COMP4DRONES

DELIVERABLE

D1.2 – System Under test requirements and Test system requirements

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Keywords:	Use case, transport, construction, logistics, surveillance, inspection, agriculture, KPIs, requirements, Functionalities, components , tools, validation plan
Abstract (few lines):	This deliverable focuses on the description of the demonstrators: their technical overview, their KPIs, requirements, functionalities and the definition of the technologies and components that are going to be used. Finally, the validation plan is defined.

DISCLAIMER

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Definitions, Acronyms and Abbreviations

Acronym	Title
BIM	Building Information Modeling
GCS	Ground Control Station
HIL/MIL/SIL	Hardware/Model/Software in the Loop
KET	Key Enabling Technologies
KPI	Key Performance Indicator
RPAS	Remotely Piloted Aircraft System
RTK	Real-Time Kinematic
RTOS	Real-Time Operating System
STO	Specific Technological Objective
SW/HW	Software / Hardware
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UC	Use Case
UGV	Unmanned Ground Vehicle
USS	Unmanned Service Supplier
WP	Work Package
COTS	Commercial Off-The-Shelf
WP	Work Package
COTS	Commercial Off-The-Shelf
FUN	Functionality
REQ	Requirement
COMP	Component

Executive Summary

After the description of the main Use Cases and their demonstrators in the D1.1. The deliverable D1.2 aims to provide more detailed information regarding the main technologies used, develop, and improved in each demonstrator. Continuing with the methodology described in the WP2 and based on the different system development methodologies standards, D1.2 described the main characteristics of each demonstrator starting from the analysis of the current status of the technologies that are going to be used, and bringing them to the application in each demonstrator. To be sure that the development of the technologies is in line with the project objectives different technical KPIs have been also defined at this stage. With these new KPIs (related to the business KPIs defines in the D1.1.) the technical requirements and the main functionalities have been defined to be sure that the development of the demonstrators does not lose the focus on the main objectives. D1.2. also recaps the components that are going to be developed in each technical WP and the tools that enable the development of these components and the improvements of themselves. The traceability matrices of all these requirements, functionalities, and components it is also defined at the demonstrator level to be sure that all of them are focused on the objective of achieving the goals of the demonstrators.

Finally, these matrices together with the preliminary validation plan defined will be the starting point for the evaluation of the demonstrators in the next task, which will be the one that will report the results of the demonstrators and close the loop validating that the results fulfil the technical KPIs, which at the same time must validate the KPIs and objectives established in the D1.1.

1 Introduction

The purpose of this document is to present the Validation and Verification methodology, a widely used Engineering Design Model and already explained in the WP2 of the C4D project. This model represents an important process that ensures the correct development of any system design. Many standards and guidance across different industries and engineering sectors propose this methodology. For instance, ARP-4754 (Aerospace Recommended Practice) set the Guidelines For Development Of Civil Aircraft and Systems, and a Validation and Verification model is purposed during this standard, the one presented in Figure 1 Avionics system development.

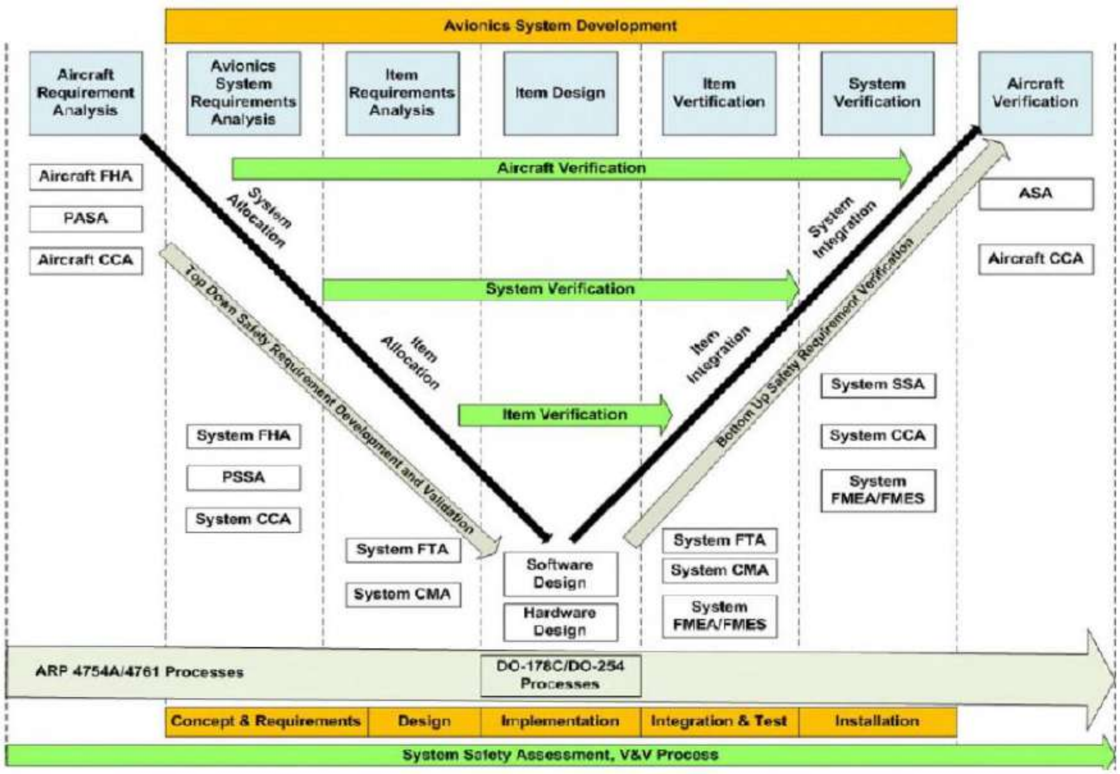


Figure 1 Avionics system development

However, this model is a very specific one related to avionics systems design. A more generic and simpler one is the one in Figure 2. The left-hand branch is the validation process, whereas the right branch is the verification process.

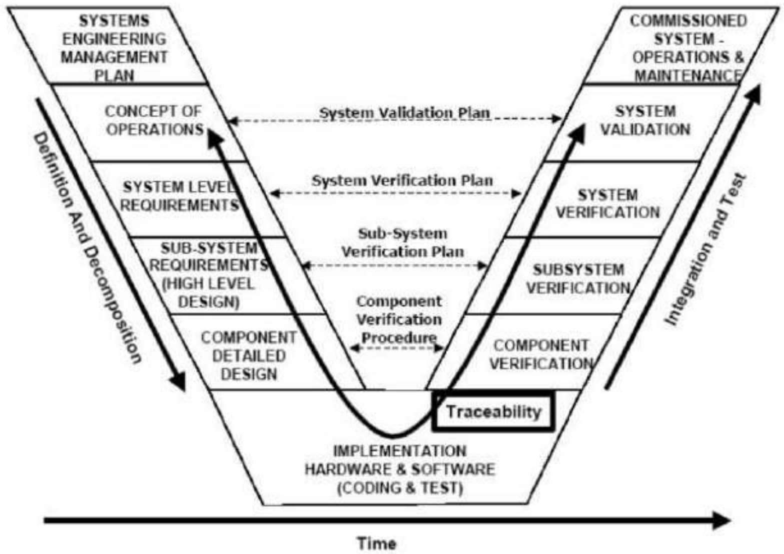


Figure 2 Engineering systems Design V model

This document will be focused on the first conceptual design phase of the process, up to the validation plans. At base of this document, deliverable D1.1 collects the information about the demonstrators, and the main requirements at the End User level. These initial requirements are the starting point for defining the main technical requirements, functionalities and the components and tools that are going to be developed to fulfil the requirements and the main KPIs.

Briefly, the document will concern the following concepts for each of the demonstrators defined in the comp4drones project. Each concept is more thoroughly defined below continuing the methodology explained in the D2.2 and to serve as a guiding for the execution of the work to be done.

Steps:

1. Current state of technology
2. Use Case Concept of operation
3. System-level requirements
4. Functionalities identification
5. Components
6. Tools
7. Traceability matrices
8. Validation Plan

The first step of this process and the prerequisite is to set and define the engineering problem. A system design process should be born from a real problem which, for instance, an industrial sector wants to improve. Hence, firstly, it is needed a description of the current state of the technology, its processes, their current procedures, etc… A good procedure for that is to interact with stakeholders from the industry. A detailed analysis of how the operations are performed nowadays is needed to fully understand the problem.

Following step just before the definition of the requirements is to think and design a conceptual ConOps which ideally would be performed for the system. This use case definition has to be aligned with what the end-user has requested and with what in the most optimal case, with any technological, economic, or resource constraints, would be performed by the system. This conceptual ConOps can be in the form of a flow chart, for example, starting since the beginning of the operation, describing all the tasks and decisions that the system will perform, until the end of the mission.

Once the problem presented by the end-user has been understood, and the system to be designed figured out, the most important step of the process starts: the requirements capture. It must be highlighted that this capture is critical for the whole design process. A good capture will set a robust basis for the development of the design, whereas not capturing all the needed requirement can derive to a wrong, incomplete or not functional system. During the drafting of the system requirements, all the stakeholders have to be taken into account and the requirements must be categorized due to the different level of compliance needed.

The definition of the main functionalities of the system can help the developers to identify the functionalities of the system to be developed. Since the requirements are a high level of specification, this step represents a lower step in the V&V model, being a lower level of specifications of the process. These functionalities could be either hardware functionalities, software functionalities, modules, etc. All of them together will intrinsically define the final system. As it was done for the requirements,

As it can be seen in Figure 2, in the edge below the final step just before starting the Verification branch is the box named as traceability. The easiest traceability is to trace the functionalities of the previous step with all the requirements capture but also components defined in each demonstrator can be related with the functionalities identified.

It must be said that it could be possible that not all the requirements can be traced with the functionalities. It is because some of them are requirements related with external stakeholder needs for the operation in addition to the system itself, such as human operator. With these functionalities, the system functional architecture can be defined, which will set the links between the whole functionalities and define the overall system.

Finally, the validation plan represents the horizontal lines of the V&V Model and are the link between the Validation branch and the Verification branch. There are many ways to achieve this validation plan. A good practice is to define different environments of validation in the next scenarios:

- **Laboratory environment:** tests performed within an environment. These tests aim mainly to verify a functionality itself, without no integration with others. However, some test of the final system can be performed within a laboratory before performing any operation outdoors.
- **Simulated environment:** Between the laboratory test and the outdoor environment, components and tolls be validated at simulated environments. Sometimes due to the complexity of the application these steps could give significant results and allow to reduce the time at real environment validation.
- **Outdoor controlled environment:** somehow, these tests extrapolate the final systems tests in the laboratory to a more realistic scenario, but not the final one. These tests will verify the whole operation of the system before the real operation.
- **Industrial relevant/Real environment:** just before the real operation and final demonstration of the system, it can be tested in the real environment for which it has been designed.

It is here where the importance set in the requirements capture takes on. Those functionalities linked with requirements whose importance is a MUST/SHALL/LEVEL 1 have to be demonstrated and tested in a real or industrial relevant environment. However, and very often due to safety reasons, some advanced technologies cannot be deployed in the real environment, or they are linked with second or third level of priority requirements. Probably for these functionalities it would be enough to be validated in the laboratory or in an outdoor controlled environment.

This validation plan can be designed for each functionality, but the integration between then, defined by the functional architecture of the system, has to be as well validated at system level validation.

2 UC1-Demo 1 Transport: Traffic Management

2.1 Current state of the technology

Current Traffic Control Center platforms integrate a wide variety of sensors and sources of information that feed the system and allow operators to monitor the status of the transport infrastructure and detect possible incidents on the road. These systems include CCTVs and different sensors are deployed along the road. However, these technologies are fixed to the concrete areas of the infrastructure where they are installed, and do not cover the whole segments of the road, leaving numerous sections unmonitored.

Once an incident has been notified in the TTC, the operators activate the necessary resources to respond to the incident in the most effective and suitable way. However, when the incident occurs in areas that are not well covered, this can result in an inefficient and incorrect response by the authorities, since more information from the location would be needed to activate the correct resources.

Up until now, the drone applications in emergency operations in transport infrastructure have been performed using ad-hoc solutions to specific mobility events. The deployment of drones in critical infrastructures is still not widely implemented, especially in services for improving security and rapid response. Having a drone as a dynamic source of information would allow TTCs to cover those unmonitored areas and activate the correct resources in a more efficient way.

Also, current drone operations performed in the Spanish territory comply with Spanish RPAS regulation under “Real Decreto” 1036/17, signed on December 17th 2017, and European regulation framework that includes Regulation (EU) 2018/1139, Delegated Regulation (EU) 2019/945, and Implementing Regulation (EU) 2019/947. However, most of them are still not being performed under a UTM platform. The UTM services will allow drone operators to conduct its operations for the applications in a safe way and coordinated with the designated authorities. In this project, the deployed UTM ecosystem will follow the European approach that is based on an open ecosystem and aligned with the Single European Sky initiative and the measures established in SES2+, with a central piece (UTM CIS) and a U-Space Service Provider (UTMUSSP).

2.2 Use Case Concept of Operation

This demonstrator’s concept of operation includes all the steps and actions taken by the systems involved (Mantis, CMPD, UTM and HORUS) in the different stages of the mission: pre-mission, pre-flight, flight-mission, end-of-mission.

The figure below summarizes all the steps performed by the drone system during the mission defined for this demonstrator:

➢ ***Deployment, assembly and start up of the system***

1. *The UAV operator checks the deployment area (surface, possible obstacles...)*
2. *The system is deployed: UAV, GCS, GDT and bungees.*
3. *The UAV operator performs visual preflight checks of the UAV.*
4. *Batteries level are checked.*

➢ ***Mission request and approval***

1. *MANTIS system receives a mission request from the CMPD.*
2. *The mission is loaded in the MANTIS GCS, checked and validated by the UAV operator.*
3. *The UAV operator reports the feasibility of the proposed mission or, otherwise, reports the relevant needed changes.*
4. *Once the mission is approved by the CMPD and the UAV operator, CMPD commands the mission starting time.*

➢ ***Pre-flight checklist***

1. *The system is powered on.*
2. *The UAV operator performs preflight checks (UAV, GCS and GDT).*
3. *The UAV operator performs camera preflight.*
4. *The UAV operator checks other traffics in the area and coordinates with them if needed.*

➢ ***Start of flight sequence***

1. *The UAV takes off, climbs to cruise altitude and heads towards the mission area.*
2. *Once over the target, UAV camera starts sending real-time video and telemetry to CMPD and GCS.*
3. *Video is recorded in the GCS.*
4. *The UAV operator maneuvers the air vehicle and the camera in order to obtain the most optimal position to take the images with the highest possible coverage and quality.*

➢ ***UAV recovery***

1. *Once the mission has been completed, the UAV heads to the landing area.*
2. *The UAV performs landing.*
3. *Both video and telemetry are collected from the GCS.*

The system is power off and disassembled

The current use case, derived from the end user's requirements, has been designed as it is illustrated in Figure 3

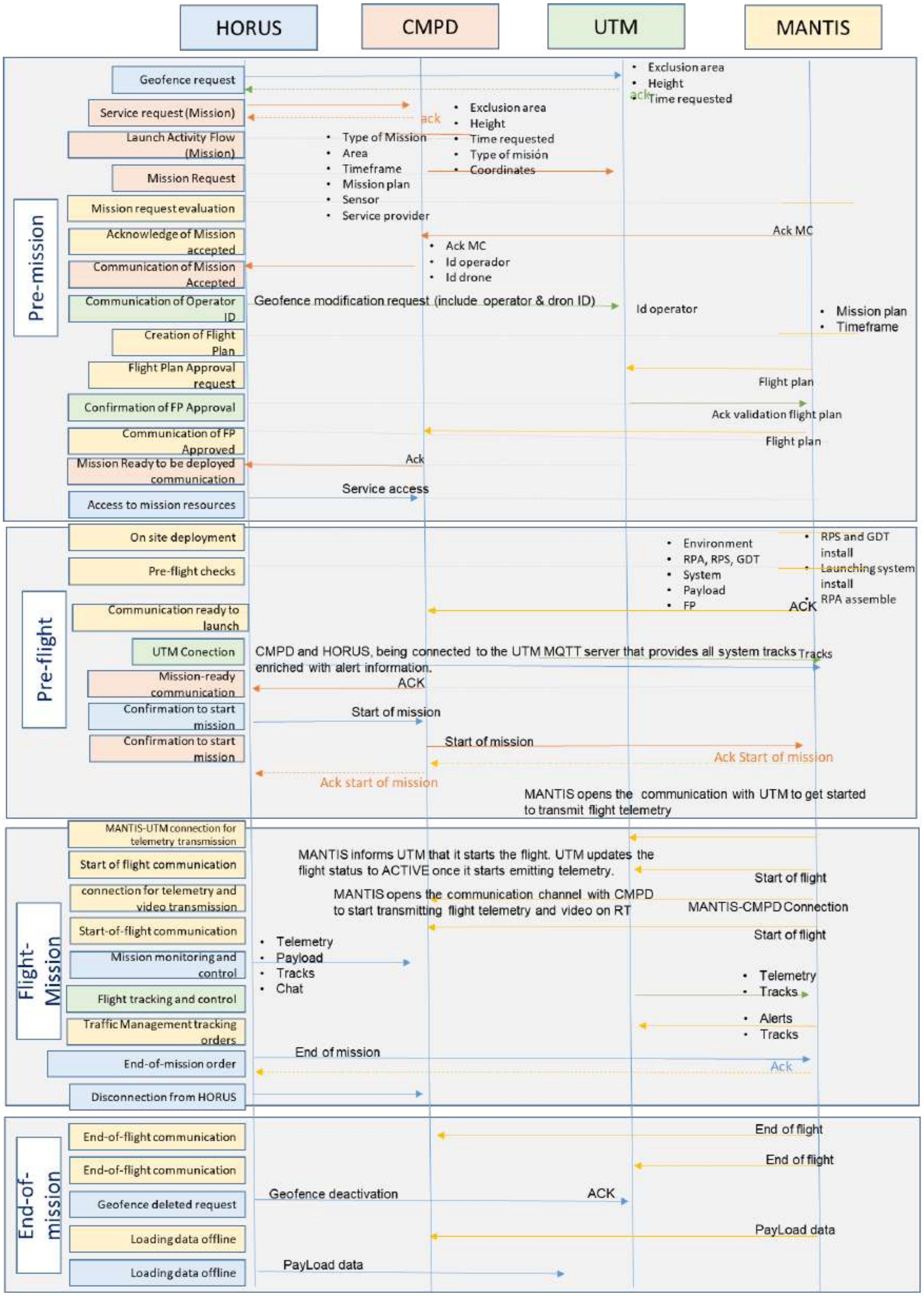


Figure 3 UC1 – D1 demonstrator's concept of operation scheme

2.3 System Requirements, KPI´s and Metrics

To have clear idea of the objectives and purpose of the demonstrator it is important to highlight the main metrics defined in deliverable D1.1 and that will lead to the definition of the most applicable requirements of the systems and components developed within the project.

2.3.1. Technical KPI`s and Metrics

In D1.1 the main business KPIs for this demonstrator were introduced. Complementary to those KPIs already identified, the table below presents the technical KPIs of Demo1, with their definition, measurement indicator and target value:

ID	KPI	Definition and measurement of Indicator	Target Value
UC1-D1-KPI-T1	Improvement of automatic tracking system of objects and persons	The indicator for this KPI will be the number of times it is necessary to locate the object/person being tracked by the automatic tracking system. The video tracking system uses contrast algorithms between the object/person to follow and the background in which it is located. All this is framed within a small area (red box).	Between 0-2 (currently it is between 2-4)
		The indicator will be calculated by the number of times the tracked object/person needs to be re-located. When contrast decreases, sometimes the automatic tracking system may not be able to identify the movement followed by the target and this way loses the automatic tracking.	
		Improving the resolution of the video (from SD to HD) increases the number of contrasting pixels available in the tracking area so the tracking algorithm should increase its reliability.	
UC1-D1-KPI-T2	Operational System Improvement: Increasing detection, recognition and identification distances of objects/people	The indicator of this KPI will be the flight height at which the drone operator is able to detect, recognize and identify objects/people. Depending on the needs of the mission, it will be necessary to fly at higher or lower altitudes. Indeed, it is not the same if the objective of the mission is to detect that there is a traffic accident on a road, that when the goal is to recognize the types of vehicles involved in the accident or when the license plates of the cars involved in the accident need to be identified. The closer we get to the need for identification, the lower the flight height of the aircraft.	>= 10% of current height
		The calculation of the indicator shall be based on the flight height used for the detection, recognition and identification of objects/persons. Increasing the resolution of the video generated by the drone will allow greater clarity of vision to the system operator favouring detection,	

		recognition and identification for higher flight heights. This will promote the safety of both the aircraft and the objects/people in the environment.	
UC1-D1-KPI-T3	Communications: Integration with external systems by standards	The indicator of this KPI will be the correct integration for the execution of the Use Case 1. The exponential growth in the use of drones has created the need for coordination of air traffic of unmanned aircraft with manned aircraft. The EU has launched the U-Space project aimed at defining the set of methods, processes and tools that allow the coexistence of both types of aircraft. The integration of the MANTIS system with a UTM system that implements European regulations will allow to expand its safe field of operation and at the same time the integration with other end applications that request drone services (In our case HORUS through 4G communications) The calculation of the indicator will be based on the correct functioning of communication with integrated systems	>=90%
UC1-D1-KPI-T4	Optimization of available bandwidth usage	The indicator of this KPI will be the bandwidth used to send the video from the aircraft to the control station. The data rate required to send a scanned SD video quality is between 1.5-2.0 MB/s. Currently this data corresponds to approximately 10% of the total available bandwidth. The calculation of the indicator will be based on the rate of video data sent from the aircraft to the control station. It shall be expressed in the % usage of the total available bandwidth. Increasing video resolution to HD will require a higher send data rate to optimize the use of the currently underutilized available bandwidth.	20%
UC1-D1-KPI-T5	AI image processing	The indicator of this KPI will be the correct processing of the images using AI during the Use Case 1. The calculation of the indicator will be based on the percentage of objects correctly classified using the AI algorithms. Precision: algorithm's ability to find only objects of interest. It is the percentage of real positives with respect to all the positives detected Recall: Ability of the algorithm to find all existing objects in the scene (ground truth). It is the	90%

		percentage of positives detected with respect to all the positives of the ground truth. The increase in the resolution of the video to HD will allow to apply AI algorithms in the videos obtained by the MANTIS	
UC1-D1-KPI-T6	Number of vehicles detected as well as other traffic parameters (speed, distance between vehicles) by drones	Reduction of false positive rate in the detection of the different parameters	10%

Table 1 UC1 D1 List of KPIs

2.3.2. *Main requirements (functional, interface, performance, security, usability…)*

D1.1 introduced the main functional requirements of the demonstrator. In this section, the remaining technical requirements for the demonstrator are shown, linked to specific KPIs of the demonstrator:

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC1-DEM1-PRF-2	Image stabilization (I)	The image acquisition system shall have hardware and software stabilization	H	Drone provider	UC1-D1-KPI-T1
UC1-DEM1-PRF-3	Image stabilization (II)	The image acquisition system shall have 3-axis gyro stabilization	H	Drone provider	UC1-D1-KPI-T1
UC1-DEM1-DSG-1	Camera dimensions and weight	Weight and dimensions of OEM Camera shall be compliant with MTOW of the UAV	H	Drone provider	UC1-D1-KPI-T1
UC1-DEM1-OPR-1	Camera movement and zoom	The drone system shall be able to capture the incident from different angles and perspectives.	H	Drone provider	UC1-D1-KPI-T1
UC1-DEM1-SEC-3	Cybersecurity	The communications between Mantis-GCS systems must be resilience	H	Drone provider	UC1-D1-KPI-T3
UC1-DEM1-INT-1	Communications bandwidth	The bandwidth of the air and ground radio links must be sufficient to send the video in HD	H	Drone provider	UC1-D1-KPI-T4

UC1-DEM1-SEC-4	Secure communication module	The drone must incorporate a secure communication module for communication and control.	H	Drone provider	UC1-D1-KPI-T4
UC1-DEM1-DSG-2	Area resolution	The area of operation shall be covered by the UTM system with a resolution of 5x5m2	H	UTM	UC1-D1-KPI-T3
UC1-DEM1-INT-2	Video integration	HORUS shall integrate the video stream received from the drone and display it in real time on the TCC HMI through a secure channel	H	HORUS	UC1-D1-KPI-T2
UC1-DEM1-USB-2	Image identification	The computer vision shall identify the length of traffic queue and assess if there is any immediate danger for the incoming traffic.	L	HORUS	UC1-D1-KPI-T2
UC1-DEM1-INT-3	Flight plan authorization workflow	UTM system shall be able to receive flight plan created by CMPD in the predefined format, calculate and request for authorization	H	UTM	UC1-D1-KPI-T3

Table 2 UC1 D1 List of Main Requirements

2.3.3. Regulatory requirements

The requirements below are related with the SORA analysis performed (Reference to the methodology in D2.5.) and the boundary conditions introduced in D1.1, as well as to the regulatory framework that dictates the deployment of the scenarios of the demonstrator.

