard (EF1), Distributed Perception (EF4), and ETA Sharing (EF7), and it was performed in a shadow-mode on the public road. In particular, EF1 and EF4 provided an extended and enhanced awareness to the teleoperator to increase the safety of teleoperation, by presenting the alerts, and displaying/detecting the obstacles (3D object detection), respectively. The role of EF7 was to re-calculate ETA values for teleoperated vehicle based on the real-time locations and road data. The results presented in Section 4 show the superiority of 5G-based C-V2X (Uu) compared to WiFi-P/ITS-G5 and simple adaptive cruise control, in terms of the distance error between lead and follower vehicle, which is calculated as percentage of difference between actual and desired distance. The result shows less than 5% error, which falls into the target value domain, while maximum achievable speed was 90km/h. Also, the minimum achievable headway to the lead vehicle resulted in 0.8s, where 1s was the target.

In Vlis-4.4, the remote driving (UC4.4), together with Enhanced Awareness Dashboard (EF1), Vulnerable Road User Interaction (EF2), Distributed Perception (EF4), Active Collision Avoidance (EF5) and ETA Sharing (EF7), was tested over 5G connectivity. The results presented in Section 4.3 show the steering, throttle, and brake accuracy. The vehicle was teleoperated driving at the speed that corresponds to the maximum allowed speed in the Vlissingen pilot site area (15km/h). The results show that MAE and RMSE values for throttle are 2.2% and 3%, respectively, which meets the requirements of less than 4%, and 6%. Similar results are obtained for brake accuracy, where MAE AND RMSE are 4% and 5%, respectively. Somewhat larger errors are achieved in the case of steering angle, where MAE and RMSE are larger than expected for 4%, but only during slalom tests, while during regular driving the error was minimal (less than 1%).

Concerning the testing in the Antwerp pilot site, Antw-4.1 test included Automated Barge Control use case. The idea of testing this use case is motivated by many opportunities for automating barge operations, such as mitigation the risks of human mistakes and improvements of efficiency and safety in an environmentally sustainable way. However, there is a lack on studying the network performance and the impact of network connectivity on the autonomous ship operations, and in general a lack of performance assessments in real-life environments as most of the studies are based on the simulation results or scaled ship setups. In 5G-Blueprint, we obtained some preliminary results and presented one of the seminal approaches on automating barge control with the help of 5G systems, where we created a cellular-based automated barge control system in a real-life environment with the barge sailing in the Port of Antwerp Bruges, connecting dynamically to the available 5G network. Based on the results we presented, 5G outperforms 4G both in terms of latency and bandwidth, but in terms of the overall signal quality as well, thereby meeting the network requirements that are carefully defined in D5.1 [4]. In particular, the improvement in latency gained by 5G compared to 4G is reflected through the average latency, which is 26.62ms with 4G, and 15.06ms with 5G. In case of jitter, the values for both 4G and 5G can be considered as negligible, since they result in 2.34ms, and 3.57ms, respectively. Concerning bandwidth, the average measurements result in 36Mbps, which offers the chance to work with a significantly better video quality and increased security in port environments.

The measurements we obtained in the real-life environment provide promising initial results, whereas more tests with 5G SA, leveraging on eMBB and URLLC network slices is planned. In general, all MVP results presented in Section 4.3 are showing good consistency between the KPI target values and data measured in the pilot sites using the 5G network. As for the 5G network measurements, the results are extensively documented in the deliverable D 5.2. Substantial work still needs to be done on integration of Enabling functions which is planned on October 2022 - April 2023 on the final pilot sites in terms of the full-scale implementation, which will be documented in the deliverable D7.4 (due to M37).

The main focus of our planned testing and validation is on the challenging cross-border scenarios for barge/vehicles/trucks sailing/driving between Belgium and the Netherlands, thereby testing and validating the impact of enhancements on the 5G SA roaming on achieving the service continuity for cross-border teleoperation. In addition, more tests with higher traffic load (e.g., multiple camera feeds), and various weather conditions, are planned as well.

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7 ANNEX

7.1 Technical details of testing procedures for UC4.1: Automated barge control

Table 29 UC 4.1 KPI Technical test procedure.