Requirement ID	Short Description	Description	Priority (H/M/L)	Source
UC1-DEM1-REG-1	Visual Meteorological Conditions	According to Spanish civil regulations, flights are to be performed under VMC (Visual Meteorological Conditions) and therefore, during daylight time.	H	Drone provider
UC1-DEM1-REG-2	Drone pilot authorized	Drone pilot must be authorized to fly the drone	H	Drone provider
UC1-DEM1-REG-3	Drone operator registered	Drone operator must be registered in the national aviation authority registration list	H	Drone provider
UC1-DEM1-REG-4	Compliance with current regulatory framework	All flights that take place within the Spanish territory are to comply with Spanish RPAS regulation under "Real Decreto"	H	Drone provider

		1036/17, signed on December 17th 2017, and European regulation framework that includes Regulation (EU) 2018/1139, Delegated Regulation (EU) 2019/945, and Implementing Regulation (EU) 2019/947		
UC1-D1-DEM1-REG-5	Compliance with regulations	The UTM shall be compliant with European Union regulations	H	UTM

Table 3 UC1 D1 List of Regulatory Requirements

2.4 Functionalities identification

Main functionalities of the system have been defined in order to give more information about the characteristics needed for the performance of the mission operations. Since the requirements are a high level of specification, this step represents a lower step in the V&V model, being a lower level of specifications of the process. All of them together will intrinsically define the final system. As it was done for the requirements, Table 4 show the functionalities identified for the demonstrator 1.

ID	Functionality	Description	System function
UC1-D1-FUN-01	Geofencing - UTM	This function allows the reservation of the air space over the location area for the incident management drone operations, as requested by HORUS platform. Activation and deactivation of these areas by the UTM platform.	Positioning
UC1-D1-FUN-02	Flight plan management	Reception of flight plan created by Mantis and authorization from UTM.	Flight Navigation
UC1-D1-FUN-03	Flight tracking and control (mission) - UTM	This function provides the tracking, conformance monitoring, traffic information, and telemetry monitoring of the drone during the mission.	Flight Navigation
UC1-D1-FUN - 04	Deconfliction - UTM	With this function, during the scenario 2 of the demonstrator, UTM will provide proximity conflict detections & deconfliction workflows for the different missions that take place at the same time than the incident management mission.	Flight Navigation
UC1-D1-FUN - 05	HD image acquisition	This function allows the HD video capture with the HD single electronic optical payload and infrared payload (gyro-stabilized).	Intelligent data handling
UC1-D1-FUN-06	Image streaming / Drone connections and communications	This function allows the compression of sensor data (HD video) for its streaming to the HORUS platform through secure communications with the GCS and CMPD.	Communications Intelligent data handling

		Reception and display of video stream received from drone and the airspace traffic of the drones utilized for the area operation. Analysis of the images obtained and providing operational data to the end user.	
UC1-D1-FUN-07	Autonomous navigation	This function allows the autonomous navigation providing automatic tracking of objects and persons during the mission.	Flight navigation

Table 4 UC1 D1 List of Functionalities

2.5 Components

To fulfil the requirements of the demonstrator, carry out the mission operation, and comply with the different functionalities different components must be developed and integrated into the platform that is going to carry out the final validation of the system. The components related to the UC1 Demo 1 are listed below with a short description of each one, but the development of these components is carried out in the technical work packages of the project:

- **WP3-IND-1**

The WP3-IND-1 component corresponds to the design of a payment load with digital video. The payload will have a video resolution of 6720p, hardware gyro stabilization in 3 axes and software stabilization.

This component allows the acquisition of the visible optical video needed. The component will allow you to view the video in the case of use of incident management by tracking on the object of interest.

- **WP3-IND-2**

The WP3-IND-2 component corresponds to the design of a payment load with infrared optics. The payload will have a video resolution of 640x480, hardware gyro stabilization in 3 axes and software stabilization.

This component allows you to obtain the infrared video needed. The component will allow you to view the video in the case of use of incident management by tracking on the object of interest.

- **WP3-IND-3**

The WP3-IND-3 component corresponds to the design of a dual payment load with 2 optics, a visible optics with HD video and an infrared optics with digital video. The paid load will have a video resolution in the visible spectrum of at least 720p and a video resolution in the infrared spectrum of 640x480. Both videos cannot be streamed simultaneously, the operator will select from the control station the type of video you want to view at that time. In addition, you will have 3-axis hardware gyro stabilization and software stabilization.

This component would allow to obtain the video of both visible and infrared optics without the need to land the aircraft for the change of the payment load.

- **WP3-IND-4**

The WP3-IND-4 component corresponds to the communication between the frontend and the control station application backend so that user-requested actions, related to components WP3-IND-1, WP3-IND-2, and WP3-IND-3, are sent to autopilot.

This component allows the control station operator to interact with the new payment charges.

- **WP4-25 Avionics – Encoder**

The WP4-IND-1 component corresponds to the integration of the new visible and infrared optics of the WP3-IND-1 WP3-IND-2 and WP3-IND-3 components into the video encoder. This component ensures the correct control and reception of the video from the visible and infrared optics in the case of use.

WP4-26 Autopilot – Navigation The WP4-IND-2 component corresponds to the work to be carried out on the autopilot to suit the flight plans authorized by the UTM system, as well as the contingency plan to be carried out in case of loss of link between the ground stations. In addition, the adequacy of the different flight modes, related to tracking, to fit the new HD resolution of the video generated by the components WP1-IND-1, WP1-IND-2 and WP1-IND-3.

This component allows alignment between the flight plan authorized by UTM for the use case, as well as the correct execution of said flight plan and sending video when orbiting the point requested by HORUS.

- WP4-27 UTM Ground Service

In this UC1 Demo 1, the UTM Ground service acts in both pre-flight and in-flight phases due to it inherit importance providing critical information about terrain.

During pre-flight phase, it helps the whole flight planning process (mainly Flight Planning Management, Flight Planning Support and Strategic Deconfliction services) by validating the incoming Flight Plan or rejecting it and providing valid alternatives when the original Flight Plan is not valid.

During in-flight phase, the Geofencing service checks every drone position against geofences and geofence’s whitelist to verify or discard allowed flight plans and drones. Then, a list of conflicting drone tracks, attaching the conflicting geofences is returned to Air Monitoring, whom will generate correspondent alerts.

- WP4-28 UTM Airspace Structure

In this UC1 Demo 1, the UTM AirSpace Definition & Geofence Services will work in both pre-flight and in-flight phases due to it inherit importance providing critical information all airspace structure.

During UC1 of Demo1, HORUS Platform (as an Authority) will send to UTM System a request for creating a new Geofence in the UTM System. Once created in UTM platform, this Geofence will reserve a specific area where Mantis drone will operate to record the road accident evidences (no alerts will be generated as Mantis drone will be granted to fly into it).

Once Mantis finishes this flight (UC1 Demo1 has finished), the HORUS Platform (as an authority) will send to UTM the Geofence deletion request, and so UTM will delete this emergency geofence (dynamic update).

- **WP4-29 UTM Flight Plan Management & WP4-31 UTM Flight Plan Authorization**

Along UC1 Demo 1, the UTM Flight Planning Management (cooperatively working with FP Assessment and FP Authorization services) will manage all FP inputs and outputs from the different operators, approving or rejecting in first instance, and managing subsequent states.

- WP4-30 UTM Trajectory algorithms & WP4-32 Telemetry and Tracking

These UTM services are in charge of receiving and processing all the telemetry or track information coming from the flying drones. This info is considered as the incoming air traffic and it is improved with the following information:

- Operator/Drone/pilot info read from the UTM Registry: this helps identification.
- Flight Plan information: this helps the conformance monitoring process.

This will improve safety and awareness by providing (and sharing with 3rd parties when needed) to the different UTM users/roles (operators, authorities, etc…) live and complete information regarding who/where/how.

- **WP5-IND-1: Avionics – Communications /Radio Links**

This component corresponds to the hardware and software work in the avionics so that it receives the video from the components WP1-IND-1, WP1-IND-2 and WP1-IND-3 and this is in turn received by the operator at the control station via the radio link. In addition, the telemetry and sending drop from the control station to the UAV of the Command & Control commands must be maintained.

This component allows within the UC1/D1 use case, the control station operator to correctly receive the new video from the new payment charges, as well as telemetry and Command and Control commands.

- **WP5-IND-2: Communications - Autopilot**

This component corresponds to hardware and software that allows communication between the autopilot and the new payment loads obtained from components WP1-IND-1, WP1-IND-2 and WP1-IND-3. This communication must be bidirectional in order for the self-pilot to manage orders related to payment charges, relating to tracking, from the mission operator.

This component allows, within the UC1/D1 use case, to ensure that the mission operator can interact with payment loads during automatic tracking flight mode.

- **WP5-IND-3 : Communications Ports**

This component encompasses all hardware work aimed at enabling communication between the cargo payment and the fuselage of the aircraft; as well as between fuselage and avionics. This will allow the WP5-IND1 and WP5-IND2 components to have a bidirectional communication between the payloads and the fuselage, where the entire avionics is located, including the autopilot.

This component allows, within the UC1/D1 use case, to have hardware communication between the cargo payment and the avionics of the aircraft.

- **WP5-IND-4: Communications – GCS**

This component encompasses all software developments aimed at communication between the control station and the optics of payment loads developed in components WP1-IND-1, WP1-IND-2 and WP1-IND-3.

This component allows, within the UC1/D1 use case, that the operator of the control station, can send and receive commands to the optics of the payment loads (modification and request of zoom level, calibration commands, change of colour palette, etc...)

- **WP5-IND- 5: Communications - GCS- CMPD**

This component encompasses all software developments that allow you to convert a MANTIS flight plan to the format expected by UTM. It also implements all the business logic needed to correctly execute the **exchange of information between the control station and the CMPD in the use case.**

- **WP5-IND-6: Communications – UAV – GCS –UTM**

This component encompasses all software developments that allow end-to-end communication between the aircraft and UTM.

Within the UC1/D1 use case, this component will communicate to UTM both the telemetry and the time of launch and landing of the aircraft.

- **WP5-IND-7: Communications –GCS -CMPD**

This component encompasses all software developments that allow communication of the MANTIS system with the HORUS system

This component will be responsible for communicating with the HORUS system, through the CMPD system, for the exchange of messages that are contemplated within the UC1/D1 use case. These messages include requesting a new mission, accepting the mission, as well as orders to take off and landing the aircraft.

The table below summarizes these components and relates them to the demonstrator KPIs and Success criteria, Measurable Outcome and concrete objective of the project:

Partner	Work Package	Components	Demo	Component ID	KPI	Criteria	Measurable Outcome	Objective
Indra	WP3-IND-1	Payload (Single Visible HD)	UC1/D1	5.20	UC1-D1-KPI-T1, UC1-D1-KPI-T4	SC1.2	MO1.3	O1
Indra	WP3-IND-2	Payload (Infrared HD)	UC1/D1	5.20	UC1-D1-KPI-T1, UC1-D1-KPI-T4	SC1.2	MO1.3	O1
Indra	WP3-IND-3	Payload (Dual HD)	UC1/D1	5.20	UC1-D1-KPI-T2, UC1-D1-KPI-T4	SC1.2	MO1.3	O1
Indra	WP3-IND-4	GCS - HMI	UC1/D1	5.20	UC1-D1-KPI-T1, UC1-D1-KPI-T4	SC1.2	MO1.3	O1
Indra	WP5-IND-1	Avionics – Communications /Radio Links	UC1/D1	WP5-IND-1	UC1-D1-KPI-T3	SC1.2	MO1.3	O1
Indra	WP4-IND-1	Avionics - Encoder	UC1/D1	WP4-25	UC1-D1-KPI-T1, UC1-D1-KPI-T2	SC2.1	MO2.1	O2
Indra	WP4-IND-2	Autopilot - Navigation	UC1/D1	WP24-26	UC1-D1-KPI-T2	SC2.1	MO2.1	O2
Indra	WP5-IND-2	Communications - Autopilot	UC1/D1	WP5-IND-2	UC1-D1-KPI-T3	SC2.1	MO2.1	O2
Indra	WP5-IND-3	Communications - Ports	UC1/D1	WP5-IND-3	UC1-D1-KPI-T4	SC1.2	MO1.3	O1
Indra	WP5-IND-4	Communications – GCS - Autopilot	UC1/D1	WP5-IND-4	UC1-D1-KPI-T3	SC3.1	MO3.2	O3
Indra	WP5-IND-5	Communications – GCS - CMPD	UC1/D1	WP5-IND-5	UC1-D1-KPI-T3	SC3.1	MO3.2	O3

Indra	WP5-IND-6	Communications – UAV – GCS – CMPD - UTM	UC1/D1	WP5-IND-6	UC1-D1-KPI-T3	SC3.1	MO3.2	O3
Indra	WP5-IND-7	Communications – GCS - HORUS	UC1/D1	WP5-IND-7	UC1-D1-KPI-T3	SC3.1	MO3.2	O3
Indra	WP4-IND-3	UTM Ground Service	UC1/D1	WP4-27	UC1-D1-KPI-T3	SC2.1	MO2.1	O2
Indra	WP4-IND-4	UTM Airspace Structure	UC1/D1	WP24-28	UC1-D1-KPI-T3	SC2.1	MO2.1	O2
Indra	WP4-IND-5	UTM Flight Plan Management	UC1/D1	WP4-29	UC1-D1-KPI-T3	SC2.1	MO2.1	O2
Indra	WP4-IND-6	UTM Trajectory algorithms	UC1/D1	WP4-30	UC1-D1-KPI-T3	SC2.1	MO2.1	O2
Indra	WP4-IND-7	UTM Flight Plan Authorization	UC1/D1	WP4-31	UC1-D1-KPI-T3	SC2.1	MO2.1	O2
Indra	WP4-IND-8	UTM Telemetry and Tracking	UC1/D1	WP4-32	UC1-D1-KPI-T3	SC2.1	MO2.1	O2

Table 5 UC1 D1 List of components

2.6 Traceability matrices

2.6.1. Requirements vs. functionalities

The table below links all the requirements identified in demonstrator 1 (both from D1.2 and this deliverable) to the main functionalities defined:

Requirement	Short description	FUNC 1	FUNC2	FUNC 3	FUNC 4	FUNC 5	FUNC 6	FUNC 7
DEM1-FNC-1	Activation of incident geofence	X						
DEM1-FNC-2	Flight plan		X					
DEM1-FNC-3	HD video					X		
DEM1-FNC-4	Tracking			X				
DEM1-FNC-5	Real time video streaming					X		
DEM1-FNC-6	Drone navigation							X
DEM1-FNC-7	Video transmission						X	
DEM1-FNC-8	Drone GCS communication						X	
DEM1-FNC-9	Geofence communication	X						
DEM1-FNC-10	Display of airspace							
DEM1-FNC-11	Drone position			X				
DEM1-FNC-12	Airspace status			X				
DEM1-FNC-13	Drone service request							
DEM1-FNC-14	Airspace allocation		X					
DEM1-FNC-15	Trajectory conflicts					X		
DEM1-FNC-16	Unauthorized behaviour					X		
DEM1-FNC-17	Compliance with U-Space		X					
DEM1-FNC-18	Flight Plan Validation		X					
DEM1-FNC-19	Flight plan alternatives		X					

DEM1-FNC-20	Alternative authorization request		X					
DEM1-FNC-21	Manual authorization		X					
DEM1-FNC-22	Planned flight plans		X					
DEM1-FNC-23	Authorization notification		X					
DEM1-FNC-24	Telemetry reception			X				
DEM1-FNC-27	Drone conformance calculation			X				
DEM1-FNC-28	Geofence violation alarm	X						
DEM1-FNC-29	Tactical conflict alarm				X			
DEM1-FNC-30	Tracking and alert information to linked systems			X				
DEM1-FNC-31	Geofence reception and creation in UTM	X						
DEM1-FNC-32	Delete geofence in UTM	X						
DEM1-PRF-2	Image stabilization (I)					X		
DEM1-PRF-3	Image stabilization (II)					X		
DEM1-DSG-1	Camera dimensions and weight					X		
DEM1-OPR-1	Camera movement and zoom					X		
DEM1-SEC-3	Cybersecurity						X	
DEM1-INT-1	Communications bandwidth						X	
DEM1-SEC-4	Secure communication module						X	
DEM1-DSG-2	Area resolution		X					
DEM1-P&C-2	Compliance with regulations		X					
DEM1-INT-3	Flight plan authorization workflow		X					

Table 6 UC1 D1 Requirements and functionalities traceability matrix

2.6.2. Functionalities vs. Components

The table below links all the components that are part of this demonstrator to the main functionalities defined:

FUNCTIONALITY	Short description	WP3-IND-1	WP3-IND-2	WP3-IND-3	WP3-IND-4	WP4-IND-25	WP4-IND-25	WP4-IND-27	WP4-IND-28	WP4-IND-29	WP4-IND-30	WP4-IND-31	WP4-IND-32	WP5-IND-1	WP5-IND-2	WP5-IND-3	WP5-IND-4	WP5-IND-5	WP5-IND-6	WP5-IND-7
FUN-01	Geofencing - UTM												X						X	X
FUN-02	Flight plan management							X	X	X	X	X								
FUN-03	Flight tracking and control (mission) - UTM											X	X							
FUN - 04	Deconfliction -UTM								X		X	X								

FUN - 05	HD image acquisition	X	X	X	X															
FUN-06	Image streaming / Drone connections and communications					X								X			X	X	X	X
FUN-07	Autonomous navigation							X						X	X		X			

Table 7 UC1 D1 Components and functionalities traceability matrix

2.7 Validation plan

Taking into account the Validation and Verification methodology explained in the introduction of the document, once all the requirements components and tools have been identified; and after the performance of the traceability matrices the loop must be closed with the verification and validation plan for the all the systems. These Verification and validation plan can be divided into three different levels: Component verification, Verification of the main functionalities and finally the validation of the systems.

2.7.1. Components Verification

- **WP3-IND-1, WP3-IND2**

The *WP3-IND-1* be validated with a relevant environment in order to demonstrate that a TRL 6 is feasible.

Test description	1. Tests of the component in the laboratory: gyro stabilization verification, receiving commands, correct video data stream to the autopilot. Verification by visual validation, oscilloscopes and video display. 2. Non-flight external tests: The component is mounted on the aircraft. The visual tracking objective is set and the same checks are performed as in the laboratory. Checks are performed directly at the system control station validating that the video is received, that the tracking is successfully tracked with the gyro stabilization and that the communication between the component and the autopilot is correct. *3.* External tests with flight plan equivalent to the use case.
Planned inputs	*Payload powered and running; tracking objective*
Expected results	*With the movement of the target, the payload should keep it on the screen, ideally in the centre of the target, until the target disappears from the viewing area*

- **WP3-IND-4**

Test description	1. Tests integrated into the laboratory, checking its proper operation against the flight simulator 2. Integrated external tests without aircraft flight to check proper operation against the actual system.
Planned inputs	*Payload powered and connected to the fuselage; communication interface between autopilot and GCS*

Expected results	*- Recognition of the type of payload connected* *- Interaction with the payload by the operator in relation to the automatic tracking functionality* *- Correct video display*

- **WP4-25**: This component is being verified during phase 2 described in the datasheets of components WP3-IND-1 and WP3-IND-2.

Planned inputs	*Payload powered and connected to the fuselage; communication interface between autopilot and GCS; tracking objective; zoom levels*
Expected results	*Correct video display of all payloads, with the most optimal latency, refresh rate and bandwidth*

- **WP4-26**: This component is being verified during phase 2 described in the datasheets of components WP3-IND-1 and WP3-IND-2.

Planned inputs	*Payload powered and connected to the fuselage; communication interface between autopilot and GCS*
Expected results	*The lens is tracked until it disappears from the viewing area operating at the different zoom levels, both optical and digital, of which the payload is available.*

- **WP4-28**

Test description	For pre-flight phase, complete flow of Flight Planning should finish with the expected answer, computing proper values for min/max height, and deconflicting the FP when needed. For in-flight phase, the Air Monitoring service should provide live information and alerts when a drone flies lower than the declared FP altitude, being a possible cause of any ground risk. . Once a FP is approved, the UTM HMI displays a graphic that contains information (vertical and longitudinal) that helps the pilot to have an overview about ground DTM + DSM and, min/max altitude. At present, (February, the 25th) first tests are satisfactory, being able to receive on UTM side the new FP request coming from CMPD, and avoiding ground and obstacles by setting a minimum flight altitude. All the area operations are going to be covered by the UTM Ground service with a ground resolution of 5x5m2 Simulations for that flights are ok as well, and thresholds (altitude deviations) can be modified via parameters if needed.
Planned inputs	*FP is sent for approval*
Expected results	*FP approved, ground DTM + DSM and, min/max altitude*

- **WP4-29 & WP4-31**

Test description	To verify proper service working, complete flow of Flight Planning should finish with the expected answer.

	When requesting a New FP to the Flight Planning Management API, service answer should contain the status of the FP Request and the Unique ID of it. During Use Case 1, CMPD sends to the UTM Flight Planning services API the request to create a New Flight Plan. Then, the UTM system will provide an answer indicating that the FP has been approved, so then, it can be flown when requested to fly. Flow is defined and blue marked in diagram above. During UC 1, CMPD will send the request to a New Flight Plan to the UTM Flight Planning services. This service will calculate the expected trajectory and through the authorization process, it will check this new request against all planned Flight Plans, airspace structure and flight rules. Once checked, the FPM service will provide back to CMPD the result of this request. This will contain the status "APPROVED" of the New FP and a unique ID to identify it. Once approved, the flight can be flown when indicated in the request.
Planned inputs	*Flight Planning services API the request to create a New Flight Plan, request to a New Flight Plan*
Expected results	*Result of this request*

- **WP-30 & WP4-32**

Test description	To verify proper service working, the UTM team will ensure in one hand that all API requests that should be performed from Mantis, CMPD and HORUS can be performed. In the other hand, tracking service will make available the full drone tracks, that include all the conformance monitoring, registration information and alerts (if exist). During UC1 Demo1, the UTM Air Monitoring service will provide to all the 3rd party UTM data consumers all the drone traffic and registration information when requested. HORUS platform will subscribe to UTM drone tracking service, being able to draw full information regarding drones in their platform. CMPD will display UTM Air Monitoring HMI in embedded in their platform so they will be able to access all their relevant information within drones' traffic. All operators will be able to show all nearby traffic in their surroundings just for safety and air situational awareness purposes. All the subscriptors to the tracking information from UTM platform will be able to retrieve at least an update for all the live traffic every each second. Despite this parameter is configurable, due to network limitations and after a bunch of tests, we considered this value as the most appropriated.
Planned inputs	*API requests from Mantis, CMPD and HORUS*
Expected results	*drone traffic and registration information*

- **WP5-IND-1**

Test description	Integration tests in the laboratory and outdoors, checking that: 1. Telemetry is received at the control station

	2. Commands can be performed from the control station 3. Video is received at the control station
Planned inputs	*Payload powered and connected to the fuselage; GCS powered and connected to Ground Data Terminal*
Expected results	*Communication between the aircraft and the control station is established* *Telemetry and video are received at the control station* *Orders can be commanded from the control station to the aircraft*

- **WP5-IND-2**

Test description	Integrated tests in the laboratory and outdoors, checking that all flight modes related to automatic tracking work correctly
Planned inputs	*Payload powered and connected to the fuselage; GCS powered and connected to Ground Data Terminal; tracking objective*
Expected results	*The operator can command the different modes of flight, related to automatic tracking, of the aircraft* *In the face of target movement, each of the flight modes behave as expected (on-screen maintenance of the target either fixed or mobile and modification of the flight plan or not depending on the type of flight mode selected)*

- **WP5-IND-3**

Test description	*Laboratory tests checking for communication between the aircraft's payloads and fuselage*
Planned inputs	*Powered fuselage, payload connected to fuselage*
Expected results	*Communication between payload and fuselage*

- **WP5-IND-4 : Communications – GCS**

Test description	Tests integrated in the laboratory and outdoors, checking that there is communication between the control station and the optics of the payment loads
Planned inputs	*Payload powered and connected to the fuselage; GCS powered and connected to Ground Data Terminal;*
Expected results	*Zoom-level status request command is sent and the correct response is received* *Zoom level modification command is sent and the command is executed* *Calibration commands are sent and commands are executed* *Colour palette change commands are sent and commands are executed*

- **WP5-IND- 5 : Communications**

Test description	*Outdoor integrated testing to execute messaging exchange between GCS and CMPD based on defined messaging flow between systems*
Planned inputs	*Payload fed and connected to the fuselage* *Control station powered and connected to the GDT (Ground Data Terminal)* *Communication available between the GCS and the CMPD*

Expected results	*The exchange of information between the GCS and CMPD is as expected based on the messaging flow defined between the systems.*

- **WP5-IND-6 : Communications – UAV – GCS –UTM**

Test description	*Outdoor integrated testing to execute messaging exchange between UAV and UTM based on defined messaging flow between systems*
Planned inputs	*Payload fed and connected to the fuselage* *Control station powered and connected to the GDT (Ground Data Terminal)* *Communication available between the GCS and the UTM system*
Expected results	*The exchange of information between the UAV, through the GCS, and UTM is as expected based on the messaging flow defined between the systems. It will verify that the telemetry sent by the UAV reaches the UTM system in the format defined by it; as well as the notification of the launch and landing of the aircraft*

- **WP5-IND-7 : Communications -GCS– CMPD**

Test description	*Outdoor integrated tests to execute the messaging exchange between the GCS and the HORUS system, through the CMPD, according to messaging flow defined between the systems*
Planned inputs	*Payload fed and connected to the fuselage* *Control station powered and connected to the GDT (Ground Data Terminal)* *Communication available between the GCS and the CMPD system*
Expected results	*The exchange of information between the GCS, through the CMPD system, and HORUS is as expected based on the messaging flow defined between the systems. The courier exchange related to the request and acceptance of a new flight mission, as well as the aircraft's take-off and landing orders, will be verified*

2.7.2. System Functionalities Verification

At a higher level than the components, the main functionalities of the demonstrator must be validated in order to ensure that the final system will be able to meet the objectives of the demonstrator 1. Compliance with the functionality, in turn, will ensure the validation of the requirements associated with each of them.

The table below shows the relation between the environments and campaigns defined in D1.1:

Environment	Campaign	Stage	Period	Description
Laboratory environment	Campaign 1	Stage 1	M1-M3	Image and data acquisition with Mantis. Definition of scenarios.
	Campaign 2	Stage 1	M7-M10	First individual integration tests: HORUS – Mantis- CMPD – UTM (Interfaces).
	Campaign 3	Stage 2	M13-M15	Integration and tests of components prototypes (sensors, cameras, navigation and communication modules). Lab environment deployment.
Outdoor controlled or Simulated environments	Campaign 4	Stage 2	M16-M20	
	Campaign 5	Stage 3	M23-M24	

Realistic environment or real scenario	Campaign 6	Stage 3	M27-M32	Validation of final components. Deployment of the UC in real site with all the components, interfaces and integrations.
	Campaign 7	Stage 3	M34	

UC1-D1-FUN01 – Geofencing - UTM

Environment	Goal	Output
Laboratory	Integrations between UTM and HORUS platform, in which HORUS sends a geofence request to UTM, UTM validates the request and communicates the activation to HORUS.	Interface connecting HORUS and UTM platforms. First individual integration tests.
Outdoor controlled	Geofencing of incident area with updates of drone identification parameters. Simulated test flights. Deactivation of geofence from HORUS.	Telemetry of the flights, data logs of the geofence.
Realistic	Complete geofence functionalities. Violation of geofence scenarios. Test flights in realistic scenario.	Telemetry of the flights, data logs of the geofence.

UC1-D1-FUN02 – Flight plan Management

Environment	Goal	Output
Laboratory	Integrations between CMPD and Mantis, between CMPD and HORUS, in which Mantis creates a flight plan based on the needs from HORUS.	Interface connecting Mantis and CMPD, and CMPD and HORUS platforms. First individual integration tests.
Outdoor controlled	Integrations between CMPD and UTM. Simulated flight plan authorization process between platforms.	First flight authorization tests.
Realistic	Complete flight plan authorization functionalities, with all the platforms integrated. Test flight management process in realistic scenario.	Flight approved by the UTM platform based on HORUS needs, created by Mantis-CMPD.

***UC1-D1-FUN03* – Flight tracking and control (mission) - UTM**

Environment	Goal	Output
Laboratory	Integrations between UTM and HORUS, in which HORUS receives the telemetry of the drones flying over the geofence area requested.	Interface connecting HORUS and UTM platforms. First individual integration tests (simulated telemetry and tracks visualization).
Outdoor controlled	Integrations between CMPD and UTM. Simulated flight tracking of Mantis drone	First flight tracking simulated tests. Simulated telemetry and tracks monitoring.
Realistic	Complete flight tracking functionalities, with all the platforms integrated. Test flight tracking process in realistic scenario.	Real tracks and telemetry from Mantis monitored in UTM

		platform. Visualization of telemetry and tracks in HORUS:

***UC1-D1-FUN04* – Deconfliction - UTM**

Environment	Goal	Output
Laboratory	Implementation of conflict detections over the geofence area received by HORUS and flight plan created by Mantis.	Implementation of functionality for the use case.
Outdoor controlled	Simulated tests of conflict detection and deconfliction workflow for the simulated mission.	First simulation test. Denials and alternatives for the conflictive missions.
Realistic	Complete deconfliction functionalities, with all the platforms integrated. Test deconfliction process in realistic scenario (scenario 2).	Real simulation tests. Execution of denials and alternatives for the conflictive missions.

***UC1-D1-FUN05* – HD image acquisition**

Environment	Goal	Output
Laboratory	Initial tests of the image acquisition system. Correct gyro stabilization, commands.	Visual validation of the images captured and analysis of quality, stabilization.
Outdoor controlled	Exterior image acquisition tests with components installed on Mantis (ground tests).	Visual validation of the images captured, verification over GCS.
Realistic	Complete image acquisition functionalities, with all the components integrated. Exterior flight tests and visualization of HD images from Mantis.	Real image acquisition tests. HD video acquisition.

UC1-D1-FUN06 – Image streaming

Environment	Goal	Output
Laboratory	Initial reception of images from Mantis drone to the HORUS platform in real time.	Visualization of image captured by Mantis in HORUS.
Outdoor controlled	First integrations of CMPD and HORUS for receiving the images from MANTIS. First HD image acquisition with Mantis components.	First integration interfaces for video visualization.
Realistic	Complete image streaming functionalities, with all the platforms integrated. Visualization of HD images from Mantis in HORUS during the execution of the mission in a real scenario.	Real image acquisition tests. HD video reception integrated in HORUS.

UC1-D1-FUN07 – Autonomous navigation

Environment	Goal	Output
Laboratory	Initial analysis of the data received from the HD cameras in the autopilot.	Analysis and visual validation of tracking capabilities.
Outdoor controlled	First exterior tests of autopilot and tracking, setting a tracking objective (ground tests).	Analysis and visual validation of tracking capabilities.

Realistic	Complete autonomous navigation functionalities. Visualization of autonomous tracking of Mantis the execution of the mission in a real scenario.	Real autonomous navigation tests. Analysis and visual validation of tracking capabilities.

2.7.3. System validation (KPIs)

Finally, the table below shows the verification method for each of the technical KPIs identified:

KPI ID	KPI	Verification Method
UC1-D1-KPI-T1	Improvement of automatic tracking system of objects and persons	In flight by automatically tracking an object/person on the move.
UC1-D1-KPI-T2	Operational System Improvement: Increasing detection, recognition and identification distances of objects/people	In flight carrying out missions for detection, recognition and identification of objects/people
UC1-D1-KPI-T3	Communications: Integration with external systems by standards	During the execution of the Use Case 1
UC1-D1-KPI-T4	Optimization of available bandwidth usage	On the ground or in flight by checking the data rate needed to receive HD video with quality.

Table 8 UC1 D1 system validation plan

3 UC1-Demo 2 Transport: Port Operations

3.1 Current state of the technology

Current port surveillance operations are being performed using traditional means, integrating different security systems such as CCTV. The surveillance of the port area relies in its security personnel, who performs long surveillance rounds along the different sections of the infrastructure, using a surveillance vehicle and also walk rounds. However, these surveillance rounds take large amounts of time to cover the whole area, becoming inefficient and, in most cases, are limited, leaving some blind spots that are not possible to inspect with current technology.

The Port Control System integrate all the different sources of information that monitor the infrastructure of the port, including all the sensors and cameras deployed. However, current control system lacks integrations with drones, which could be deployed of a captive drone as a mobile system for security and aerial surveillance in real time.

Up until now, the drone applications in port surveillance operations have been performed using ad-hoc solutions to specific mobility events. The deployment of drones in critical infrastructures is still not widely implemented, especially in services for improving security and rapid response. The application will be deployed in the Port of Vigo (Spain) and will provide a mobile “eye in the sky” for the daily tasks of surveillance that are carried out in the surroundings of the port. With this demonstrator, the ambition is to provide high quality thermal images/data in real time from different angles, of uncovered areas (possible blind spots) by the surveillance and security systems currently available at the port.

3.2 Use Case Concept of Operation

This demonstrator’s concept of operation includes all the steps and actions taken by the systems involved (captive UAV system and Port Control Centre) in the different stages of the mission: pre-flight, captive UAV mission, and image acquisition and control.

The figure below summarizes all the steps performed by the drone system during the mission defined for this demonstrator:

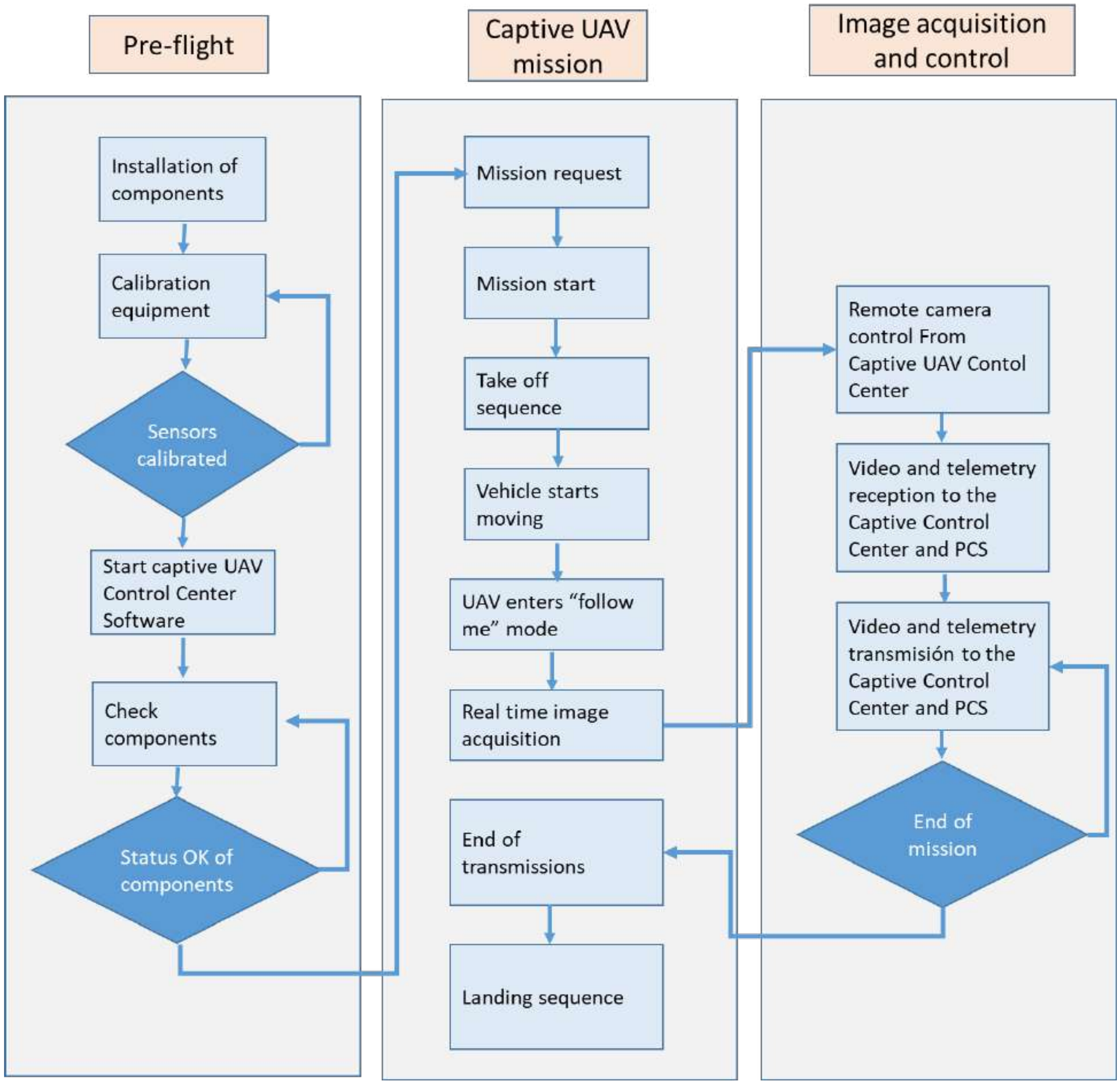


Figure 4 UC1 – D2 demonstrator's concept of operation scheme

- Previous actions
  - Deployment, assembly and start-up of the system

Below are detailed the steps to proceed with the deployment and assembly of the equipment:

1. Have the equipment in the vehicle (generator and landing support).
2. Secure the generator with a sling.
3. Install components in UAV.
4. Turn on all the equipment of the system.
5. Calibrate sensors if required.
6. Start the "Captive UAV Control Center" software.

7. Check the connectivity of the modules.

Pre-flight checklist

Before starting the flight, the following checks will be carried out:

1. Verification of coverage level, communications with sensors, status of indicator lights and telemetry reception.
2. Check the correct status of the Control Station.
3. Visual verification of the physical state of the components.

Start of flight sequence:

- The “Captive UAV Control Center” receives an order from the “Port Control Center” in order to carry out a Surveillance mission.
- The operator of the “Captive UAV Control Center” receives the order and proceeds to the start of the mission at the indicated location.
- The UAV engines are armed and the take-off sequence begins:
  - Take off is ordered from the “Captive UAV Control Center”.
  - The UAV ascends to an altitude higher than the operating altitude in order to deploy the necessary cable to execute the mission.
- Vehicle starts moving.
- The UAV enters in “follow me“ mode and flies at the indicated operating altitude, following the path of the vehicle as it moves.
- INDRA vehicle goes to the requested points in order to take the required images/video recordings in real time.
- From the “Captive UAV Control Center” the camera is remotely operated to guide it to the most optimal position to take the images with the highest possible coverage and quality.
- Video and telemetry are transmitted both to the “Captive UAV Control Center” located in the vehicle and to the “Control Center” of the Port of Vigo.
- Once the mission has been completed the flight finishes and the drone operator stops sharing the telemetry and live images from the drone.
- Once the vehicle stops, the UAV begins the landing sequence:
  - Landing is ordered from the “Captive UAV Control Center”
  - The UAV descends vertically by folding the cable until it is located on the resting platform.
  - The engines are disarmed.
  - The message indicating the status of the UAV at that moment is displayed.
- The system is turned off, disassembled and the equipment is collected.

3.3 System Requirements, KPI´s and Metrics

To have clear idea of the objectives and purpose of the demonstrator it is important to highlight the main metrics defined in deliverable D1.1 and that will lead to the definition of the most applicable requirements of the systems and components developed within the project.

3.3.1. Technical KPI`s and Metrics

In D1.1 the main business KPIs for this demonstrator were introduced. Complementary to those KPIs already identified, the table below presents the technical KPIs of Demo2, with their definition, measurement indicator and target value:

	KPI	Definition and measurement of Indicator
UC1-D2-KPI-T1	Increase the deviation angle of the drone from the horizontal plane of the vehicle	The indicator for this KPI will be obtaining the maximum deviation angle of the drone from the horizontal plane of the vehicle.
		To measure the efficiency of mobility, we establish that the maximum angle of deviation of the drone with respect to the horizontal plane of the vehicle is ≤ 20°.
UC1-D2-KPI-T2	Reduce response time of the drone	The indicator of this KPI will obtain information on the response time since the drone receives the position of the vehicle until it reaches that position.
		To measure the efficiency of mobility, we establish that the response time since the target position is received and the drone is located in that position is ≤ 1 sec.

Table 9 UC1 D2 List of KPIs

3.3.2. Main requirements (functional, interface, performance, security, usability…)

D1.1 introduced the main functional requirements of the demonstrator. In this section, the remaining technical requirements for the demonstrator are shown, linked to specific KPIs of the demonstrator:

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC1-DEM2-P&C-1	Drone loss of control	The system shall be able to recover an eventual total loss of control over the drone using the single channel 2.4 GHz	*H*	Drone provider	UC1-D2-KPI-T2
UC1-DEM2-DSG-1	Versatile vehicle integration system	The design of the captive system shall be conceived to allow an easy coupling with any mobile vehicle with a surface of at least W x L centimeters’	*L*	Drone integrator	UC1-D2-KPI-T2
UC1-DEM2-PRF-1	Maximum take-off speed	The maximum take-off speed of the drone must be under 3m/s	H	Drone provider	UC1-D2-KPI-T2
UC1-DEM2-PRF-2	Maximum landing speed	The maximum landing speed of the drone must be under3m/s	H	Drone provider	UC1-D2-KPI-T2
UC1-DEM2-USB-1	Maximum tilt angle	The maximum tilt angle of the drone must be 20º	H	Drone provider	UC1-D2-KPI-T1
UC1-DEM2-USB-2	Maximum angular velocity	The maximum angular velocity of the drone must be 180º/s	H	Drone provider	UC1-D2-KPI-T1
UC1-DEM2-P&C-2	Stationary flight accuracy range	The captive drone system must offer a stationary flight accuracy of at least 3m	H	Drone provider	UC1-D2-KPI-T1

Table 10 UC1 D2 List of Main Requirements

3.3.3. Regulatory requirements

The requirements below are related with the SORA analysis performed (Reference to the methodology in D2.5.) and the boundary conditions introduced in D1.1, as well as to the regulatory framework that dictates the deployment of the scenarios of the demonstrator.

Requirement ID	Short Description	Description	Priority (H/M/L)	Source
UC1-DEM2-REG-1	Limited weight according to regulations	Drone designed with a weight of < 10 kg to be able to fly in populated areas according to current regulations.	H	Drone provider
UC1-DEM2-REG-2	Maximum operation height	The operation height of the drone must be 40m	H	Drone provider
UC1-DEM2-REG-3	Visual Meteorological Conditions	According to Spanish civil regulations, flights are to be performed under VMC (Visual Meteorological Conditions) and therefore, during daylight time.	H	Drone provider
UC1-DEM2-REG-4	Drone pilot authorized	Drone pilot must be authorized to fly the drone	H	Drone provider
UC1-DEM2-REG-5	Drone operator registered	Drone operator must be registered in the national aviation authority registration list	H	Drone provider
UC1-DEM2-REG-6	Compliance with current regulatory framework	All flights that take place within the Spanish territory are to comply with Spanish RPAS regulation under “Real Decreto” 1036/17, signed on December 17th 2017, and European regulation framework that includes Regulation (EU) 2018/1139, Delegated Regulation (EU) 2019/945, and Implementing Regulation (EU) 2019/947	H	Drone provider

Table 11 UC1 D2 List of Regulatory Requirements

3.4 Functionalities identification

Main functionalities of the system have been defined in order to give more information about the characteristics needed for the performance of the mission operations. Since the requirements are a high level of specification, this step represents a lower step in the V&V model, being a lower level of specifications of the process. All of them together will intrinsically define the final system. As it was done for the requirements, Table 12 show the functionalities identified for the demonstrator 2.