No	Who	Description test step	Expected Result	P/F	Observations
1	Seafar Engineer	Check 5G connection	5G is working	P	Smooth switch to 5G
2	Seafar Engineer	Remove 4G backup antennas from balance setup	Full on 5G only	P	NA
3	Seafar Engineer	Test video feed	All cameras are working	P	NA
4	Seafar Engineer	Test Latency	Within KPI	P	NA
5	Seafar Engineer	Test bandwidth	At least 20Mbps can be used.	P	Limited to 24Mbps. This is lower than expected by the ISP

Table 30 UC4.1 Operational preparation.

No	Who	Description test step	Expected Result	P/F	Observations
1	Captain aboard	Switch ship to shadow mode and use of 5G network	The ship is in shadow mode	P	NA
2	SCC captain	Set the station to manually control the ship	The ship is switched to	P	NA
3	SCC captain	Verify if the bow and stern cameras are working	All cameras are working	P	NA

Table 31 UC 4.1 Operational Test Procedure.

No	Who	Description test scenarios	Expected Result	P/F	Observations
1	SCC captain	Bow camera- PTZ function: 1. Pan (360) 2. Tilt () 3. Zoom ()	PTZ function is working	F	The issue with the camera is none 5G related.
2	SCC captain	Stern camera- PTZ function 1. Pan 2. Tilt 3. Zoom	PTZ function is working	P	NA

3	SCC captain	Engine- control command via sensor processor 1. Move the clutch forward 2. Back the clutch to the neutral state	Command received by the ship	P	NA
4	SCC captain	Engine- control command via sensor processor 1. Move the clutch backward 2. Back the clutch to the neutral state	Command received by the ship	P	NA
5	SCC captain	Rudder- control command via sensor processor 1. Turn the joystick right 2. Back to the neutral state	Command received by the ship	P	NA
	SCC captain	Rudder- control command via sensor processor 1. Turn the joystick left 2. Back to the neutral state	Command received by the ship	P	SCC captain
6	SCC captain	Bow thrusters via sensor processor 1. Turn the joystick to 45 degrees 2. Back to the neutral state	Command received by the ship	P	NA
7	SCC Captain	VHF radio via Mimer (ROIP) 1. Push the button on-screen to open a channel to speak to another vessel	Possible to speak with other vessels	P	NA

7.2 Technical details of testing procedures for UC4.2: Automated driver-in-loop docking, and supporting enabling functions

Table 32 Testing procedure for UC4.2 and supporting enabling functions in Vlissingen.

No	Who	Description test step	Expected Result	P/F	Observations
01	HAN	Before the actual test a few (safety) checks/test will take place to ensure a safe and fruitful test. Think of: testing the Kill-Switch, Safety-Clickers to avoid too much steering (i.e. stall current), responsiveness of throttle, forward/reverse and steering angle, (emulated) data of GPS, etc.	Completed checklist of safety checks.	P	
02	HAN	Preliminary and Validatory tests: to ensure that the sensors, controllers and actuators are working properly. These tests consist of simple manoeuvres (straight line & 90 degree turn) for each of the involved systems (TC, BDMP and PTC): a.Teleoperator driven tests	Verification of functionality.	P	

		b.Motion Planner (BDMP) tests c.Path Tracking Controller (PTC) tests d.Combined BDMP path and PTC tests			
03	BEM	Trajectory with destination to the yard is emulated	A series of (emulated) GNSS positions and a timestamp.	P	This was visually confirmed in the logs of BEM and on the EAD
04	BEM	ETA info engine is activated and starts computing routes and ETA's based on traffic circumstances at the time of testing.	A route and ETA which is refreshed every 10 s	P	Route was computed and ETA was refreshed every 1 s
05	BEM	When requested by HAN, the ETA is shared over HTTP.	Han requests ETA when necessary and ETA is shared within 100 ms	P	Numerical analysis of the response times during the tests indicates that the 99th percentile of all http calls to the ETA api is below < 30ms
06	HAN	HAN receives the ETA message which triggers their UC, including all the stages of the actual docking procedure.	UC is automatically triggered	P	

7.3 Technical details of testing procedures for UC4.3: CACC-based platooning, and supporting enabling functions

Table 33 Testing procedure for UC4.3 and supporting enabling functions in Vlissingen.

#	Test	Test Description	Expected outcome	P/F	Results / Notes
1	Controller loop verification	This test will be performed to check the right connection and data transfer in closed loop setup	Monitoring software will be used to monitor the messages received in the control loop from/to vehicle	P	Closed loop is working as expected with no error messages / warnings in the vehicle
2	Shadow mode testing	During this test, the original ACC system will be used to follow the lead vehicle. The controller will run in parallel, but the controller output is not connected to the vehicle. This test is performed to verify the working of controller in an open loop.	Comparison will be made between the acceleration from OEM ACC system and the CACC controller output.	P	The controller provided similar acceleration profile to that of the OEM ACC system.