ID	Functionality	Description	System function
UC1 –D1 - FUN – 01	Captive UAV System	The vehicle provides a platform to host the UAV	Flight control
UC1 –D1 - FUN – 02	GNSS positioning	This function provides the captive UAV its GPS position to the captive UAV so that the system can operate in tracking mode	Flight navigation
UC1 –D1 - FUN - 03	UAV-Surface vehicle navigation	This function provides the Captive UAV with tracking capabilities that allows the drone to follow the surface vehicle autonomously.	Flight navigation
UC1 –D1 - FUN - 04	Mission monitoring	This function centralizes all the information received from the “UAV Captive System”. It has a dedicated interface to display telemetry and video and to be able to interact in real time with the UAV.	Intelligent data handling

Table 12 UC1 D1 List of Functionalities

3.5 Components

To fulfil the requirements of the demonstrator, carry out the mission operation, and comply with the different functionalities different components must be developed and integrated into the platform that is going to carry out the final validation of the system. The components related to the UC1 Demo 2 are listed below with a short description of each one, but the development of these components is carried out in the technical work packages of the project:

- **WP1-IND-1Power Supply- Captive Kit**

It is a component that provides the necessary power for the operation of the system. It has a module embarked on the drone that is responsible for adapting the voltage provided by the suitcase to that required by the drone and communicates with another module on the ground that is responsible for collecting the power supply supplied by the power point that provides the alternating current at 220VAC.

This component is involved in the case of use by providing power to the system uninterruptedly.

- **WP1-IND-2 Installation - Captive UAV System**

It is a stand containing the captive kit and the drone collection system. At the top of this bracket, a base on which the multi-circuiter rests is available. The system will also be powered by a separate generator. All this will be anchored in a trailer enabled for this function.

This component provides the necessary material to be able to install the system on a vehicle to execute the use case

- **WP1-IND-3 GNSS Receiver**

The Vehicle Control Unit has a GNSS device connected via USB, providing the UAV with the GPS position of the vehicle in order to allow the operation of the system in tracking or "follow me" mode.

Within the use case, this component will provide the UAV with the GPS position of the vehicle

- **WP1-IND-4 Real-time display in "Captive UAV Control Center"**

It is the SW application responsible for monitoring the system, allowing the real-time reception of the data provided by the drone, interacting with the parameters of the camera integrated in the drone and commanding the basic actions that the drone will perform (take-off, landing, etc.).

This component includes all the software development that allows you to interact with the drone and the payment load, as well as monitor the system

- **WP4-IND-45 Tracking algorithm**

Tracking algorithm Captive UAV/Surface Vehicle – Navigation" is a SW encoded on an SBC processing platform on board the drone and in communication with its external sensors. Its objective is to collect the information of the position of the drone, compare it with the position of the moving target and send this information to the drone flight control system who will be in charge of translating it to the route to follow. The UAV will make the necessary position / heading corrections to converge with the vehicle's path.

This component is responsible for ensuring that the UAV has the ability to follow the route traced by the moving vehicle at all times.

The table below summarizes these components and relates them to the demonstrator KPIs and Success criteria, Measurable Outcome and concrete objective of the project:

Partner	Work Package	Components	Demo	Component ID	KPI	Criteria	Measurable Outcome	Objective
Indra	WP1	Power Supply-Captive Kit	UC1/D2	WP1-IND-1	UC1-D2-KPI-1 UC1-D2-KPI-2 UC1-D2-KPI-3 UC1-D2-KPI-4	SC1.2	MO1.3	O1
Indra	WP1	Installation - Captive UAV System	UC1/D2	WP1-IND-2	UC1-D2-KPI-1 UC1-D2-KPI-2 UC1-D2-KPI-3 UC1-D2-KPI-4	SC1.2	MO1.3	O1
Indra	WP1	GNSS Receiver	UC1/D2	WP1-IND-3	UC1-D2-KPI-T1	SC1.2	MO1.3	O1
Indra	WP1	Real-time display in "Captive UAV Control Center"	UC1/D2	WP1-IND-4	UC1-D2-KPI-1 UC1-D2-KPI-2 UC1-D2-KPI-3 UC1-D2-KPI-4	SC1.2	MO1.3	O1
Indra	WP4	Tracking algorithm	UC1/D2	WP4-45	UC1-D2-KPI-T2	SC2.1	MO2.1	O2

Table 13 UC1 D1 List of components

3.6 Traceability matrices

3.6.1. Requirements vs. functionalities

The table below links all the requirements identified in demonstrator 1 (both from D1.2 and this deliverable) to the main functionalities defined:

Requirement	Short description	FUNC 1	FUNC2	FUNC 3	FUNC 4
DEM2 -1	Speed of the surface vehicle			X	
DEM2 -2	Wind conditions			X	
DEM2 -3	Drone speed			X	
DEM2 -4	System power	X			
DEM2 -5	Installation	X			
DEM2 -6	Route tracking			X	
DEM2 -7	Connection encryption				X
DEM2 -8	Geodetic Reference System		X		
DEM2 -9	Real time images				X
DEM2 -10	Low visibility conditions			X	
DEM2-P&C-1	Drone loss of control				X
DEM2-DSG-1	Versatile vehicle integration system	X			
DEM2-PRF-1	Maximum take-off speed	X			
DEM2-PRF-2	Maximum landing speed	X			
DEM2-USB-1	Maximum tilt angle			X	
DEM2-USB-2	Maximum angular velocity			X	
DEM2-P&C-2	Stationary flight accuracy range			X	

Table 14 UC1 D1 Requirements and functionalities traceability matrix

3.6.2. Functionalities vs. Components

The table below links all the components that are part of this demonstrator to the main functionalities defined:

FUNCTIONALITY	Short description	WP1-IND-1	WP1-IND-2	WP1-IND-3	WP4-45	WP1-IND-4
FUN-01	Captive UAV System	X	X			
FUN-02	GNSS positioning			X		
FUN-03	UAV-Surface vehicle navigation				X	
FUN - 04	Mission monitoring					X

Table 15 UC1 D1 Components and functionalities traceability matrix

3.7 Validation plan

Taking into account the Validation and Verification methodology explained in the introduction of the document, once all the requirements components and tools have been identified; and after the performance of the traceability matrices the loop must be closed with the verification and validation plan for the all the systems. These Verification and validation plan can be divided into three different levels: Component verification, Verification of the main functionalities and finally the validation of the systems

3.7.1. Components Verification

WP4-45 - Tracking algorithm Captive UAV/Surface Vehicle - Navigation

Test description	○ From the "Captive UAV Control Center", take off is ordered at the desired operating altitude. ○ Arming of UAV engines. ○ Start of "follow me" mode. ○ The UAV ascends to an altitude higher than the operating altitude in order to deploy the necessary cable to execute the mission. ○ The UAV enters in "follow me" mode and flies at the indicated operating altitude, following the path of the vehicle as it moves. ○ Once the vehicle stops, the UAV descends vertically by folding the cable until it is located on the resting platform.
Planned inputs	Coordinates to be followed according to PID control algorithm.
Expected results	Adjust the orientation and speed of the drone, adapting the position of the UAV to the vehicle at all times.

WP1-IND-1 Power Supply- Captive Kit

Test description	The system is connected and analysed by a meter that the voltage is always stable. We stimulate all components at their maximum power and verify by means of an application supplied by the manufacturer of the Captive Kit, that the intensity provided is sufficient at maximum consumption.
Planned inputs	Stable voltage supply.
Expected results	Correct power supply of all system components, without voltage drops or electrical outages.

WP1-IND-2 Installation - Captive UAV System

Test description	The following points are checked: • Correct installation and anchoring of all system components • Proper distribution of components and wiring. • System screws.
Planned inputs	Components that make up the system.
Expected results	System properly installed.

WP1-IND-3 GNSS Receiver

Test description	The deviation between the current coordinate and the one to be followed, i.e. the margin of error between the two, will be checked.
Planned inputs	Current coordinates of the UAV
Expected results	Coordinates of the UAV - Coordinates of the vehicle to be followed.

WP1-IND-4 Real-time display in "Captive UAV Control Center"

Test description	The following points are checked: • Correct real-time video reception: resolution, delay, etc.

	• Correct sending orders to be executed by the drone, for example: take a photo, move the camera, start a take-off, etc. • Correct reception of system telemetry: battery level, GPS coordinates, etc.
Planned inputs	Sending information through the communications system.
Expected results	Proper reception of information through the communications system.

3.7.2. System functionalities verification

At a higher level than the components, the main functionalities of the demonstrator must be validated in order to ensure that the final system will be able to meet the objectives of the demonstrator 2. Compliance with the functionality, in turn, will ensure the validation of the requirements associated with each of them.

***UC1 – D2 - FUN01* – Captive UAV System**

Environment	Goal	Output
Laboratory	Initial assembly of the captive system (in lab)	System assembled and powered; correct installation of all the components
Outdoor controlled	First exterior tests of the captive system	System components work.
Realistic	Complete captive system installation on vehicle. All components work.	Installation on vehicle.

***UC1 – D2 - FUN02 – GNSS* positioning**

Environment	Goal	Output
Laboratory	Initial assembly of the component in the captive system (in lab)	System assembled and powered; correct installation
Outdoor controlled	First exterior tests of the GNSS positioning functionality (static)	*Current coordinates of the UAV.*
Realistic	Complete GNSS positioning tests (dynamic).	*Current coordinates of the UAV. Coordinates of the vehicle to be followed*

UC1 – D2 - FUN03 – UAV surface vehicle navigation

Environment	Goal	Output
Laboratory	Development and first lab evaluation of the algorithms developed to track the captive drone with respect to the movement of the surface vehicle	First version of algorithms
Outdoor controlled	First exterior tests of the algorithms, adjustments	*Adjusted algorithms*
Realistic	Final validation of algorithms, with tests in real environment.	*Algorithms validated. The UAV captive system can follow the movement of the surface vehicle.*

***UC1 –D2- FUN04* – Mission monitoring**

Environment	Goal	Output
Laboratory	Development of first monitoring interface in the PCS to visualize the telemetry and video of the captive UAV system	First version of interface
Outdoor controlled	First tests of the reception of images and data from the captive UAV system	*Reception of images and data*
Realistic	Final validation of the interface developed and the connections, with tests in real environment performing a realistic scenario.	*Final interface validated.*

3.7.3. System validation (KPIs)

In summary, we plan to carry out the following campaigns:

1. A first campaign where the algorithms developed to track the captive drone with respect to the movement of the mobile vehicle will be evaluated. This first campaign will allow the first tests to begin and detect the development and/or configuration necessary adjustments for its correct operation.
2. A second campaign where the adjustments made in the monitoring algorithm will be evaluated, based on the information obtained in campaign 1, as well as the feeding and fixing systems of the “UAV Captive System”.
3. A third and final validation campaign where a use case will be carried out in a real environment (Port of Vigo).

Finally, the table below shows the verification method for each of the technical KPIs:

KPI	Definition and measurement of Indicator	Description and enhancements	Verification Method	*Campaign tests*
Improvement of efficiency in surveillance tasks: shorter surveillance rounds	The indicator for this KPI will be the reduction in time to perform these tasks because we can observe areas that would otherwise require a displacement to that point.	Possibility of deployment of the system at any point and practically unlimited autonomy, being able to be operational for very long periods, limited by the system maintainability.	Conduct a surveillance round and check times	*In campaign 3 we will follow the route at different speeds, checking the time needed to complete it.*
	The indicator will be calculated compared to the volume of surface currently controlled at a specific time by the port surveillance equipment.	Possibility of connecting from any WIFI point to validate its operation or obtain real-time data.		

Improvement of efficiency in surveillance tasks: increase of controlled areas in the same space of time	The indicator for this KPI will be the increase in controlled surface at the same time because we have a camera 25 meters above the ground, which gives us a wide range of vision.	Possibility of deployment of the system at any point and practically unlimited autonomy, being able to be operational for very long periods, limited by the system maintainability.	Conduct a surveillance round and check the volume of the controlled surface in a specific time	*In campaign nº 3 we will follow the route optimizing the flight mode to cover the desired field of vision, validating the adequate speed and route to manage the total time of the mission.*
	The indicator will be calculated compared to the volume of surface currently controlled at a specific time by the port surveillance equipment.	Possibility of connecting from any WIFI point to validate its operation or obtain real-time data.		
Improvement of efficiency in surveillance tasks: increase of visible areas and elimination of blind spots.	The indicator for this KPI will be the obtain information of areas not currently visible with the existing surveillance system	Possibility of deployment of the system at any point and practically unlimited autonomy, being able to be operational for very long periods, limited by the system maintainability.	Conduct a surveillance round and verify all new points that have been covered and for which no information has been previously available.	*In campaign no. 3 we will follow the route observing the area at different heights and orientations, validating a greater coverage of the areas.*
	The indicator will be calculated compared to the areas that are currently not covered.	Possibility of connecting from any WIFI point to validate its operation or obtain real-time data.		
Improvement of efficiency in surveillance tasks: greater ability to detect movements in low visibility conditions	The indicator for this KPI will be obtaining information on any type of movement in low visibility conditions around the port.	Possibility of deployment of the system at any point and practically unlimited autonomy, being able to be operational for very long periods, limited by the system maintainability.	Conduct a surveillance round and verify the ability to detect movements in low visibility areas.	*In campaign No. 3 we will demonstrate a greater response to external stimuli due to the UAV's operational versatility and the ability to observe different viewing angles.*
	The indicator will be calculated compared to the movements currently detected.	Possibility of connecting from any WIFI point to validate its operation or obtain real-time data.		

Table 16 UC1 D2 system validation plan

- **Improvement of efficiency in surveillance tasks: shorter surveillance rounds**

One of the activities that is being valued within the use case is the monitoring of a 31,000 m2 car field located in the port area of Vigo. Considering that the route to be covered would be about 1.40 km and that an individual walking, it takes approximately an average of 15 minutes to travel a distance of 1 km, it would currently take about 20 minutes to cover this area. The use of captive UAVs would reduce the route to 800 m, taking only 5 minutes to cover it. This means that in the 20 minutes it currently takes to make a walking round, an area of 124,000 m2 could be monitored.

Figure 5 UC1 – D2 Improvement of efficiency in surveillance tasks

- **Improvement of efficiency in surveillance tasks: increase of visible areas and elimination of blind spots.**

One of the activities that is being valued within the use case, is the monitoring of an area of 80,000 m2 located in the port area of Vigo, in which there are 13 port ships, 6 secondary streets and 3 main streets. To monitor all hidden areas, a route of about 4 km would be defined for an individual walking. The use of captive UAVs circulating at a minimum speed of 10 km/h would reduce that route to 2 km, by not having to travel the perpendicular streets, eliminating all the current restrictions associated with both height and limitations inherent in the human eye itself.

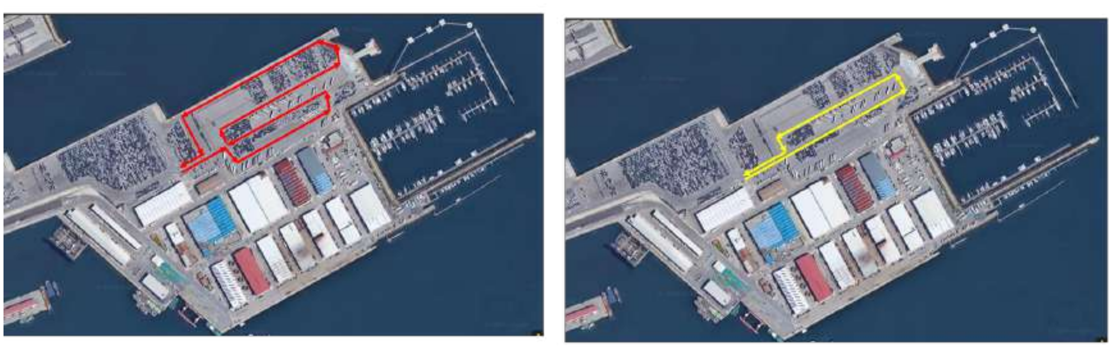


Figure 6 UC1 – D2 Improvement of efficiency in surveillance tasks.

- **Improvement of efficiency in surveillance tasks: greater ability to detect movements in low visibility conditions**

One of the activities that is being valued within the use case, is the monitoring of an area of 80,000 m2 located in the port area of Vigo, in which there are 13 port ships, 6 secondary streets and 3 main streets. With the infrared camera of the captive UAV, it will be checked that a person can be detected hidden in an area without lighting.

Figure 7 UC1 – D2 Improvement of efficiency in surveillance tasks

4 UC1-Demo 3 Transport: Rail Baltica

4.1 Current state of the technology

The importance of predictive maintenance for the railway is increasing for high railway capacity. The railway sector has migrated from the traditional analytics into more predictive maintenance. Until around five years back there was reactive maintenance, but with the current capacity restraints on railways, the situation is entirely different. Limited resources don't afford to send out a maintenance team when it isn't clear what's going on - it is necessary to have to anticipate failures. This is a crucial element to keep the high capacity of the rail!

In the last five years, and mostly in the last three years, there have developed good models to predict the degradation of mechanical and electrical components. This way it is possible to anticipate failures and minimize the time of the track position to carry out the repairs.

The quality of the track has to be very high, for example for high-speed trains as planned Rail Baltica - much higher than for normal freight trains. This makes predictive maintenance even more important. There are also developments in hyperloop technology, which can reach even much higher speeds. With 1000 km/h, failure is not an option.

Another factor is that companies from all over Europe are maintaining infrastructure, for example, a company from Sweden can be maintaining infrastructure in parts of the Spanish network, etc. This also contributes to spreading new technologies in Europe. If a new technology for predictive maintenance pops up in one country, it is mostly adopted by all EU members.

A big change in 2020 is the transformation from predictive maintenance to digital twins of railway infrastructure. The fourth industrial revolution brought elements such as the Internet of Things (IoT), big data and Artificial Intelligence. Big data in railways is one of the big topics today. Railways produce a lot of data, and if this is processed well there are benefits for everyone. For the prediction of the track geometry, Artificial Intelligence is used and generates much better results than in the past, it makes it much more efficient. If a sudden complication appears, AI can learn from the event and possibly predict similar events in the future. It is possible to predict a lot with the help of AI, but still there are many times that for example, a signalling system is down, and there is no information why.

Complementing the described set of technologies supporting the railway maintenance process with the functionality of unmanned aerial vehicles is an opportunity to make artificial intelligence solutions mobile and obtain the necessary information at the right time.

Today railway connectivity is supported by 2G and it was inaught , but Rail Baltica is planning new infrastructure with 5G connectivity. Related to advantages for the rail operators the application of 5G can be grouped into three areas for railway communications:

- Critical environments communications
- Augmented bandwidth with high-speed communications
- Mass communications with the Internet of Things (IoT).

Only two of these areas are most vital to railway communications. The first point, critical environment communications, is very advantageous for maintenance and control applications, and it is also useful for critical operations. Using 5G, the railway can undertake and establish secure and reliable communications that result in super-low latency.

Most mobile networks are configured for use on the ground up to 2 m with different adaptations in different environments - especially in urban areas with a large number of high-rise buildings.

The first step was to find out the availability of the network in VLL airspace up to 120 m. Therefore, the technological capabilities were validated by performing test flights with a drone and making sure of the following assumptions that would be critical for the customer - in this case, Rail Baltica, to use drone technologies for monitoring its infrastructure:

- drone control via the mobile network up to the permitted height of 120 m (test flight at Ādaži aerodrome - end of 2019);
- drone remote control via mobile network, performing BVLOS (test flight at Ādaži aerodrome - end of 2019);

- remote control of the drone via the mobile network by changing the telecommunications operator during the flight, including crossing the state border (cross-border Latvia-Estonia test flight on the planned Rail Baltica route - the second and third quarters of 2020).

The validation of the technology confirmed the possibility to control the drone via the mobile network, including at altitudes up to 120 m, remotely, BVLOS, and changing operators with very low latency in the 4G network.

Test flights and network measurements allowed to make assumptions of network KPIs for safe and controlled drone flights. The next step is to validate network KPI values with data-based network measurements up to 120 m and simulate a 3D mobile network map to assess the feasibility of safe, controlled drone monitoring at the appropriate height and speed on the Rail Baltica route, with additional

4.2 Use Case Concept of Operation

The concept of operations will include the management of drone operations supplemented with flight planning, flight approval, tracking, and airspace dynamic information.

The drone's mission will be conducted via a mobile network. When the mission route is identified next step will be to simulate the safest flight path in terms of network infrastructure (coordinates, flight altitude). During the flight, the transmission of the necessary inspection data to the command centre (AI solution data, video or photo information, etc.) will be enabled, primarily providing a mobile network signal for drone control and controlling the signal quality in case of additional data transmission.

4.3 System Requirements, KPI´s and Metrics

The focus of this demonstration is not from the perspective of autonomous flight but how to raise the level of autonomy of drone missions with drone C2 in the mobile network.

The main technical requirements for the demonstrator are shown below and include the main requirements and all those that are considered to have an influence on the development of the systems and components that will allow the objectives of the demonstrator to be carried out. In turn, these requirements will be related to the technological KPIs defined for the demonstrated although not always all the requirements can be related, since it can be a type of requirement imposed by the boundary conditions, the regulation or by integration needs.

4.3.1. Technical KPI`s and Metrics

KPI	Definition and measurement of Indicator	Description	Metrics
GSM C2 link power	Reference Signals Received Power (RSRP)	Mission reconfiguration before and during the flight	> -110 dB reference in simulated network
GSM C2 link quality	Reference Signal Received Quality (RSRQ)		> -12 dB
GSM C2 link interference	Signal-to-interference-plus-noise ratio (SINR)		> 5 dB
GSM C2 link channel quality	Channel Quality indicator (CQI)		5
GSM C2 link strength complex	Latency		< 50 ms
GSM C2 link reliability	Downlink C2 data link		at least 60-100 kbps
4G/5G data transfer rate	Uplink end user specific data link		at least 3 mbit
Reliability of second GSM C2 data link	Multi GSM SIM switch		Down time less than 1 sec

Table 17 UC1 D3 List of KPIs

4.3.2. Main requirements (functional, interface, performance, security, usability…)

Requirement ID	Short Description	Description	Priority	Source	Link to KPI
DEM3-FNC-1	Communication channel	The drone must communicate using 4G and 5G network. LTE-M based mobile network connectivity for autonomous flight C2.	H	Service provider/ SW Developer	UC1-D3-KPI-01 - UC1-D3-KPI-11
DEM3-FNC-2	Alternative communication channel	There must be the capability of deploying secondary (alternative) communications channel.	H	Service provider/ SW Developer	UC1-D3-KPI-01 - UC1-D3-KPI-11
DEM3-FNC-3	Flight planning framework	The EU and national level legal framework requirements and guidelines must be followed for each element of demonstration architecture.	H	Service provider	UC1-D3-KPI-01

DEM3-FNC-4	Flight plan	The drone operator shall create a flight plan based on the daily basis inspection plan or incident communicated by railway technical surveillance/ safety system.	H	Service provider/ SW Developer	UC1-D3-KPI-01
DEM3-FNC-5	Tracking	The Command Centre shall be able to track drone throughout the mission.	H	Service provider/ SW Developer	UC1-D3-KPI-01
DEM3-FNC-6	Real time photo/video streaming	The drone shall provide high quality photo/video materials in real time to the Command Center over 4G/5G.	M	Service provider/ SW Developer	UC1-D3-KPI-01
DEM3-FNC-7	Drone navigation	The drone must autonomously navigate with high position accuracy during take-off, flight and landing	H	Service provider/ SW Developer	UC1-D3-KPI-01
DEM3-FNC-8	Authorisation of flight plan	The Control Centre shall be able to send/receive the authorization request for a flight plan proposed to the national civil aviation authorities. The complete authorization process shall be performed.	M	Service provider/ SW Developer	UC1-D3-KPI-01

Table 18 UC1 D3 List of Main Requirements

4.3.3. Drone integration requirements

Requirement ID	Short Description	Description	Pr io	Source	KPI´s
UC1-DEM3-DR-01	Sensors/ AI solutions integration	The capacity of connectivity to provide high-resolution data from sensors/ AI solutions (payload of drones).	M	Service provider/ SW Developer	UC1-D3-KPI-01
UC1-DEM3-DR-02	Flight planning	Drone mission planning based on trusted route simulation in mobile network 3D map.	M	Service provider/ SW Developer	UC1-D3-KPI-01 - UC1-D3-KPI-11

Table 19 UC1 D3 List Of drone integration Requirements

4.3.4. Regulatory requirements

Requirements related with SORA analysis (Reference to the methodology in D2.5.)

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC1-DEM3-REG-01	Permit for test flights from CAA	Drone operator must have a detailed plan (documentation) to get permission for the test flights	H	Drone operator	-
UC1-DEM3-REG-02	Pilot licenses	Drone pilot must be authorized to fly the drone	H	Drone operator	-
UC1-DEM3-REG-03	Operator registration	Drone operator must be registered in the national aviation authority registration list	H	Drone operator	-
UC1-DEM3-REG-04	Safety assessment	Drone operator must evaluate the risk of the operation, indicating and justifying risk mitigation activities.	H	Drone operator	UC1-D3-KPI-01 - UC1-D3-KPI-11
UC1-DEM3-REG-05	Operational procedures	Drone operator must have operational procedures	H	Drone operator	-
UC1-DEM3-REG-06	Controlled ground area	Drone operator must ensure that the flight zone is controlled on the ground, with no uninvolved people on it.	H	Drone operator	-

Table 20 UC1 D3 List of Regulatory Requirements

4.4 Functionalities identification

The main functionalities of the system or mobile network service provider infrastructure have been defined to give more information about the characteristics needed for the performance of the mission operations from the perspective of connectivity capacity and C2.

ID	Functionality	Description	System function
UC3-D3-FUN – 01	Drone C2 by cellular network	The cellular network as a communication channel for drone command and control functionality to perform the designed mission.	Flight control Tracking and position reporting Communication infrastructure monitoring Communication coverage information Operation plan preparation/ optimisation Operation plan processing

UC3-D3-FUN – 02	Data transmission during drone mission	The cellular network as a communication channel for mission data collection and transmission for completing the designed mission task.	Communication infrastructure monitoring Communication coverage information
UC3-D3-FUN - 03	The most reliable route for a drone mission	GSM 4G/5G signal strength and other indicator analysis for flight path planning.	Intelligent mission management Tracking and position reporting Surveillance data exchange Operation plan preparation/ optimisation Operation plan processing

Table 21 UC1 D3 List of Functionalities

4.5 Components

- **COMP01 – Customized 4G cellular network and its coverage for C2 and connectivity**

U-Space services are based on communication technology, where it is foreseen that it will be the key enabler to unlock the underlying potentials of UAVs' operations. In this regard, the safest and most successful real-time communication can be done through the mobile (cellular) network. UAVs missions require a very low latency communication for the remote C2 traffic and a high capacity data transmission for bandwidth-demanding applications, such as video surveillance streaming.

- **COMP02 – 5G cellular network and its coverage for C2 and connectivity**

Upcoming generation of mobile networks 5G is envisioned to be the communication standard to support diverse UAV operations and applications. 5G can be configured to enable effective UAV-to-UAV (U2U) and UAV-to-Infrastructure (U2I) communication far easier than previous technologies.

In this vein, 5G technology is assumed to guarantee wider bandwidth and very low-latency connectivity, which place it as a key enabler of UAV-based services and applications. Indeed, 5G brings into light several new concepts that can be beneficial for UAV.

On one hand, 5G New Radio (NR) provides larger bandwidth to accommodate high data-rate demanding applications, such as VR/AR, 4K video streaming, which may be used by UAVs for high-quality video streaming or remote steering of the UAVs. Moreover, 5G NR uses new physical layer numerology that drastically reduces Radio Access Network (RAN) latency; and when it is combined with the edge computing capabilities at the vicinity of the radio network, very low latency will be achieved for UAVs remote C2 applications. On the other hand, Network Slicing (NS) is a novel concept introduced in 5G aiming at partitioning of a general-purpose mobile network into virtual network instances that are individually tuned to accommodate different services characterized by different requirements in terms of communication Quality of Service (QoS), within a common physical infrastructure. The introduction of NS allows the mobile operators to support efficiently three classes of services using the same physical infrastructure:

- Enhanced Mobile Broadband (eMBB) for applications requiring high data rates,
- massive Machine Type Communications (mMTC) intended to cover IoT applications that require support for a massive number of devices, and
- ultra-Reliable and Low Latency Communication (uRLLC) for applications with strict requirements on the communication latency and reliability.

However, UAVs services cannot fall into only one class of service. Indeed, the remote command and control applications of UAVs are considered as uRLLC applications, while the services offered by the UAV (e.g., live video streaming) may also require an eMBB or mMTC network slice instance. Hence, UAVs may need a combination of a uRLLC slice instance and either an eMBB or an mMTC slice feature.

- **COMP03 – Software for 3D mapping of cellular network for UAV**

3D mapping solution determines safe flight corridors at a given time and is a critical component of any UAV flight plan. Input to the Specific Operations Risk Assessment (SORA) the methodology will be based on live real-time network updates, to ensure there is adequate cellular connectivity within the proposed flight path and time. This is necessary to satisfy the minimum requirements for establishing and maintaining network remote IDs, command and control connectivity, and enough payload for pictures and/or video transmissions or other devices requiring connectivity. These services will be available soon and will be based on 5G mobile network, but the preparatory steps are already being implemented on 4G / LTE. UAV flight paths need to avoid heavily populated areas, but these locations can generally fluctuate depending on different variables, including traffic, special events, seasonality, and time of day. Dependent on regional regulatory and privacy legislation, the platform could also potentially provide highly accurate and reliable ground risk assessments of population densities based on location, date and time - all in high resolution. This information, when paired with geographical terrain and cellular signal data, will further, enhance the creation of safe flight corridors that can be adjusted in near real-time as the environment changes.

Partner	Work Package	Components	Demo	Component ID	KPI	Criteria	Measurement Outcome	Objective
LMT	WP1	Customized 4G cellular network and its coverage for C2 and connectivity	UC1D3		UC1-D3-KPI-01 - UC1-D3-KPI-11	SC3.1	MO3.3	O3
LMT	WP1	5G cellular network and its coverage for C2 and connectivity	UC1D3		UC1-D3-KPI-01 - UC1-D3-KPI-11	SC3.1	MO3.3	O3
LMT	WP1	Software for 3D mapping of cellular network for UAV	UC1D3		UC1-D3-KPI-01 - UC1-D3-KPI-11	SC3.1	MO3.3	O3

Table 22 UC1 D3 List of components

4.6 Tools

Main tool that allow enabling different characteristics of the components for the demonstrator 3 are listed below.

- **TOOL1 – The Connectivity platform enabling beyond visual line of sight UAV operations in cellular networks (AirborneRF)**

The connectivity platform brings together the mobile network operator’s (MNO) radio network with UAV airspace control. During flight planning tool is used to calculate where a UAV can fly safely, within the rules and the radio-space. It considers both national airspace control and the radio coverage delivered by the MNO so that the network can be used to reliably control the UAV within a three-dimensional safety corridor.

The connectivity platform is sufficiently scalable to allow for route recalculation during flight. It uses measurements collected by the UAV to update and improve its predictive models both short terms, during flight, and longer term for the next flight.

Next table show the relationship between the component, main requirements and how it is also related with the objectives of the project and the main measurements outcomes expected and criteria.

Partner	Work Package	Components	Tool ID	Requirements	Criteria	Measurement Outcome	Objective
LMT	WP1	The Connectivity platform	TOOL1	DEM3-FNC-1 DEM3-FNC-3 DEM3-FNC-4 DEM3-FNC-5 DEM3-FNC-6 DEM3-FNC-7 DEM3-FNC-8 DEM3-PRF-1 DEM3-PRF-2	SC3.1	MO3.3	O3

Table 23 UC1 D1 List of Tools

4.7 Traceability matrices

4.7.1. Requirements vs. functionalities

Requirement	Short description	FUNC 1	FUNC2	FUNC 3
UC1-DEM3-FNC-1	Communication channel	X	X	
UC1-DEM3-FNC-2	Alternative communication channel	X	X	
UC1-DEM3-FNC-3	Flight planning framework	X	X	X
UC1-DEM3-FNC-4	Flight plan			X
UC1-DEM3-FNC-5	Tracking	X		
UC1-DEM3-FNC-6	Real time photo/video streaming		X	
UC1-DEM3-FNC-7	Drone navigation	X	X	
UC1-DEM3-FNC-8	Authorisation of flight plan	X		X
UC1-DEM3-PRF-1	Information about other airspace users	X		
UC1-DEM3-PRF-2	Most reliable connectivity	X	X	X
UC1-DEM3-PRF-3	Change of operators during the flight	X	X	

Table 24 UC1 D3 Requirements and functionalities traceability matrix

4.7.2. Functionalities vs. Components

FUNCTIONALITY	Short description	COMP 01	COMP 02	COMP 03
UC3-D3-FUN - 01	Drone C2 by cellular network	X	X	
UC3-D3-FUN - 02	Data transmission during drone mission	X	X	
UC3-D3-FUN - 03	The most reliable route for a drone mission			X

Table 25 UC1 D3 Components and functionalities traceability matrix

4.8 Validation plan

In order to enable the demonstration scenarios and achieve the project objectives, it is necessary to sequentially test and validate the identified components, functionality and system concept. The testing, validation, and demonstration process will be performed in two environments - outdoor controlled or TestBed environment and realistic or real scenario environment.

Environment	Activity Block	Stage	Period	Description
Outdoor controlled or TestBed environments	Activity Block 1	Stage 1	M1-M3	Technology Verification: research on the possibilities to conduct a drone flight in a mobile network and validation of identified technologies.
	Activity Block 2	Stage 1	M4-M10	Technology Verification: tests of cross border flight, BVLOS flight, interconnectivity – switch from one operator to another, remote ID, mobile network coverage, tracking, cellular network simulation for safe autonomous mission planning
	Activity Block 3	Stage 2	M11-20	Technology Experimentation: network measurements under different conditions.
	Activity Block 4	Stage 2	M12-M20	Technology Experimentation: composition of integration requirement (sensors, AI solutions) and cellular network as a communication channel.
	Activity Block 5	Stage 2	M16-22	Technology Experimentation: identification and testing of the necessary data and information for 3D mapping of cellular network for UAV and the most reliable route simulation
Realistic environment or real scenario	Activity Block 6	Stage 3	M23-M34	Technology Implementation: Validation of final components. Deployment of the UC in real site with all the components, functionalities, and integrations.

4.8.1. Components Verification

- **COMP01 – Customized 4G cellular network and its coverage for C2 and connectivity**

Test description	Extensive network measurements under different conditions - different altitude, frequencies, areas, terrain, obstacles, etc. conditions that affect the strength and reliability of the network. Tested network values will be verified by sessions of drone flights controlled in the cellular network.
Planned inputs	Tested values of cellular network parameters
Expected results	Reliable communication cannel for UAV and C2 functionality

- **COMP02 – 5G cellular network and its coverage for C2 and connectivity**

Test description	Identifying, enabling, and testing network benefits against 4G networks.
Planned inputs	Tested technological potential of 5G technologies and compared with the performance of 4G technologies.
Expected results	Conditions to enabling 5G advantages for UAV

- **COMP03 – Software for 3D mapping of cellular network for UAV**

Test description	Tests of solution for cellular network 3D mapping, using the following data and information: network infrastructure data; network measurement data; control data for simulation validation; airspace date for UAV; date about other elements affecting the calculation of a safe route of UAV
Planned inputs	Tested and validated rout simulation process
Expected results	Reliable route for UAV mission

4.8.2. System Functionalities Verification

- **UC3-D3-FUN-01: Drone C2 by cellular network**

Environment	Goal	Output
Outdoor controlled	Test drone behaviour and communication mistakes in a real environment	The full mission conducted in a cellular network (from take-off till landing)
Realistic	Complete C2 system for UAV in cellular network	Cellular network as most reliable communication channel for Drone C2

- **UC3-D3-FUN-02: Data transmission during drone mission**

Environment	Goal	Output
Outdoor controlled	Variations with the types, amount, and speed of the data to be transmitted	Critical data real-time transmission
Realistic	Complete sensor/ AI solution integration process	During the drone's mission, high-quality data is transmitted to the Command centre via the mobile network

- **UC3-D3-FUN-03: The most reliable route for a drone mission**

Environment	Goal	Output
Outdoor controlled	Validation of input data impact on the simulation results	Completed missions according to the simulated routes
Realistic	Completed intelligent mission planning functionality integration requirement values for drone control in cellular network	Drone mission plan supplemented with reliable route information

5 UC2-Demo 1: Construction: Digitalization of the state of the constructive process of a Civil Infrastructure

5.1 Current state of the technology

Civil infrastructures and construction elements are subject to frequent inspections for carrying out inventories or for damage and defects detection during the construction, use and maintenance phases. Nowadays, the inspection, assessment and maintenance of civil infrastructures are mainly performed through human visual observations by inspectors, a tedious and time-consuming work prone to human errors. Additionally, a typical infrastructure inspection requires many man-hours, hands-on inspection and can be very slow and, therefore, expensive.

Nowadays, road-condition surveys provide a reliable analysis of the current state and future needs of the road network. Condition surveys provide crucial initial data for allocating funds, for improving roads, planning improvement measures, and maintaining surfacing. All the operations described below are done with conventional techniques; these suppose a very high time and cost expenditure when carrying out any civil works construction.

Planning (acquisition of source data)	Construction & Surfacing	Maintenance
Traffic surveys • Automatic traffic counts • Intersection counts • Non-motorised traffic counts • Traffic functionality audits • Destination surveys Road profile measurements Inventory of surfacing damage Noise measurements	Roadside technology construction and maintenance Surfacing sawing services Road profile measurements (quality and condition measurements)	Inventory of equipment and machinery for road and street areas (traffic signs, railings, culverts, etc.) Inventories of road signs Inventories of lighting Winter maintenance quality measurements Gravel road inventories Digital photography of the road network

Due to these issues, the construction industry is currently immersed in full digital development by widely incorporating the BIM (Building Information Modeling) concept in the civil works environment. Within the BIM concept, the well-known digital twin (Digital Twin) is developed for which each construction element has a digital representation associated with it, down to the last screw and accessory that make it up. In recent years, drones have been a major advance in element recognition and have helped create digital twins.

Current trends in artificial intelligence (AI) and unmanned aerial vehicles (UAVs) can support a smooth inspection process, using low-cost drones, RGB cameras, automated detection algorithms and remote operations. In particular, UAVs are another trend with many practical applications and clear advantages over the traditional inspection process. Instead of closing down nearby roads and sending an inspector up into an expensive snooper truck to create detailed drawings on documents, a drone can get into spots where inspectors cannot access at all, record high-resolution video and shoot several high-definition quality photos without impacting the traffic.

With a vision more focused on mass data capture, drones have been shown to be a useful tool in direct applications such as photogrammetry or LiDAR, which allow creating three-dimensional models using triangulation meshes and point clouds of the largest area. Ultimately, the point clouds derived from these technologies can be used to build a digital terrain model (DTM) or a digital surface model (DSM) and maps with information specific to the study area, such as thermal images.

Moreover, Artificial intelligence is well suited for complex environments monitoring and can help make inspections faster, cheaper and in a more efficient way combining image processing methods and nonlinear deep machine learning algorithms, which emulate human´s brain activity in understanding complex patterns.

5.2 Use Case Concept of Operation

The current use case, derived from the end user's requirements, has been designed as it is illustrated in Figure 8 UC2 – D1 demonstrator's concept of operation scheme. This use case will comprise the flight of an UAV equipped with a set of cameras, and a post-processing phase in which a high-performance computer will be required. The use case will start with the online part of the mission (left hand side of the Figure 8). First, it will be established a list of control points. These control points will be manually placed, and with a high precise and accurate ground GPS station, their coordinates will be saved. These points will be use later for georeferencing correction purposes. These control points must be chosen before the flight since they must appear in the images captured during the flight.

After that, the UAV can start its mission. The mission will have been designed previously. Thus, at the time of the mission to be carried out, the mission will be directly load on the UAV core. At the very beginning, once the UAV is started, the accurate GNSS system will be statically initialized. By doing this it will be ensured that the system will capture accurate enough georeferencing data. Once the time specified by the manufacturer for the initialization of the system has elapsed, it will be checked that the measures taken by it are correct. After that, the UAV will take off. From the mission loaded previously, it will fly through the specified WP in an autonomous manner. During the flight, the set of cameras will collect data based on the conditions specified by the user. These images will be gathered along with the GPS position and the telemetry of the UAV and the set of cameras. The UAV will fly until the mission is completed. After that, the UAV will land, and the operator will perform a visual inspection to determine if a further maintenance is needed.

After the online mission, the data will be downloaded in the high-performance computer to process it into the expected solution. For that, several steps will be followed. First, the images taken by the cameras must be matched with the telemetry of the UAV and with the GNSS system collected data. At this time, the highly precise coordinates of the control points will be used to correct the georeferencing process. Then, the georeferenced point-cloud will be created. With it, a specialized software will make use of it to detect and identified the construction elements, such as traffic signals, and finally, it will be export to a BIM model.

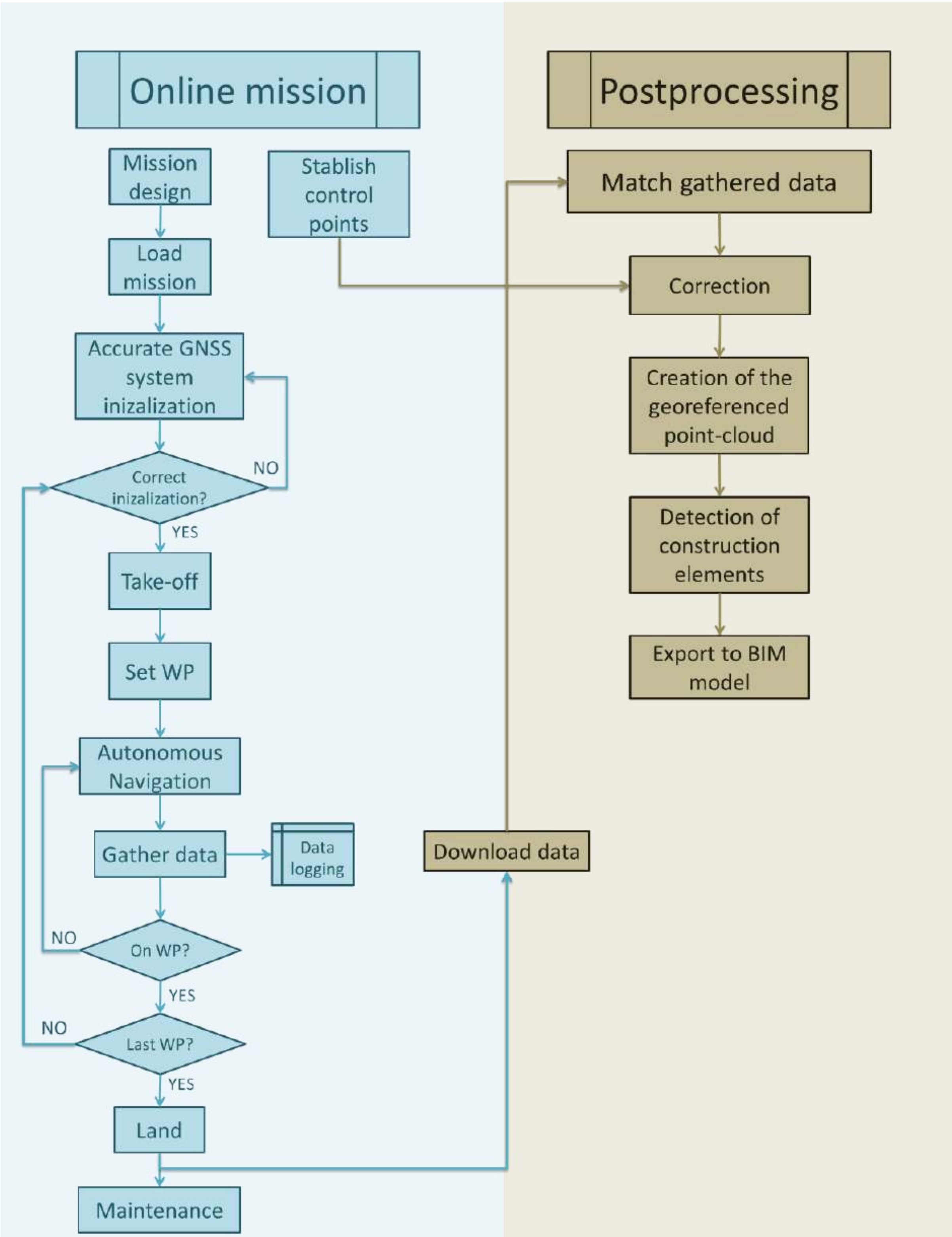


Figure 8 UC2 – D1 demonstrator's concept of operation scheme

5.3 System Requirements, KPI´s and Metrics

To have clear idea of the objectives and purpose of the demonstrator it is important to highlight the main metrics defined in deliverable D1.1 and that will lead to the definition of the most applicable requirements of the systems and components developed within the project.

The main technical requirements for the demonstrator are shown below, and together with the main requirements defined in D1.1., these requirements are considered to have an influence on the development of the systems and components that will allow the objectives of the demonstrator to be carried out. In turn, these requirements will be related to the technological KPIs defined for the demonstrated although not always all the requirements can be related, since it can be a type of requirement imposed by the boundary conditions, the regulation or by integration needs.