3	CACC activation	This test will be performed to check the activation / deactivation of the CACC system. The original ACC control switch will be used to activate/ deactivate CACC	CACC triggered via the standard ACC switch on the vehicle overriding the OEM ACC.	P	CACC can be activated from standstill. The original ACC control switch works without any error for CACC activation. When brake is pressed the CACC system is deactivated.
4	V2V communication	This test will be performed to verify the functioning of the OBU and the data transfer through V2V communication	Transmission/reception of the necessary parameters over V2V from the lead vehicle to the following vehicle. The delays and loss in communication (if present) will be monitored	P	The parameters setup to be published over V2V to the lead vehicle was received successfully by the following vehicle
5	Vehicle following test	The lead vehicle will be driven by a test driver at constant speed(45kmph). The test will be performed for different headway times	The following vehicle is expected to follow the lead vehicle with a constant distance based on the set headway time	P	The controller was able to keep the ego vehicle to the set following distance with minimal error.
6	Gap closing test	The acceleration of the lead vehicle will be gradually increased to increase the gap between the lead and the following vehicle	The following vehicle is expected to close the gap created by the acceleration of the lead vehicle.	P	The controller was able to close the gap created by the acceleration of the lead vehicle within the predefined limits in terms of time and acceleration.
7	Collision avoidance test	The lead vehicle will be driven at a constant low speed before making an emergency braking to decrease the gap.	The following vehicle is expected to perform an emergency braking and avoid collision with lead vehicle.	P	The controller was able to perform collision avoidance.The controller was able to provide the maximum deceleration and come to a complete stop when the vehicle in front stopped.
8	LiDAR pointclouds broadcasted	The the time required to publish and receive the point clouds after the snapshot	Measureing the time between the LiDAR's snapshot, processing, publishing, then receiving it. The point clouds should be received no later then 80ms from the time of the snapshot	P	The point clouds were received after 50-90ms after the snapshot depending on the signal strength in the location of the vehicles.

9	Fusion algorithm computation time	Time required to transform and fuse the point clouds	Point clouds transformed and fused in a maximum of 500ms	P	The fusion took around 300miliseconds to fuse both point clouds
10	Object detection average precision and accuracy	Object's available being successfully detected by the algorithm	Visual comparison between objects seen by eye can be detected.	P	In many cases the objects were detected correctly. However, some further validation work needs to be implemented to ensure higher accuracies in complex scenarios.

7.4 Technical details of testing procedures for UC4.4: Remote-takeover, and supporting enabling functions

Table 34 Testing procedure of UC4.4 in Vlissingen.

No	Description test step	Expected Result	P/F	Observation
01	Safety systems test, the safety driver deactivates the remote takeover system to ensure it is fully functional. At any given time and manually the driver can take control of the vehicle (if the communication is lost, any malfunction or during safety critical situations).	From in vehicle Roboauto hardware, the CAN signal sent in the vehicle to V-tron drive by wire: - If remote station status in neutral (drive is deactivated): brake signal in vehicle is fully (100%) applied, throttle is not applied (0%) and steering angle is 0°. - If connection is lost: brake signal in vehicle is fully applied (100%), throttle is not applied (0%) and steering angle is 0°. From in vehicle driver during teleoperation: - Pressing manual steering override button should immediately give steering capability to the safety driver.	P	All safety systems functioned as expected
02	Steering responsiveness and accuracy tuning will be performed to optimize the performance.	Requested steering wheel angle matched by the vehicle when teleoperating mode with minimal delay and held stable as the vehicle moves.	P	
03	Brake responsiveness and accuracy tuning will be performed to optimize the performance.	Tuning of the brake responsiveness, between the teleoperation hardware and the vehicle, should result in a predictable braking behavior in the vehicle. Unwanted jerk should be minimized for longitudinal	P	