5.3.1. Technical KPI`s and Metrics

nº	KPI	Definition and measurement of indicator	Target value
UC2-D1 - KPI – T1	Recognition of work elements through AI.	Detection of main work elements position in the road through point cloud	Accuracy less than 20cm
UC2-D1 - KPI – T2		Detection of the total number of elements	At least 90% of the elements
UC2-D1 - KPI – T3	Improved performance of navigation solution.	Accuracy, Continuity and Integrity of position and attitude estimates are improved for practical usability for digitisation. The target is 10cm CEP error in position, <1deg RMSE error for all attitude components, and having valid data for 90% of the fly (continuity), with bounded position and attitude error for any valid output with fix or without fix (<5m, <10deg) (integrity),in open-sky conditions.	10cm CEP error in position
			<1deg RMSE error for all attitude components
			Valid data for 90% of the fly (continuity)
UC2-D1 - KPI - T4	Navigation following waypoints and capturing data.	The drone is able to fly autonomously covering the area of interest and capturing data along the whole flight.	90% data capturing flights completed

Table 26 UC2 D1 List of KPIs

5.3.2. Main requirements (functional, interface, performance, security, usability…)

D1.1 introduced the main functional requirements of the demonstrator. In this section, the remaining technical requirements for the demonstrator are shown, linked to specific KPIs of the demonstrator:

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC2-DEM1-FUN-01	Point Cloud	The drone system shall capture a high-density **point cloud**	H	SW Developer	KPI-T1 KPI-T2

UC2-DEM1-FUN-02	RGB data	The drone system shall capture **RGB data of the surface**.	H	SW Developer	KPI-T1 KPI-T2
UC2-DEM1-FUN-03	Point cloud in Open format	The point cloud shall be in an **open format** such as LAS.	H	SW Developer	KPI-T1 KPI-T2
UC2-DEM1-FUN-04	Point cloud with precise location	The point cloud shall include precise location for the samples.	H	SW Developer	KPI-T1 KPI-T2
UC2-DEM1-FNC-05	RGB data at 45 degrees	The drone system may capture RGB data at an angle of 45 degrees from the perpendicular.		SW Developer	KPI-T1 KPI-T2 KPI-T3
UC2-DEM1-FNC-06	Provide current drone status for vulnerability detection	The drone shall be able to provide system information on demand.	M	SW Developer	KPI-T4
UC2-DEM1-FNC-07	Drone identification	The drone shall be identified and registered in the UTM platform	H	Drone integrator	U-SPACE
UC2-DEM1-FNC-08	Position, Attitude estimation system	The GNSS/INS navigation system shall provide an accurate attitude & position trace that can be synchronized vs an absolute time reference for digitisation purposes	H	System developer	KPI - T3
UC2-DEM1-FUN-09	Provide safety feature	The drone may be upgraded to include safety features	L	SW Developer	KPI – T4
UC2-DEM1-INT-01	Geo-referencing system output trace formats	It shall support the extraction of the attitude/position output trace in a format directly accepted by digitisation software	L	System developer	KPI - T3
UC2-DEM1-PRF-01	Geo-referencing system estimation performance	Improved Position, Attitude estimation performance (attitude components <1dg, position accuracy <10cm)	H	System developer	KPI - T3
UC2-DEM1-PRF-02	Geo-referencing system cost performance	A low-cost solution for the accurate attitude-position output trace for digitisation (below FOG-based solutions < 3K € the cheapest)	H	System developer	KPI - T3

UC2-DEM1-PRF-03	Flying time	The drone system shall be able to fly at least 10min before changing its batteries.	H	System developer	KPI - T4
UC2-DEM1-PRF-04	Storage capacity	The drone system shall be able to store at least 20 GB of data per flight.	H	System developer	KPI - T4
UC2-DEM1-SEC-01	Georeferencing data integrity	Integrity vs shadows, interferences, and malicious attacks of the attitude and position data for digitisation	M	System developer	KPI - T3
UC2-DEM1-SEC-02	Collect history data	The drone communication shall be secure	H	Drone integrator	Improve network performance
UC2-DEM1-SEC-03	Secure communications	The drone shall collect and store a log of history data for future analysis	H	Drone integrator	Improve network security, Improve network performance
UC2-DEMO1 - SEC-04	Vulnerability detection	The system shall give information about the drone status for the vulnerability detection.	H	Drone integrator	Improve network security, Improve network performance
UC2-DEMO1-SEC-05	Software actualization	The system shall be able to update security libraries, protocols, certificates, or software versions	M	Drone integrator	Improve network security
UC2-DEM1-USA-01	Geo-referencing system Auto-calibration	The geo-referencing system will support an auto-calibration, such that, after integration, it will not require any user configuration for its operation	H	System developer	KPI - T3
UC2-DEM1-USA-02	Geo-referencing system Configuration	The geo-referencing system will be encompassed by a configuration tool which enables optional specific configuration of basic parameters (profile, antenna position, etc)	M	System developer	KPI - T3
UC2-DEM1-USA-03	Maximum size	The drone system shall be small enough to fit inside a regular van for transportation.	H	Drone integrator	The system can be transported in a regular van

UC2-DEM1-USA-04	Recharging	Recharging of the batteries of the drone system need to be done onsite.	H	Drone integrator	Designed to have a separate maintenance station than the operational one
UC2-DEM1-USA-05	Maintenance	The drone system shall be prepared to perform small repairs and maintenance onsite.	H	Drone integrator	The system is designed to have a separate maintenance station than the operational one
UC2-DEM1-USA-06	Weight	The drone system shall be lighter than 25Kg in order to reduce the danger of the operation.	H	Drone integrator	The system is weighed just before the take-off and it weighs less than 25kg

Table 27 UC2 D1 List of Main Requirements

5.3.3. Drone integration requirements

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC2-DEM1-DR-01	Cameras	The drone must carry a set of cameras to take images from the construction site in an efficient way and minimizing time of flight.	H	Drone integrator	KPI – T1 KPI – T4
UC2-DEM1-DR-02	Images resolution	The drone must be able to acquire high-resolution visual images so that details of construction elements can be captured.	H	End user	KPI – T1 KPI – T2 KPI – T4
UC2-DEM1-DR-03	Camera compensation	The drone system must be able to compensate roll and pitch movements to obtain stabilized images.	H	Drone integrator	KPI – T1 KPI – T2 KPI – T4
UC2-DEM1-DR-04	Camera pointing	The drone system must be able to point the set of cameras to a certain orientation.	H	Drone integrator	KPI – T1 KPI – T4
UC2-DEM1-DR-05	VTOL capability	The drone system must be able to take-off and land vertically and from a small unprepared area.	H	Drone integrator	KPI – T3 KPI – T4

UC2-DEM1-DR-06	Automatic flight	The drone system must be able to perform the flight path in an automatic way	H	Drone integrator	KPI – T3 KPI – T4
UC2-DEM1-DR-07	Waypoints	The drone must be able to accept and execute a list with a high number of waypoints (up to 100)	H	Drone integrator	KPI – T4
UC2-DEM1-DR-08	Windy conditions	The drone must be able to fly under windy conditions up to 5 m/s	H	Drone integration	KPI – T4

Table 28 UC2 D1 List of Drone integration Requirements

5.3.4. Regulatory requirements

The requirements below are related with the SORA analysis performed (Reference to the methodology in D2.5.) and the boundary conditions introduced in D1.1, as well as to the regulatory framework that dictates the deployment of the scenarios of the demonstrator.

Requirement ID	Short Description	Description	Priority (H/M/L)	Source
UC2-DEM1-RE-01	Permit plan	Drone operator must have a detailed plan for obtaining the permit to fly well in advance of the experiments	H	Drone operator
UC2-DEM1-RE-02	Pilot licenses	Drone pilot must be authorized to fly the drone	H	Drone operator
UC2-DEM1-RE-03	Operator registration	Drone operator must be registered in the national aviation authority registration list	H	Drone operator
UC2-DEM1-RE-04	Safety assessment	Drone operator must evaluate the risk of the operation	H	Drone operator
UC2-DEM1-RE-05	Operational procedures	Drone operator must have operational procedures.	H	Drone operator
UC2-DEM1-RE-06	Controlled ground area	Drone operator must ensure that the flight zone is controlled on the ground, with no uninvolved people on it, by establishing a height/horizontal distance buffer of 1 to 1.	H	Drone operator

Table 29 UC2 D1 List of Regulatory Requirements

5.4 Functionalities identification

Main functionalities of the system have been defined in order to give more information about the characteristics needed for the performance of the mission operations. Since the requirements are a high level of specification, this step represents a lower step in the V&V model, being a lower level of specifications of the process.

These functionalities could be either **hardware functionalities, software functionalities, modules, etc**. All of them together will intrinsically define the final system. As it was done for the requirements, Table 30 UC2 D1 List of Functionalitie show the functionalities identified for the demonstrator 1.

ID	System Functionality	Description	System function (WP2)
UC2-D1-FUN - 01	UAV platform	Aerial platform in charge of carrying the camera and perform the designed mission.	Flight control Flight navigation Positioning
UC2-D1-FUN - 02	High-quality camera for data gathering	A high-resolution camera, with its rate of frames per second configurable in order to adapt it to the needs of the mission.	Intelligent data handling
UC2-D1-FUN - 03	Mission plan logger with specialized waypoint set	This function will allow the aerial system to load and save the desired mission.	Intelligent mission management
UC2-D1-FUN - 04	Accurate positioning and attitude system	A highly accurate and a robust positioning and attitude system will engage in the system.	Georeferencing
UC2-D1-FUN - 05	Autonomous navigation system	Since the mission will be performed in an autonomous way, and autonomous navigation system, such as an INS (Inertial Navigation System), which fused inertial measurements with high accurate GNSS signal, will be needed	Take-off and landing Planning and scheduling
UC2-D1-FUN - 06	Advanced image stabilization system	A stabilization system will be implemented on the camera in order to decouple the movement of the camera from the movement of the UAV. It will improve the quality of the pictures.	Intelligent data handling
UC2-D1-FUN - 07	Data logger	During the mission, this system will be logging the pictures and the telemetry of the UAV, which both will be match later during the post-processing.	Intelligent data handling
UC2-D1-FUN - 08	Specialized software for data matching (images and aerial system telemetry) and correction:	Once the mission has finished, and before the point-cloud construction all the images must be correlated with the recorded telemetry of the UAV. Although the high accurate GNSS system installed in the UAV will be highly reliable, some corrections will be needed with the control points installed manually and georeferenced with a GNSS ground station.	Intelligent data handling
UC2-D1-FUN - 09	Specialized software for georeferenced point-cloud creation	After the matching of both images and telemetry, and corrected, this functionality will create a point-cloud of the area.	Intelligent data handling
UC2-D1-FUN - 10	Autonomous identification and detection of construction elements	After the point cloud creation, a specialized algorithm will finally identify and detect any construction element within the flown area.	Intelligent data handling

UC2-D1-FUN – 11	Integration of modular system with hybrid architecture	The integration in drone system of a hybrid architecture computing system that allows a modular architecture, capable of integrating new sensors, safety elements/features and components.	Intelligent data handling / Obstacle Detection and Avoidance / Fail-safe Mission

Table 30 UC2 D1 List of Functionalities

5.5 Components

To fulfil the requirements of the demonstrator, carry out the mission operation, and comply with the different functionalities different components must be developed and integrated into the platform that is going to carry out the final validation of the system. The components related to the UC2 are listed below with a short description of each one, but the development of these components is carried out in the technical work packages of the project.

- **COMP01 – WP3-04 - Computer Vision Components for Drones**

The *Computer Vision Component for Drones* is a post-processing computer vision system which intends to improve the digitalization of the state of the constructive process of a Civil Infrastructure by providing automatic algorithms for the auto-detection and geo-referencing of road elements from scenarios captured by drones with an in-device camera.

The *Computer Vision Component* is being trained with two kinds of point clouds: the ones generated by the simulated data aggregator, and the other ones generated from images captured by drones

After training and processing, the *Computer Vision Component* provides the inventory of elements detected and their position in the terrain to serve as input for the creation of the BIM model.

- **COMP02 – WP4-39 - Simulated data aggregator supporting intelligent decision in computer vision components**

Developing and testing computer vision components for drones in real world is an expensive and time-consuming process. Therefore, the *Simulated Data Aggregator supporting intelligent decision in computer vision components* is a simulator-based component, being *AirSim* the base simulator, which intends to generate high amounts of training data in order to support the development of any computer vision component for intelligent decision in drones. Concretely for UC2 Demo 1, the *simulated data aggregator* generates a high amount of point clouds in LAS format from scenario-tailored input data: the specific drone configuration parameters, the digital terrain model and the 3D models (CAD files) of the objects to detect. Such point clouds allow training the *Computer Vision Component for Drones* in an early way.

This component speeds up the constructive process of a civil infrastructure while saving costs by training any computer vision system for drones without need to perform multiple data collection campaigns to get real training data.

- **COMP03 – WP3-01 - Drone Pre-Certified MPSoC-based module**

This module allows to integrate multipurpose heterogeneous computing capabilities into a drone system, thanks to its reduced form factor. Its various communication means and complex algorithm implementation capability, allows adding new features to the overall system, such as image acquisition and processing, complex algorithm execution or safety-related functionality implementations.***COMP04 – WP5-02 Security Management Toolchain***

There are several attacks, such as, eavesdropping, hacking, or identity spoofing, which compromise the security of communication links. WP5-02-IKER component provides different monitoring, update, and visualization features in order to detect anomalous behaviour and vulnerabilities within the drone. For that purpose, in this component, most security-relevant variables (software versions, abnormal execution and communication patterns, protocol and certificates, etc.) will be tightly measured and monitored.

Finally, the outdoor geo-referencing system, i.e. the new GNSS-based Low-cost position & Attitude Determination (GLAD+) of ACORDE relies on the components COMP05, COMP06 and COMP07, developed in WP3-WP5.

- **COMP05 – WP3-15_2 - Improved (cost, performance) HW/SW platform for navigation solutions**

New, lower cost and improved HW platform for the low-cost outdoor geo- positioning& attitude provided by ACORDE (GLAD+). The new platform will rely on a new brand of low-cost GNSS receivers, supporting multi-constellation and secured positioning, and a more standardized interface for ease integration with autopilot (mavlink).

- **COMP06 – WP4-16 - Enhanced Navigation SW**

The navigation SW is in charge of computing the geo-referenced position and attitude. It performs the fusion of the information from the inertial sensors (IMU), from several GNSS receivers and from other low-cost sensors (barometer, temperature). The algorithm uses advanced data fusion algorithms, e.g., extended Kalman filtering, specific purpose mixed real-integer solving algorithms, and also heuristic-based functionalities. It supports complex, advanced of configurability, which is simplified in terms of navigation profiles for the user.

- **COMP07 – WP5-11-ACO - Navigation system with anti-jamming and anti-spoofing features**

This component comprises jamming and spoofing detection, and enables counter-measures at some extent which increase the integrity (i.e., trustability) of the navigation data, which can be compromised both by unintended jamming signals, or by malicious (jamming and spoofing) attacks.

Partner	Work Package	Components	Component ID	KPI	Criteria	Measurable Outcome	Objective
HIB	WP3	Computer Vision Component for Drones	COMP01 WP3-04	Ease of HW/SW configuration	SC1.1	MO1.3	O1
HIB	WP4	Data aggregator	COMP02 WP4-39	Ease of HW/SW configuration	SC1.1	MO1.3	O1
IKERLAN	WP3	HW/SW System on Module	COMP03 WP3-01	Reuse of components	SC1.2	MO1.3	O1

IKERLAN	WP5	Security Management Toolchain	COMP04 WP5-02	Improve network Security	SC3.1	MO3.1 MO3.3	O3
ACORDE	WP3	Position and Attitude Estimation	COMP05 WP3-15_2	Ease of HW/SW configuration	SC1.1	MO1.1 MO1.3	O1
ACORDE	WP4	Enhanced navigation SW	COMP06 WP4-16	Position and Attitude Performance	SC2.1 SC2.2	MO2.1	O2
ACORDE	WP5	Anti-Jamming and Anti-Spoofing Features In Geo-Referencing System	COMP07 WP5-11-ACO	Trustable Geo-Referencing system	SC3.1	MO3.2	O3
				Easy and flexible Integration of Trustable Geo-Referencing	SC3.1	MO3.3	O3

Table 31 UC2 D1 List of components

5.6 Tools

Most of the requirements are imposed by the use case and the components (HW / SW / Comm) must satisfy them. For example, “The GNSS / INS navigation system shall provide an accurate attitude & position trace that can be synchronized vs an absolute time reference for digitization purposes” could be satisfied by the new GNSS-based Low-cost position & Attitude Determination (GLAD+) system.

However, the design technology requirements are satisfied by different tools that allow quantifying the improvements that their tool was going to achieve. These improvements will allow enabling the tools and help the different processes of modelling, design, verification, and synthesis of the use case.

- **TOOL1 WP6-20 – ESDE: ESL eSW Environment Design Environment**

The ACORDE ESL eSW Design Environment (ESDE) enables high-level design and validation of algorithms to be run on a microcontroller-based platform. The main benefits of the tool are: a) The fast development and simulation of embedded SW, as reusable and re-targetable functional component; b) Automation of firmware generation, to avoid the slow and error prone manual translation from algorithm models to the embedded software implementation; and c) the speed up of firmware testing, by relying on virtual platform models. The framework relies on SystemC/C++ for specification of an executable model, and relies on Eclipse for integrating several libraries and facilities for GNSS system specification, for embedded software generation, and for targeting virtual models. In this demo ESDE is used to explore the performance of current and improved functionalities of the multi-GNSS receiver-based attitude estimation algorithm. The impact of algorithmic improvements and of alternative implementations (e.g., mapping to future computing architectures) will be of utility for deciding final shape of the ACORDE geo-referrencing firmware, and its future evolution.

- **TOOL2 WP6-22 - IoT Environment Extra-functional requirements validation and monitoring toolchain**

The extra-functional verification component is a start-up and runtime testing component with an onboard test system and a remote monitorization platform. Looking from a Safety operation perspective, the on-board test system will perform different start-up analysis and runtime tests during the system operation to ensure its correct operation, checking for the presence of faults and reporting them to the monitoring platform.

The system is composed of two main elements. The first one will consist on a self-test checking subsystem, boarded on the drone device. That subsystem will perform different system checks when the main application starts and will also perform runtime diagnostics during applications normal operation. The different checks will identify if the system is running as expected or a fault is detected.

The second one is the monitorization subsystem element developed in WP5 and used in conjunction with the self-test checking tool. This subsystem is the responsible of reporting faults to the final user as soon as they are detected. To this end, the tool will send the information from the device to an intermediate manager, and it will generate analysis reports for the final user.

- **TOOL3 WP6-23 - Event based IoT Environment validation methodology and toolchain**

The Event based IoT Environment validation toolchain is a model-based tool to design and develop event-driven IoT architectures efficiently. The solution is based on AsyncAPI Toolbox, which helps in implementing asynchronous communications using a model-based approach.

While IoT event-driven architectures present advantages like scalability and flexibility, they also face interoperability challenges, among participant agents in the system. Indeed, communication problems arise when message content and its categorization are not consistent. These issues may lead to loss of information loss and as a consequence to malfunctioning or loss of performance of the system. This scenario does not fall that far from the environment presented in COMP4DRONES, where different drones can be working/collaborating together and receiving and sending messages.

Thus, in addition to asynchronous communication implementation capabilities, the Event-based IoT Environment validation toolbox will provide testing features that will facilitate the verification and validation of the communication consistency for the system. This feature will help communication component developer to foresee and avoid system malfunctions that can derive from communication consistency failures, and ensure a robust communication among CPSs.

Next table summarized all the tools defined for this demonstrator:

Partner	Work Package	Description	TOOL	Requirements		Criteria	Measurable Outcome	Objective
ACORDE	WP6	ESDE: ESL eSW Environment	TOOL1 WP6-20	DTC-13 DTC-14 DTC-15 DTC-16 DTC-17 DTC-18	DTC-19 DTC-20 DTC-21 DTC-22 DTC-23	SC4.1	MO4.1	O4
IKERLAN	WP6	IoT Environment Extra-functional requirements validation and monitoring toolchain	TOOL2 WP6-22	DTC-46		SC4.1	MO4.2	O4

IKERLAN	WP6	Event based IoT Environment validation methodology and toolchain	TOOL3 WP6-23	DTC-47 DTC-48 DTC-49 DTC-50		SC4.1	MO4.2	O4
UNICAN	WP6	SoSSim simulation & performance analysis	TOOL4 WP6-26	DTC-79		SC4.1	MO4.2	O4

Table 32 UC2 D1 List of Tools

5.7 Traceability matrices

5.7.1. Requirements vs. functionalities

The table below links all the requirements identified in this demonstrator (both from D1.2 and this deliverable) to the main functionalities defined:

Requirement	Short description	FUNC 1	FUNC2	FUNC 3	FUNC 4	FUNC 5	FUNC 6	FUNC 7	FUNC 8	FUNC 9	FUNC 10	FUNC 11
UC2-DEM1-FUN-01	Point Cloud								X	X	X	
UC2-DEM1-FUN-02	RGB data		X				X					
UC2-DEM1-FUN-03	Point cloud in Open format								X	X	X	
UC2-DEM1-FUN-04	Point cloud with precise location								X	X	X	
UC2-DEM1-FNC-05	RGB data at 45 degrees		X				X					
UC2-DEM1-FNC-06	Provide current drone status for vulnerability detection	X										
UC2-DEM1-FNC-07	Drone identification	X										
UC2-DEM1-FNC-08	Position, Attitude estimation system				X	X						
UC2-DEM1-INT-01	Geo-referencing system output trace formats				X					X		
UC2-DEM1-PRF-01	Geo-referencing system estimation performance				X	X				X		

UC2-DEM1-PRF-02	Geo-referencing system cost performance				X							
UC2-DEM1-PRF-03	Flying time	X										
UC2-DEM1-PRF-04	Storage capacity							X				
UC2-DEM1-SEC-01	Georeferencing data integrity				X	X			X			
UC2-DEM1-SEC-02	Collect history data					X		X	X			
UC2-DEM1-SEC-03	Secure communications							X				
UC2-DEM1-SEC-04	Vulnerability detection							X				
UC2-DEM1-SEC-05	Software actualization							X				
UC2-DEM1-USA-01	Geo-referencing system Auto-calibration				X					X		
UC2-DEM1-USA-02	Geo-referencing system Configuration				X					X		
UC2-DEM1-USA-03	Maximum size	X										
UC2-DEM1-USA-04	Recharging	X										
UC2-DEM1-USA-05	Maintenance	X										
UC2-DEM1-USA-06	Weight	X										
UC2-DEM1-DR-01	Cameras		X									
UC2-DEM1-DR-02	Images resolution		X				X					
UC2-DEM1-DR-03	Camera compensation						X					
UC2-DEM1-DR-04	Camera pointing						X					
UC2-DEM1-DR-05	VTOL capability	X										
UC2-DEM1-DR-06	Automatic flight			X		X						
UC2-DEM1-DR-07	Waypoints			X								
UC2-DEM1-DR-08	Windy conditions	X										
UC2-DEM1-RE-01	Permit plan											
UC2-DEM1-RE-02	Pilot licenses											
UC2-DEM1-RE-03	Operator registration											
UC2-DEM1-RE-04	Safety assessment											
UC2-DEM1-RE-05	Operational procedures											
UC2-DEM1-RE-06	Controlled ground area											

Table 33 UC2 D1 Requirements and functionalities traceability matrix

5.7.2. Functionalities vs. Components

The table below links all the components that are part of this demonstrator to the main defined functionalities

FUNCTIONALITY	Short description	COMP 01 WP3-04	COMP 02 WP4-39	COMP 03 WP3-01	COMP 04 WP5-02	COMP 05 WP3-15_2	COMP 06 WP4-16	COMP 07 WP5-11-ACO
FUN - 01	UAV platform					X	X	X
FUN - 02	High-quality camera for data gathering	X					X	
FUN - 03	Mission plan logger with specialized waypoint set					X		
FUN - 04	Accurate positioning and attitude system					X	X	X
FUN - 05	Autonomous navigation system					X	X	
FUN - 06	Advanced image stabilization system	X						
FUN - 07	Data logger				X			
FUN - 08	Specialized software for data matching (images and aerial system telemetry) and correction:							
FUN - 09	Specialized software for georeferenced point-cloud creation		X					
FUN - 10	Autonomous identification and detection of construction elements	X						
FUN – 11	Integration of modular system with hybrid architecture			X				

Table 34 UC2 D1 Components and functionalities traceability matrix

5.8 Validation plan

Taking into account the Validation and Verification methodology explained in the introduction of the document, once all the requirements components and tools have been identified; and after the performance of the traceability matrices the loop must be closed with the verification and validation plan for the all the systems continuing the process defined in the FIGURE XX. These Verification and validation plan can be divided into three different levels: Component verification, Verification of the main functionalities and finally the validation of the systems.

5.8.1. Components Verification

- **COMP01 – WP3-04 - Computer Vision Components for Drones**

The *Computer Vision Components for Drones* be validated with a relevant environment in order to demonstrate that a TRL 6 is feasible.

Previous test requirements	After the online mission, generation of the geo-referenced point clouds in LAS format from the images captured by the drone in the *First Data Collection Campaign*.
	Convolutional Neural Network (CNN) implemented in the *Computer Vision Components for Drones* previously trained with the simulated point clouds related to the considered scenario performed during the *First Data Collection Campaign*
Test description	The *Computer Vision Components for Drones* will receive the real geo-referenced point clouds in LAS format during the post-processing stage, and will intend to detect through the previously-trained CNN the traffic signs and their corresponding position related to the considered scenario performed during the *First Data Collection Campaign*. The expected results will be compared with the real scenario for validation.
Planned inputs	Point clouds in LAS format generated from the images captured by the drone related to the same scenario considered in the *First Data Collection Campaign*.
Expected results	The inventory of traffic signs (road elements) and their corresponding position in the scenario considered in *First Data Collection Campaign* in the needed format to create the BIM.

- **COMP02 – WP4-39 - Simulated data aggregator supporting intelligent decision in computer vision components**

The *Simulated Data Aggregator* will be validated with a relevant environment in order to demonstrate that a TRL 6 is feasible.

Test description	The *Simulated Data Aggregator* will generate simulated point clouds related to the considered scenario performed during the *First Data Collection Campaign* in order to be compared with the point clouds coming from the images captured by the drone in the same scenario.
Planned inputs	• Drone configuration parameters • Flight height. • Digital terrain model (of the scenario considered in the *First Data Collection Campaign*) • 3D models (CAD files) of the traffic signs to be detected
Expected results	Points cloud in LAS format related to the same scenario considered in the *First Data Collection Campaign* with the same format as the point clouds generated from the images captured by the drone, including precise location of the samples.

- **COMP03 – WP3-01 - Drone Pre-Certified MPSoC-based module**

Previous test requirements	Identification of safety or data processing functionality or new component integration to implement in the Module
	Implementation of the safety, data processing functionality or new component integration in the Module

Test description	This test will validate that the module works correctly and that is able to integrate new functionalities or sensors. The SoM will be tested, preferably, in laboratory condition, implementing a functionality or new component. This set up will replicate the architecture of drone FMU – Companion Computer, normally used in industry for such systems and will validate that the component can be included in drone systems.
Planned inputs	Data to feed the implemented functionality, such as sensor data or any event that would trigger the implemented design. Or connection of the selected sensor in the SoM
Expected results	New component or functionality validation thanks to the use of the developed Module.

- **COMP04 – WP5-02 - Security Management Toolchain**

The security Management Toolchain will be validated with a relevant environment in order to demonstrate that a TRL 6 is feasible

Test description	The Security Management Toolchain will be tested in laboratory condition simulating a drone flight as well as a test drive to validate the results on the laboratory. The results are not affected by the environment, but it will be taken into account.
Planned inputs	-Security events -Drone logs -Drone configuration files -Simulated attacks
Expected results	The results have to be in line with the expected security level. The alerts have to be triggered when it's due and all changes detected without interfering with the drone flight.

The validation of the **outdoor geo-referencing system of ACORDE (GLAD+)** will be validated on:

- **COMP05 - WP3-15_2 - Improved (cost, performance) HW/SW platform for navigation solutions**

Previous test requirements	• Implementation of the HW/SW platform (GLAD+ platform) developed in WP3 • Implementation of Logger • Documentation for mechanical, electrical and software integration. • Documentation for testing the platform, specifically for operation and testing of correct reception of the sensed data. • Delivery to Drone Integrator of all the aforementioned material.
Test description	*The drone integrator, after receiving the HW/SW platform (GLAD+ platform) and the associated integration documentation will perform the mechanical and electrical integration of GLAD+ platform on the drone. Then, a static test in an outdoor location will be performed to test the platform is working and its correct integration.*
Planned inputs	• GLAD+ platform (board, antennas, antenna cables, …). • Logger.

	• Platform Validation tests documentation • Configuration data (for drone profile, antenna geometry, closer base RTK station, among others) • Support from ACORDE engineers (previous and at the static test time)
Expected results	• Feedback from the drone integrator regarding to the integration and configuration effort. • Confirmation that the platform receives all the expected sensed data and they are in shape, with the expected quality. • Confirmation that the logger is capable to capture sensed and output data, to facilitate further development and validation actions.

- **COMP06 – WP4-16 - Enhanced Navigation SW**

Previous test requirements	*All the test requirements of COMP5, plus:* • GLAD+ Firmware supporting position and attitude including the algorithmic improvements developed in WP4. • Documentation on the validation flights (with conditions to test different aspects of the geo-referencing system and limit scenarios for the drone dynamics)
Test description	*The drone integrator will perform a number of flights for the testing of position and attitude estimation of the GLAD+ system, as described in the validation flights document.* Within the flights, typical and challenging manoeuvres according to its experience and not contemplated in the validation plan will be performed. Input and output data*, The performance of GLAD system (position and attitude accuracy, precision) is assessed, as well as the support of the new interfaces and outputs.*
Planned inputs	• GLAD+ firmware uploaded on GLAD+ platform on-board • Validation Flights document • Configuration data (for drone profile, antenna geometry, closer base RTK station, among others) • Advice from drone integration on typical manoeuvres performed, also relevant to be tested
Expected results	• Drone Telemetry and Raw data for generating the true references. • Position and Attitude output • Position&Attitude performance assessment (accuracy, precision),

- **COMP07 – WP5-11-ACO - Navigation system with anti-jamming and anti-spoofing features**

Previous test requirements	• Implementation of the HW/SW platform (GLAD+ platform) developed in WP3 • Extension of GNSS receiver's driver for supporting the signalling of jamming and spoofing event detection and to support the configuration of jamming and spoofing event detection

	• Extension of GLAD+ firmware to support of configuration of jamming and spoofing event detection, and handling of these events, i.e. acting on output validity flags (WP5).
<u>*Test description*</u>	*The validation will be performed in three stages. First, by using the tooling associated to the GNSS receivers, they will be configured to notify status regarding jamming and spoofing events. It will be checked that the configuration of the anti-jamming and anti-spoofing feature can be performed through the GNSS drivers. In the last step, once the GLAD+ firmware is extended to support the configuration and consideration of jamming/spoofing events, runs with this feature enabled and disabled will be done, and impact on the output checked.*
<u>*Planned inputs*</u>	• GLAD+ system Configurations with/without anti-jamming&anti-spoofing detection enabled
<u>*Expected results*</u>	• Confirmation that the GNSS driver can configure anti-jamming&anti-spoofing, and that it signals those events. • Confirmation of the integration of these features on GLAD+ firmware.

5.8.2. System Functionalities Verification

At a higher level than the components, the main functionalities of the demonstrator must be validated in order to ensure that the final system will be able to meet the objectives of the demonstrator 1. Compliance with the functionality, in turn, will ensure the validation of the requirements associated with each of them.

Moreover, the environment of the verification/validation will be related with the goal and the expected output of each camping. For the functionalities three different environments have been defined; Laboratory, outdoor controlled and realistic environment. Next tables summarized the main functionalities that must be verified in order to ensure that the objectives of the demonstrators are obtained. Moreover, some of the functionalities that are not listed below, are directly achieved with the validation of the components developed.

UC2 –D1 - FUN01 - UAV platform

Environment	Goal	Output
Laboratory	Correct and robust integration of the system within the UAV platform First flight of the overall integrated system	Report and acceptance of the UAV and systems integration Telemetry of the first flight in the laboratory to be analysed.
Outdoor controlled	The UAV performs an autonomous flight of the UAV with real outdoor conditions. Images are taking during the flight and in a stabilized manner	Telemetry of the flight Set of images
Realistic	The UAV follows the defined mission and complete it, considering the images to be taken for further postprocessing.	Telemetry of the flight Set of images

UC2 –D1 - FUN02- High-quality camera for data gathering

Environment	Goal	Output
Laboratory	Correct integration of the set of cameras in the UAV airframe	Acceptance of the integration by the technical manager.
Outdoor controlled	Successful performance of the set of cameras in expected similar real conditions (temperature, wind, lighting…)	Taken pictures to be analysed in expected similar real conditions.
Realistic	The set of cameras works as expected in a real scenario, responding appropriately to the user requests.	Taken pictures of the areas requested by the user to be monitored.

UC2 –D1 - FUN03- Mission plan logger with specialized waypoint set

Environment	Goal	Output
Laboratory	A mission can be logged onboard	Post mission log to be match with the designed mission
Outdoor controlled	A mission can be logged onboard. The system works properly in normal temperature conditions	Post mission log to be match with the designed mission
Realistic	A mission can be logged onboard, and the UAV performs it as designed.	Post mission log to be match with the designed mission

UC2 –D1 - FUN04 - Accurate positioning and attitude system

Environment	Goal	Output
Laboratory	The GLAD+ system is manufactured and tested in ACORDE facilities and collects navigation and raw data to its SDK via its output interfaces.	Navigation (position, attitude time) and raw data. To be used for confirmation of working output and that the SDK is in shape.
Outdoor controlled	The GLAD+ system is mounted on drone and tested by the integrator on static conditions on its facilities, relying on the GLAD+ SDK.	Navigation data (position, attitude time) and raw data. To be used for confirmation of proper integration, navigation data, and that SDK is working properly and usable for realistic tests.
Realistic	The GLAD+ system is mounted on drone and flown by the integrator trying several trajectories, manoeuvres and dynamics to test GLAD+ both on average and limit flight scenarios.	Navigation data (position, attitude time) for the flights. To be used for evaluation and validation of GLAD+ performance.

UC2 –D1 - FUN05 - Autonomous navigation system

Environment	Goal	Output
Laboratory	The system works properly, including navigation sensors, sensor fusion modules, signals to actuators, etc.	Telemetry to be analysed afterwards
Outdoor controlled	The navigation system responds properly in real conditions, i.e., with wind, GPS signal degradation. The mission will push the system to its boundaries.	Telemetry to be analysed afterwards
Realistic	Autonomous flying in a real scenario and environment	Telemetry to be analysed afterwards

UC2 –D1 - FUN 06 - Advanced image stabilization system

Environment	Goal	Output
Laboratory	The images are stabilized, and the image stabilization system respond to the user inputs. Robust and adequate integration of the system within the UAV airframe	Pictures in different gimbal positions, depending on the user input. Report of the integration
Outdoor controlled	The images are stabilized, independently of the UAV motion.	Set of images taking during flight for further analysis Telemetry of the UAV and the image stabilization system
Realistic	The images are stabilized and useful for the post-processing phase. The images are taken following the constrains set in the mission definition.	Set of images taking during flight for further analysis Telemetry of the UAV and the image stabilization system

UC2 –D1 - FUN07 - Data logger

Environment	Goal	Output
Laboratory	The capacity of the system matches the specified one, as well as the velocity of logging of the system.	Files filled, according to the system's capacity
Outdoor controlled	Correct performance of the logger in real conditions (wind, temperature, drone speed, etc.)	Files to be loaded in a computer for further analysis
Realistic	Correct performance of the logger in real scenario	Files to be loaded in a computer for further analysis

***UC2 –D1 – FUN11* - Integration of modular system with hybrid architecture**

There is no system-level validation plan envisioned for this functionality, the validation happens at component level. Similar to the components of the Use Case 4 Demo 2.

5.8.3. System Validation

Finally, during the third stage, the final data and image acquisition campaigns will be done to validate the integration of the technologies in the drone prototypes. The final check of the technologies will be carried out in a real site to proof all the interfaces and functionalities.

The results of the tests done will be evaluated according to the technical KPI´s defined in for the demonstrator and the compliance of the main functionalities, that allow to verify the features and requirements defined at end user level in the D1.1

For the digitalization of the construction site the validation will be defined into two scenarios: (1) data acquisition of the real construction site and (2) the post processing process with the data treatment and the creation of a BIM model of the terrain. For both of them a wide set of flight will be performed divides in different stages to go evaluating the performance of the system periodically. Next table summarized the verification method and the test campaigns.

KPI	Definition and measurement of Indicator	Description and enhancements	Verification Method	*Campaign tests*
Improved performance of navigation solution.	10cm CEP error in position Valid data for 90% of the fly (continuity) <1deg RMSE error for all attitude components	Accuracy, Continuity and Integrity of position and attitude estimates are improved for practical usability for digitisation.	Compare the data of the theoretical flight (autonomous and planned) with the real data of an experimental flight with an inertial navigation system, such as an applanix board (direct georeferencing system for air flights)	Performing flights with the ron platform to capture images and data with flights at different heights, speeds, camera angles and performing different trajectories (non-linear, circular ...)
Navigation following waypoints and capturing data.	The drone is able to fly autonomously covering the area of interest and capturing data along the whole flight.	90% data capturing flights completed	Perform several typical flight traces performing different data capture configurations. Depending on the GSD, overlap, number of elements to be recognized, density of the elements ... and in each one of them establish the number of theoretical images to capture.	Carry out several validation campaigns based on the different scenarios and the theoretical estimates of data captures.
Recognition of work elements through AI.	Detection of main work elements position in the road through point cloud	Accuracy less than 20cm	Carry out flight campaigns to recognize simple elements (targets, spheres ...) that have previously been georeferenced by means of conventional topography.	Carry out a comparison of the real positions measured in the field with the post-processed images after the flights.

	Detection of the total number of elements	At least 90% of the elements	Generation of a model block of the elements to be captured (signals, new jersey barriers, road elements…) by means of laser scanner or 3D modelling. Carry out a flight with the elements to be captured and comparison of the results. Carrying out experimental flights with different positions of the element, angles, flight heights ...	Carry out several validation campaigns based on the different flights

Table 35 UC2 D1 System validation plan

6 UC2 - Demo 2: Construction: Integration of technologies to define the state of the constructive process of an Underground Infrastructure

6.1 Current state of the technology

Despite advances in drone technology, the use of drones in underground environments is still limited. In this sense, it is important to identify the challenges and limitations involved in this type of work, since they are usually very small spaces, with little or almost no lighting and with an environment very rare by moisture and dust in suspension. In addition, in active execution projects, trafficking in people and machinery is common. However, its use in such environments could be widely implemented, presenting a number of advantages among which would be:

- The volume of information generated in any inspection methodology, higher in any case than traditional methods.
- Access to this information is easier to stored and with it form complete models of the workspaces, optimizing working times. Inspection speed, as it is estimated that detailed information of about 300 m of tunnel could be obtained in about 10 minutes.
- Safety of operation in risky environments for people, such as landslides or unstable areas.

Piloting drones in this kind of infrastructure also involves a number of challenges that are now partially resolved. The first and most restrictive would be the lack of sources for aircraft positioning (GNSS or GPS). That is why aircraft should calculate the position and speed of routes using data from the environment to ensure a safe distance from walls, roof and any other obstacles within the tunnel. On the other hand, there is the lack of lighting, which forces you to use your own source. Finally, the air currents generated by its propellers, which will produce suspended dust, as well as turbulence that hinder stable flight in these conditions. Finally, the battery life limits the flight time of drones also represents a critical point, which significantly limits the time of missions.

Figure 9 UC1 – Drone during inspection work in tunnels

Currently, the application of drones for tunnel inspection is limited by flight capacity and positioning within the tunnel. Today, there are several sensing technologies used among which total vision cameras, ultrasonic sensors, redundant IMUs and infrared sensors are finished. In the most advanced models are used combine the above sensors with other ultrasonic type for the detection of obstacles and even laser rangefinders (Velodine type).

In terms of inspection systems, technological advances in passive and active sensors have boosted the ability of drones in such missions. Drone sensors make it easy to capture high-resolution images, and even sensors on a drone depend on the size of the drone and mission. However, depending on the objective of the research antenna and lighting conditions, various types of sensors must be connected to the drone, including HD cameras, thermal imaging. ultrasonic, infrared (IR) sensors, laser detectors, lidar type, ultra-wideband radar (UWB) and hyper-spectral sensors.

6.2 Use Case Concept of Operation

The current use case, derived from the end-user's requirements, has been designed as it is illustrated in Figure 10. This use case will comprise the flight of an UAV equipped with LIDARs and cameras to engage the vehicle with an indoor navigation system, since the UAV is required to fly inside a tunnel, as well as for data gathering purposes, and a postprocessing phase in which a high-performance computer will be required, to create a georeferenced point-cloud of the inside of the tunnel. The use case will start with the online part of the mission (left hand side of the Figure 10). First, it will be established a list of control points inside the tunnel. These control points will be manually placed, and with a high precise and accurate indoor total station, their coordinates will be saved. These points will be used later for georeferencing correction purposes. These control points must be chosen before the flight since they must appear in the data captured during the flight.

After that, the UAV can start its mission. The mission will be designed previously. Thus, at the time of the mission to be carried out, the mission will be directly load on the UAV core. At the very beginning, once the UAV is started, the indoor positioning system will be statically initialized. By doing this it will be ensured that the system will capture accurate enough georeferencing data. Once the time specified by the manufacturer for the initialization of the system has elapsed, it will be checked that the measures taken by it are correct. After that, the UAV will take off. From the mission loaded previously, it will fly through the specified WP in an autonomous manner. During the flight, the LIDAR will collect data based on the conditions specified by the user. These data will be gathered along with the indoor position and the telemetry of the UAV. The UAV will fly inside the tunnel until the mission is completed. After that, the UAV will land, and the operator will perform a visual inspection to determine if a further maintenance is needed.

After the online mission, the data will be downloaded in the high-performance computer to process it into the expected solution. For that, several steps will be followed. First, the environment data taken by the LIDAR will be processed to construct the point cloud. Once the point cloud is created, it must be matched with the telemetry of the UAV and with the indoor localization system collected data. At this time, the highly precise coordinates of the control points will be used to correct the georeferencing process. Then, the point-cloud would be georeferenced. With it, a specialized software will make use of it to detect and identified the construction elements inside the tunnel, such as traffic signals, and finally, it will be export to a BIM model.

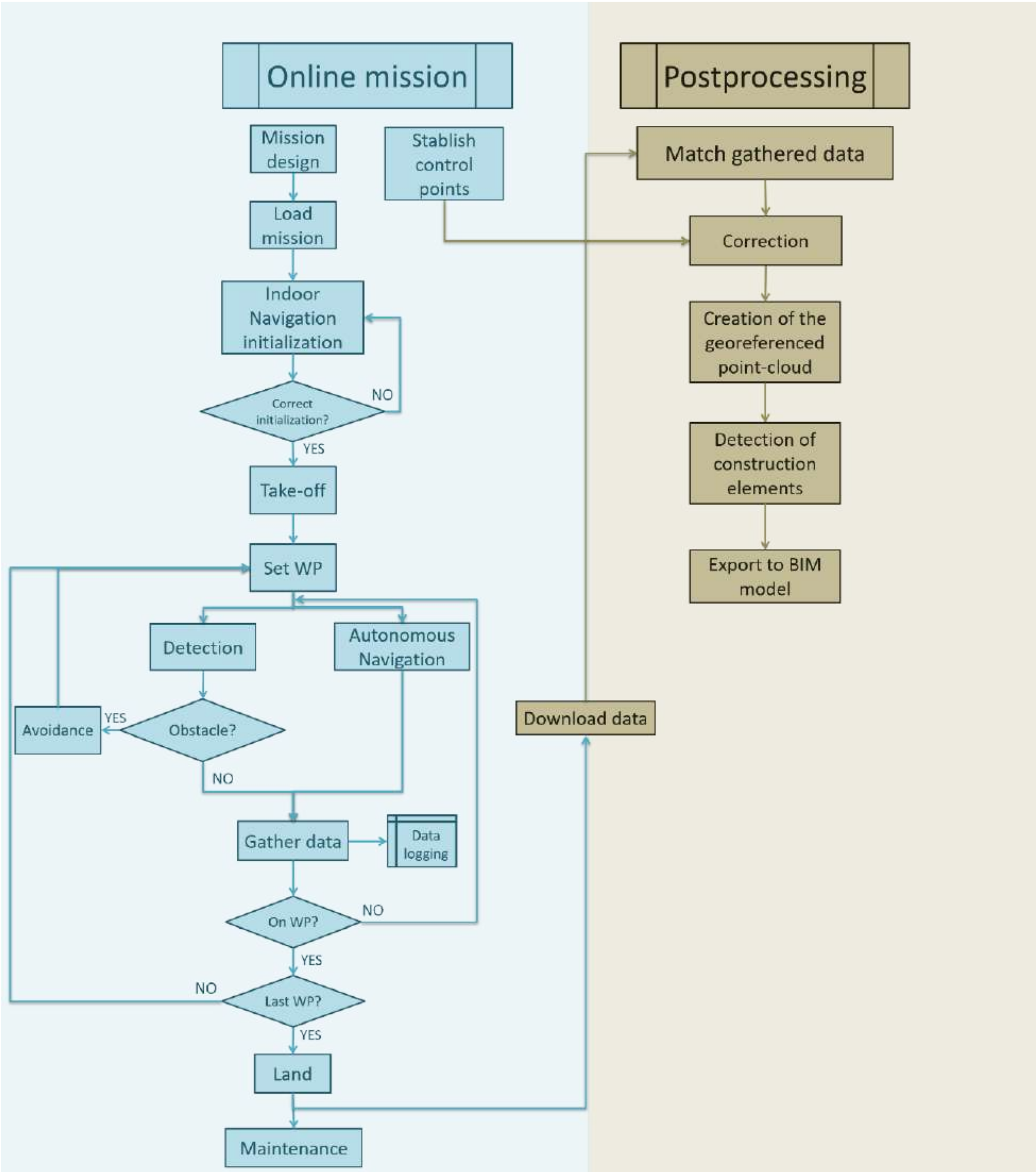


Figure 10 UC2 – D2 demonstrator's concept of operation scheme

6.3 System Requirements, KPI´s and Metrics

The main technical requirements for the demonstrator are shown below, these requirements are related with the main technological KPIs that have been defined in the Deliverable D1.1. The final system must comply with most of the requirements to be able to achieve the final objectives of the demonstrator.

6.3.1. Technical KPI`s and Metrics

nº	KPI	Definition and measurement of indicator	Target value
UC2-D2-KPI-01	Project construction using Virtual Construction Technology (BIM)	Monitoring of the work progress in real time,	Measurement deviations < 10%
UC2-D2-KPI-02	Self-Recognition of work elements through AI	Auto-detection of main work elements through point cloud.	Accuracy less than 20cm
UC2-D2-KPI-03	Position available at the tunnel to enable autonomous, way point based fly of the drone.	Position integrity for all the flight areas of the drone defined for the indoor facilities, with enough accuracy for safe flight.	Position error (CEP) <30cm in significant drone trajectories, <50cm in all the indoor infrastructure.
UC2-D2-KPI-04	Autonomous navigation inside the tunnel.	The drone is able to fly autonomously along a tunnel capturing data and avoiding collisions with the obstacles.	90% of flight mission of the drone is done autonomously (all phases of data capturing). The rest of phases corresponds to take-off, landing and approach procedures, which could be done manually by the safety pilot.