		deceleration.		
04	Throttle responsiveness and accuracy tuning will be performed to optimize the performance.	Tuning of the throttle responsiveness, between the teleoperation hardware and the vehicle, should result in a predictable acceleration behavior in the vehicle. Unwanted jerk should be minimized for longitudinal acceleration.	P	
05	Driving responsiveness and accuracy test, vehicle and teleoperation signals are logged to evaluate remote drivability performance. In order to compare delays between signal received and physical actuation from the vehicle.	Matching graphs of teleoperation inputs and physical vehicle outputs.	P	Good match, above 90 deg steering angle has a larger mismatch during slalom tests. During regular driving error is minimal.
06	Video feed quality and delay will be evaluated.	An average delay that can dictate the required response time and hence maximum safety speeds.	P	Subjective observation was positive, stable and smooth video feed Over 5G NSA. Bad quality over 5G SA.
07	If the various actuators are satisfactorily tuned and network communication is sufficiently stable, the vehicle will be tested for parking maneuvers at slow speeds.	All systems functioning during teleoperation at slow speeds and large steering angles.	P	
08	If the various actuators are satisfactorily tuned and network communication is sufficiently stable, the vehicle will be tested driving on the road on straight and curved roads, driving speed will depend on network quality.	All systems functioning during teleoperation at regular speeds and small steering angles.	P	Max speed allowed 15km/h, hence max speed was 15km/h
09	The aim of this test is to determine whether the ACS is active and correctly calibrated. The correct integration in the system will give added security to the system, as well as another redundancy safety loop.	The remote operator is driving the vehicle at 30 km/h directly at a test dummy. The test is successful if the ACA takes over the control of the vehicle and stops without hitting the dummy. The test is to be completed five times in a row.	P	
10	This test is carried out in order to determine the accuracy of the localization system on the teleoperated vehicle	The test is successful if the accuracy of the GNSS coordinates received within the Roboauto system is less than 100m	P	Occasional reset due to GPS not fixing, the antenna was the issue and was replaced
11	The test is aimed at the accessibility and validity of the data that is stored on the server, to determine if all partners can successfully access the data.	The test is successful if all relevant partners are able to subscribe to and read data from the topics specified in the data sharing table and the validity of the published data is verified.	P	

Table 35 Testing procedure of enabling functions supporting UC4.4 in Vlissingen.

No	Who	Description test step	Expected Result	P/F	Observations
1	Be-Mobile	At start-up a vehicle-id and (potentially destination) must be selected. The selected vehicle-id is referred to below as the active vehicle	All relevant information of the vehicle are shown (last gps position, route, tbt, eta,...)	P	All relevant information of the vehicle is shown (last gps position, route, tbt, eta,...)
2	Be-Mobile	A new GPS point on the MQTT server of Roboauto is available for the active vehicle.	Position of vehicle is updated on the secondary screen	P	Position of vehicle is updated on the secondary screen

Table 36 Testing procedure of enabling function EF2 supporting UC4.4 in Vlissingen.

No	Who	Description test step	Expected Result	P/F	Observations
1	V-Tron/Be-Mobile	TOV/Platoon continuously drives the Oostenrijkweg and Luxemburgweg in Vlissingen.	Every second a VAM is published on the EF2-MQTT	P	
2	LN/Be-Mobile	VRU walks on the Belgiëweg West approaching the Oostenrijkweg when the TOV is approaching on the Oostenrijkweg (while being obscured by the earthen dam between Oostenrijkweg and Luxemburgweg)	Every second a VAM is published on the EF2-MQTT Trajectory in VAM message is shown on the secondary screen	P	The TO visually confirmed that the VAM (location and predicted path of VRU) messages are shown on EAD (EF1) . BEM monitoring confirmed that VAM message where received from the MQTT of Locatienet
3	LN	TOV and VRU path intersect	A DENM message is published on the EF2-MQTT	P	
4	Be-Mobile	The information in the DENM message is published on the EF1 dashboard.	TO receives warning of potential collision with VRU	P	The TO visually confirmed that the DENM (location of collision + time to collision) messages are shown on EAD. BEM monitoring confirmed that VAM and DENM message where received from the MQTT of Locatienet
5	All	Steps 06 to 08 are repeated until the exit criteria are met.	Test run complete with valid results only	P	

Table 37 Testing procedure of enabling function EF7 supporting UC4.4 in Vlissingen.

No	Who	Description test step	Expected Result	P/F	Observations

01	Roboauto/Be-Mobile	At least every second new GNSS data is available on the MQTT of roboauto	Should be visible in internal logs of BEM	P	Internal logs and monitoring of BEM indicated that this was indeed the case (also see 4.3)
02	Be-Mobile	TO selects correct vehicle-id and enters destination on secondary screen based on which the route is computed	Route is visible on secondary screen	P	The TO visually confirms that the route information is visible and correct
03	V-Tron+Be-Mobile	TOV/Platoon continuously drives the route towards the destination	GPS position on secondary screen is updated + Based on current position of the truck the turn-by-turn, eta and speed information is continuously updated	P	The TO visually confirms that the GPS position, turn-by-turn, eta and speed information is updated according to the movement of the truck
04	Be-Mobile	eta-api is operational	When correctly queried, the eta-api of BEM should return the eta of the vehicle	P	Internal logs and monitoring of BEM indicated that this was indeed the case (also see 4.2)

Table 38 EF6 results.

No	Who	Description test step	Expected Result	P/F	Observations
1	KPN/ Sentors	Via a PC that is connected to the modem, an SSH connection is established to the VM.	A log-in to the VM is possible.	P	To access the VM from remote, a VPN connection needs to be established.
2	Sentors	The camera is connected to the 5G modem. Using the known IP address of the modem, and using port forwarding, from the VM a connected is established to the camera.	The camera is reachable from the VM	P	This test can only be done at the premises, since (obviously) the modem needs to be within radio coverage of the SA network.
3	Sentors	The software on the VM establishes an RTP connection to the camera.	A real-time video feed is received by the VM	P	Several routing options needed to be set-up at the thin client before the connection could be established.
4	Sentors	The recognition software is configured to run on this RTP feed.	Metadata from the camera stream is shown on the console, such as frames-per-second.	P	All software packages and external libraries were installed successfully. The software runs on shared GPU, so the processing times may vary.

5	KPN/ Sentors	5G characteristics are measured, such as Mbs, packet/frame-drop, latency.	5G performance in an office setting is measured.	F	The 5G modem (Netgear NR5200) provided very little detail of network characteristics, aside from uptime. Going forward, this should be replaced by a modem with much more logging capabilities.
6	Sentors	A container image is put in front of the camera	The recognized container code is shown in the VM console.	P	This worked very robustly. The VM has no GUI so feedback could only be provided via the console. On-premises a additional PC and monitor were used to also demonstrate the live footage of the camera.
7	Sentors / BEM	The service to push messages to EF1 is started. A test message is send.	The provided container code is shown on the EF1 dashboard.	P	Only the API header needed adjustment. Container code shown on the EAD (EF1)
8	Sentors / BEM	A container image is put in front of the camera.	The recognized container code is shown on the EF1 dashboard.	P	The end-to-end chain worked robustly and overall end-to-end latency was about 1 second

7.5 Technical details of testing procedures for enabling function EF8

Table 39 Testing procedure of enabling function EF8 in Antwerp.

No	Who	Description test step	Expected Result	P/F	Observations
1	BE	Be-Mobile offers the location and ETA (EF7) of simulated vehicle to Room40	ETA (EF7) correctly received by R40 and active site monitoring is enabled by R40	P	ETA (EF7) from simulated vehicle is received by R40
2	R40	Room40 will have 5G connected drone take off and monitor the area around the vehicle	live video livestream is broadcast through 5G to the R40 platform	P	A live video stream was correctly received
3	R40	Room40 use this ETA and location to offer alerts to the TO via EF1 (secondary dashboard)	An mqtt message is correctly sent to the TO	P	The mqtt message was correctly recieved
4	R40	Room40 get position and anomalies from the drone	live video livestreams and telemetry are broadcast through 5G to the R40 platform	P	Streamed data was correctly recieved
5	R40	Room40 process the anomalies at Room40, and sends the message	A link to a live video stream or anomaly event is sent out in the mqtt messaging	P	Anomalies were correctly detected
6	R40	Room40 sends a video stream		P	Video link was correctly transmited
7	R40	Each 10 second a message (OK and not ok messages) will be send, to Be-Mobile. Room40 still to define what the message will contain / No location will be shown on the map of the anomaly.	OK/not OK message is received and displayed to the TO	P	Mqtt messages were correctly passed
8	BEM	If anomaly is detected (not ok message) , EF1 will shown in a widget regarding anomalies in red, as a message. Message will be specified in Json.	Alert message with Anomaly description displayed through EF1 to TO	P	Alert message and Anomaly description is displayed on EF1
10	BEM	Be-Mobile will offer the link to the live video of the recording of the anomaly in the Room40 widget on the EF1	video link is correctly displayed	P	Video is displayed on the EF1 and can be live viewed