Table 36 UC2 D2 List of KPIs

6.3.2. Main requirements (functional, interface, performance, security, usability…)

D1.1 introduced the main functional requirements of the demonstrator. In this section, the remaining technical requirements for the demonstrator are shown, linked to specific KPIs of the demonstrator:

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC2-DEM2-FUN-01	Autonomous drone operation	The drone system shall fly autonomously along the tunnel.	H	Drone system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-FUN-02	Data captured	The drone system shall capture all the data and save it on-board for latter processing.	H	Drone system	UC2-D2-KPI-04 UC2-D2-KPI-02

UC2-DEM2-FUN-03	Operation monitoring	The drone system shall communicate with a ground control station in order to be able to monitor the mission operation.	H	Drone system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-FUN-04	Point cloud	The drone system shall save all the raw LiDAR data.	H	Drone system	UC2-D2-KPI-01 UC2-D2-KPI-02 UC2-D2-KPI-04
UC2-DEM2-FUN-05	GNSS unavailability	The drone system shall navigate without using GNSS localization.	H	Drone system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-FUN-06	Low visibility	The drone system and sensors shall work in very low light conditions.	H	Drone system	UC2-D2-KPI-04
UC2-DEM2-FUN-07	Humidity and dust	The drone system and sensors shall work under indoor construction conditions of humidity and dust.	H	Drone system	UC2-D2-KPI-04
UC2-DEM2-FUN-08	Obstacle detection	The drone system shall be able to detect an obstacle on its flying route.	M	Drone system	UC2-D2-KPI-04
UC2-DEM2-FUN-09	Obstacle avoidance	The drone system shall be able to automatically avoid flying against obstacles.	M	Drone system	UC2-D2-KPI-04
UC2-DEM2-FUN-10	Indoor Positioning	An indoor positioning system will provide real-time geo-referenced position to drone	H	Indoor Positioning System	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-INT-01	Indoor positioning system interface	The indoor positioning system shall provide real-time navigation information at the drone side, that can be integrated by the autopilot, including raw data (ranges)	H	Indoor positioning system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-PRF-01	Indoor positioning system accuracy	The system shall provide real -time navigation data with submetric accuracy in all the infrastructure	H	Indoor positioning system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-PRF-02	Indoor positioning system cost	The system shall imply an affordable and scalable cost for the infrastructure (<3K€ for 1K tunnel)	H	Indoor positioning system	UC2-D2-KPI-03
UC2-DEM2-PRF-03	Flying time	The drone system shall be able to fly at least 10min before changing its batteries.	H	Drone system	

UC2-DEM2-PRF-04	Indoor data capturing per flight	The drone system shall be able to flight capturing data 100 meters per each flight.	M	Drone system	UC2-D2-KPI-01 UC2-D2-KPI-04
UC2-DEM2-PRF-05	Storage capacity	The drone system shall be able to store at least 10 GB of data per flight.	H	Drone system	UC2-D2-KPI-04
UC2-DEM2-PRF-06	Volumetric measures	Sub-metric accuracy in all the volume of the indoor infrastructure	H	Drone system	UC2-D2-KPI-04 UC2-D2-KPI-03
UC2-DEM2-SEC-01	Distributed log and history data set	Incorporate an automatic information saving system.	M	Drone System	UC2-D2-KPI-04
UC2-DEM2-SEC-02	Secure communications	Avoid interferences and communication losses	M	SW Developer	Improve network security, Improve network performance
UC2-DEM2-SEC-03	Vulnerability detection	The system shall give information about the drone status against the vulnerability detection.	H	SW Developer	Improve network security, Improve network performance
UC2-DEM2-OPE-01	Indoor positioning for autonomous navigation	The system shall provide real -time navigation data, with sufficiently accuracy for autonomous, way point based navigation within the core of the empty indoor infrastructure.	H	Indoor positioning system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-OPE-02	Indoor positioning for safe navigation	The indoor position navigation accuracy shall allow to track a sufficiently accurate route to allow effective geofencing on the empty indoor infrastructure.	H	Indoor positioning system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-OPE-03	Indoor positioning resilience with obstacles	The indoor position navigation accuracy shall have resilience against the presence of objects within the indoor infrastructure (machinery, etc) in operational conditions	M	Indoor positioning system	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-OPE-04	Indoor positioning accuracy for routes avoiding	The indoor position navigation accuracy shall allow to track a sufficiently accurate route to avoid obstacles provided they	M	Indoor positioning system	UC2-D2-KPI-03 UC2-D2-KPI-04

	obstacles with known position	position is known in advance.			
UC2-DEM2-USA-01	Indoor positioning system usability	The deployment of the system has to be easy for workers. The system will enable automatic anchor positioning, and manual recalibration by topographers, facilitated by configuration software and communication interfaces.	M	Indoor positioning system	UC2-D2-KPI-03
UC2-DEM2-USA-02	Maintenance	The drone system shall be prepared to perform small repairs and maintenance onsite.	H	Drone system	The system is designed to have a separate maintenance station than the operational one
UC2-DEM2-USA-03	Weight	The drone system shall be lighter than 25Kg in order to reduce the danger of the operation.	H	Drone system	The system is weighed just before the take-off and it weighs less than 25kg

Table 37 UC2 D2 List of Main Requirements

6.3.3. Drone integration requirements

The requirements below are related with the SORA analysis performed (Reference to the methodology in D2.5.) and the boundary conditions introduced in D1.1, as well as to the regulatory framework that dictates the deployment of the scenarios of the demonstrator.

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC2-DEM2-DR-01	Sensors integration	The drone must carry a structure to integrate all necessary sensors for indoor navigation.	H	Drone integrator	UC2-D2-KPI-03 UC2-D2-KPI-04 UC2-D2-KPI-01 UC2-D2-KPI-02
UC2-DEM2-DR-02	Sensors accuracy	The indoor navigation sensors must provide high-resolution data so that details of construction elements can be captured.	H	Drone integrator	UC2-D2-KPI-03 UC2-D2-KPI-04

UC2-DEM2-DR-03	Automatic flight	The drone system must be able to perform the flight path in an automatic way	H	Drone integrator	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-DR-04	Waypoints	The drone must be able to accept and execute a list with a high number of waypoints (up to 100)	H	Drone integrator	UC2-D2-KPI-03 UC2-D2-KPI-04
UC2-DEM2-DR-05	Navigation conditions	The drone must be able to fly under indoor conditions up to 1 m/s	H	Drone integration	UC2-D2-KPI-03 UC2-D2-KPI-04

Table 38 UC2 D2 List of Drone integration Requirements

6.4 Functionalities identification

Main functionalities of the system have been defined in order to give more information about the characteristics needed for the performance of the mission operations. Most of the functionalities listed below are related with the Indoor navigation for the underground constructions.

ID	Functionality	Description	System function
UC2 – D2-FUN - 01	UAV platform	Aerial platform in charge of carrying the LIDAR and the indoor navigation system to perform the designed mission.	Flight control Flight navigation Positioning
UC2 – D2-FUN - 02	Mission plan logger with specialized waypoint set	This function will allow the aerial system to load and save the desired mission.	Intelligent mission management
UC2 – D2-FUN - 03	LIDAR for data gathering	A sensor is needed to gather information of the environment to later create a 3D model of the tunnel.	Intelligent data handling
UC2 – D2-FUN - 04	Autonomous indoor navigation system	Since the mission will be performed in an autonomous way, an autonomous indoor navigation system, such as an INS (Inertial Navigation System), which fused inertial measurements with data coming from the onboard sensors, e.g., cameras and LIDAR.	Take-off and landing Planning and scheduling
UC2 – D2-FUN - 05	Autonomous detection and avoidance of obstacle while flying	This functionality will implement autonomous detection and avoidance of obstacles while flying. This includes the capability to create a map of the surrounding environment and the detection of potential obstacles in collision with the trajectory of the UAV. In case of detecting an obstacle, the flying drone will autonomously re-plan the trajectory and get to the destination without the intervention of the operator.	Flight control Flight navigation Positioning
UC2 – D2-FUN - 06	Data logger	During the mission, this system will be logging the environment data caught by the LIDAR and the telemetry of the UAV, which both will be match later during the postprocessing.	Intelligent data handling

UC2 – D2-FUN – 07	Specialized software for point-cloud creation	Once the mission has finished, this functionality will create a point-cloud of the area from the data gathered by the LIDAR.	Intelligent data handling
UC2 – D2-FUN-08	Indoor positioning	This functionality provides real-time 3D accurate geo-position within the indoor infrastructure, and also provide raw ranging data to allow fusion with complementary sensors, i.e. to service FUN-04.	Flight Control Flight Navigation Positioning

Table 39 UC2 D2 List of Functionalities

6.5 Components

The components related to the Demonstrator 2 of the UC2 are listed below with a short description of each one. The components listed below are the specific ones for the application in a tunnel environment that allows the indoor navigation. Some of the components for the post processing system could potentially be used also in these types of applications, Training the AI algorithms with new elements.

The three former components form the ACORDE IPS system.

- **COMP01 – WP3-15_1 - Customized platform solution for the Indoor Positioning System**

The IPS provides a georeferenced, high-rate position to the drone platform in indoor scenarios where GNSS is not available. It is based on the estimation of accurate ranges from a mobile tag to statically deployed anchors. The mobile tag can either provide the ranges to the anchors for being externally fused with other data sources or its auto calculated position. This component primarily focuses on the development of the customized solution for anchors and tag platforms of ACORDE (developed in WP4), specifically suited for indoor, real-time accurate 3D positioning within long infrastructures, e.g. tunnels. The posed solution aims a Pareto trade-off between cost and features at the positioning and medium access levels targeted by the IPS firmware, deployed in COMP02 and COMP03 respectively.

- **COMP02 – WP4 -17 - Anchor&Tag firmware of the Indoor Positioning System**

The Indoor Positioning System (IPS) firmware comprises both, anchor firmware and tag firmware. Beyond supporting the layering on UWB technology, the anchor and tag firmware will cope with some specific requirements on the IPS for the positioning on the tunnel infrastructure (3D accuracy, real-time, a long linear structure, position available on the drone). The tag firmware will be able to provide real-time high rate, highly accurate position after fusing inertial sensor data with UWB-based range data. This ranging data is obtained in collaboration with anchor nodes. The anchor node firmware will support a compatible MAC protocol and ranging protocol for the answers to the tag node. The anchor firmware will support the configuration from an external user (e.g., a topographer) of its own accurate geo-position for optimize the reference for the ranging data offered to the tag. The anchor firmware will also support auto-positioning (for not making necessary this configuration).

- **COMP03 –WP5-19-ACO - Robust and Enriched Communication for Indoor Positioning System**

This component (developed in WP5) encapsulates novel features developed by ACORDE for robust and enriched Indoor Positioning System. A more robust communication will be enabled by relaying on a novel medium access protocol developed by ACORDE, which improves the performance of known protocols like ALOHA or slotted ALOHA. This is complemented with a design of the anchors deployment design capable to consider the tunnel geometry and afore-known obstacles (by relying on the IPS-MAF tool developed by ACORDE in WP6). This component also comprises enriched communication among tags and beacons, and among beacons. Enriched communication in this context stands for an augmented ranging protocol which targets the improvement of the position accuracy.

- **COMP04 – WP3-30 - Indoor intelligent navigation**

The indoor positioning system is a software development that will run on the aircraft's onboard computer. It will estimate the localization of the aerial robot using all the input data. This module will detect obstacles and send proximity alarms to the controller in order to avoid them. The objective is that the precision of the navigation in real time that allows the aircraft to fly inside a tunnel is less than 1m. This module allows the autonomous navigation of the drone in indoor environment such as a tunnel under construction. This module is integrated in ROS, together with the autopilot communication protocol and driver of sensor. The output of this module would be the localization of the robot and commands to given to the positioning control system.

Next table summarized all the components and related them with the main Criteria and objectives of the Comp4drones project:

Partner	Work Package	Components	Demo	Component ID	KPI	Criteria	Measurable Outcome	Objective
ACORDE	WP3	Customized platform solution for the Indoor Positioning System	COMP01	WP3-15_1	Ease of HW/SW integration (Number of parameters, Number of mechanical elements, Number of lines of code)	SC1.1	MO1.1	O1
					Ease of HW/SW configuration (Time spent for configuration, Number of user interactions)	SC1.1	MO1.3	O1
ACORDE	WP4	Anchor&Tag firmware of the Indoor Positioning System	COMP02	WP4-17		SC2.1	MO2.1	O2

ACORDE	WP5	Robust and Enriched Communication for Indoor Positioning System	COMP03	WP5-19-ACO	Robust Communication (Ratio of success/lost messages)	SC3.1	MO3.2	O3
CATEC	WP4	Indoor intelligent navigation	COMP04	WP3-30		SC2.1	MO2.1	O2

Table 40 UC2 D2 List of <components

6.6 Tools

Main tool that allows enabling different characteristics of the components for the demonstrator 2 are listed below.

- **TOOL1 WP6-21 – Indoor Positioning System Modelling&Analysis Framework (IPS-MAF)**

The Indoor Positioning System Model&Analysis Framework (IPS MAF) enables the modelling of an IPS and the high-level analysis of main aspects impacting on the performance of the positioning solution. In this demo, IPS-MAF is being used to design the most cost-effective deployment able to fulfil position requirements, and moreover, to test and select the positioning algorithms employed on the task and on the anchors. IPS-MAF supports the description of the infrastructure and the deployment of the anchors to perform a static analysis of the Dilution of Precision (DOP) within the infrastructure (a main parameter impacting position accuracy). It also supports the modelling of the tag and of the anchor behaviours and the analysis of its impact on the estimated position. Specifically, the high-level trilateration algorithms employed by the anchors for its automatic geo-positioning, and also the positioning algorithm of the tag can be modelled. As well as the deployment and the tag/anchor algorithms, high-level modelling of lower-level aspects, such as the impact of sensor sensibilities, ranging accuracies, type of medium access protocols employed are in the scope of the tool.

Next table show the relationship between the component and the main requirements defined in the WP6. It is also related with the objectives of the project and the main measurements outcomes expected and criteria.

Partner	Work Package	Components	Tool number	Requirements	Criteria	Measurable Outcome	Objective
ACORDE	WP6	Indoor Positioning System Model & Analysis Framework	TOOL01 WP6-21	UC2-DEM2-DTC-68 UC2-DEM2-DTC-69 UC2-DEM2-DTC-70 UC2-DEM2-DTC-71 UC2-DEM2-DTC-72 UC2-DEM2-DTC-73 UC2-DEM2-DTC-74 UC2-DEM2-DTC-75 UC2-DEM2-DTC-76	SC4.1	MO4.3	O4

Table 41 UC2 D2 List of Tools

6.7 Traceability matrices

6.7.1. Requirements vs. functionalities

The table below links all the requirements identified in this demonstrator (both from D1.2 and this deliverable) to the main functionalities defined:

Requirement	Short description	FUNC 1	FUNC2	FUNC 3	FUNC 4	FUNC 5	FUNC 6	FUNC 7	FUNC 8
UC2-DEM2-FUN-01	Autonomous drone operation		X		X	X			
UC2-DEM2-FUN-02	Data captured			X			X		
UC2-DEM2-FUN-03	Operation monitoring								
UC2-DEM2-FUN-04	Point cloud			X				X	X
UC2-DEM2-FUN-05	GNSS unavailability				X				
UC2-DEM2-FUN-06	Low visibility			X					
UC2-DEM2-FUN-07	Humidity and dust	X							
UC2-DEM2-FUN-08	Obstacle detection					X			
UC2-DEM2-FUN-09	Obstacle avoidance					X			
UC2-DEM2-FUN-10	Indoor Positioning								X
UC2-DEM2-INT-01	Indoor positioning system interface								X
UC2-DEM2-PRF-01	Indoor positioning system accuracy								X
UC2-DEM2-PRF-02	Indoor positioning system cost								X
UC2-DEM2-PRF-03	Flying time	X							
UC2-DEM2-PRF-04	Indoor data capturing per flight			X	X				
UC2-DEM2-PRF-05	Storage capacity						X		
UC2-DEM2-PRF-06	Volumetric measures							X	
UC2-DEM2-SEC-01	Distributed log and history data set						X		
UC2-DEM2-SEC-02	Secure communications	X							
UC2-DEM2-SEC-03	Vulterability detection	X							
UC2-DEM2-OPE-01	Indoor positioning for autonomous navigation			X	X				X
UC2-DEM2-OPE-02	Indoor positioning for safe navigation			X	X				XX
UC2-DEM2-OPE-03	Indoor positioning resilience with obstacles					X			X
UC2-DEM2-OPE-04	Indoor positioning accuracy for routes					X			X

	avoiding obstacles with known position								
UC2-DEM2-USA-01	Indoor positioning system usability				X				X
UC2-DEM2-USA-02	Maintenance	X							
UC2-DEM2-USA-03	Weight	X							
UC2-DEM2-DR-01	Sensors integration	X							
UC2-DEM2-DR-02	Sensors accuracy				X				
UC2-DEM2-DR-03	Automatic flight				X	X			
UC2-DEM2-DR-04	Waypoints		X		X				
UC2-DEM2-DR-05	Navigation conditions				X				

Table 42 UC2 D2 Requirements and functionalities traceability matrix

6.7.2. Functionalities vs. Components

The table below links all the components that are part of this demonstrator to the main defined functionalities:

FUNCTIONALITY	Short description	COM	COMP	COMP	COMP
UC2 - D1-FUN - 01	UAV platform	X	X	X	X
FUN - 02	Mission plan logger with specialized waypoint set				X
FUN - 03	LIDAR for data gathering				X
FUN - 04	Autonomous indoor navigation system				X
FUN - 05	Autonomous detection and avoidance of obstacle while flying				X
FUN - 06	Data logger				X
FUN - 07	Specialized software for point-cloud creation				X
FUN - 08	Indoor Positioning	X	X	X	

Table 43 UC2 D2 Components and functionalities traceability matrix

6.8 Validation plan

6.8.1. Components Verification

The verification and validation plan for the all the components related with de demonstrator for the underground infrastructure digitalization is explained in the next tables. All of the process is mainly related with one of the biggest challenges of the demonstrator that is the indoor navigation.

- **COMP01 – WP3-15_1 - Customized platform solution for the Indoor Positioning System**

Previous test requirements	• Electrical Lab tests with Evaluation Kit • Evaluation of performance of evaluation kit • Design&Manufacturing of 2 or more anchor platforms • Design&Manufacturing of 1 tag platforms
Test description	• Electrical tests with the real anchor and tag platforms • Communication tests between nodes (anchor-anchor, anchor-tag)

Planned inputs	• Tags Configuration, Anchor configuration • Test firmware
Expected results	• Anchors&Tag platforms working in the nominal source voltages. • Anchors&Tag platforms properly working (communication interfaces properly working, on expected communication range) • Anchors&Tag platforms power consumption under design bounds.

- **COMP02 – WP4-17 - Anchor&Tag firmware of the Indoor Positioning System**

Previous test requirements	• *Algorith*m implementation of tags and anchors (for simulation-based test) • IPS-MAF tool (for simulation-based tests) • Physical implementation of system (tags and anchors). It includes anchor and tag platforms and their firmware. • Logger system
Test description	• Simulation-based validation of anchors and tag algorithms • Validation of the physical implementation of the indoor positioning system (IPS) with final anchors and tag firmware, on a deployment in a controlled environment
Planned inputs	• For simulation-based validation: deployment description, infrastructure description, tag mechanical model (trajectory) • For validation over the physical platform: anchor and tags configuration, test definition (tag flight description), • Reference positioning data for the anchors
Expected results	• Logs with the position – time information • Reference positioning data for the anchors (on the validation over physical implementation)

- **COMP03 – WP5-19-ACO - Robust and Enriched Communication for Indoor Positioning System**

Previous test requirements	• Electrical Lab tests with Evaluation Kit • Evaluation of performance of evaluation kit • Design&Manufacturing of 2 or more anchor platforms • Design&Manufacturing of 1 tag platforms • Logger system • Set of antennas, cables • Mechanical set-ups, fixing items, holders, • Enhanced ranging protocol implemented for both anchors and tags.
Test description	• Test the configuration of the radio layer • Test the implementation of the novel medium access control (MAC) layer designed by ACORDE (Robust) • Test of feasibility of enriched ranging protocol (ranging layer) upon the MAC layer (depending of the effective capacity of MAC layer). • Test antenna configurations
Planned inputs	*Specific test firmware and logging*
Expected results	• It is possible to operate with different radio parameters (channel, preamble, size, etc).

	• It is possible to configure the ranging frequency (1-10Hz). • Measurements of packet loss • Assessment of feasibility of enriched ranging protocol and involved accuracy enhancement. • Assessment of better antenna configuration

- **COMP04 – WP3-30 - Indoor intelligent navigation**

The component 4 is univocally associated to Functionality 04 described, so this validation plan explained in next chapter is applicable to the component.

6.8.2. System Functionalities Verification

At a higher level than the components, the main functionalities of the demonstrator must be validated in order to ensure that the final system will be able to meet the objectives. Compliance with the functionality, in turn, will ensure the validation of the requirements associated with each of them.

Next tables summarized the main functionalities that must be verified in order to ensure that the objectives of the demonstrators are obtained. Moreover, one of the functionalities is not listed below because is achieved with the validation of the components developed.

UC2 – D2 - FUN01 - UAV platform

Environment	Goal	Output
Laboratory	Correct and robust integration of the system within the UAV platform First flight of the overall integrated system	Report and acceptance of the UAV and systems integration Telemetry of the first flight in the laboratory to be analysed.
Outdoor controlled	The UAV performs an autonomous flight of the UAV with real outdoor conditions. LIDAR takes proper data and the UAV detect and avoid obstacles.	Telemetry of the flight
Realistic	The UAV follows the defined mission and complete it, detecting and avoiding any unexpected obstacle.	Telemetry of the flight

UC2 – D2 - FUN02- LIDAR for data gathering

Environment	Goal	Output
Laboratory	Correct integration of the LIDAR in the UAV airframe	Acceptance of the integration by the technical manager.
Outdoor controlled	Successful performance of the LIDAR in expected similar real conditions (temperature, wind, lighting…)	Map created from the points taken by the LIDAR to be analysed in expected similar real conditions.
Realistic	The LIDAR works as expected in a real scenario.	Point-cloud o the environment in which the aircraft has flown.

UC2 – D2 - FUN03- Mission plan logger with specialized waypoint set

Environment	Goal	Output
Laboratory	A mission can be logged on-board	Post mission log to be match with the designed mission
Outdoor controlled	A mission can be logged on-board. The system works properly in normal temperature conditions	Post mission log to be match with the designed mission
Realistic	A mission can be logged on-board, and the UAV performs it as designed.	Post mission log to be match with the designed mission

UC2 – D2 - FUN04- Autonomous indoor navigation system

Environment	Goal	Output
Laboratory	The system works properly, including navigation sensors, sensor fusion modules, signals to actuators, etc.	Telemetry to be analysed afterwards
Outdoor controlled	The navigation system responds properly in real indoor conditions, i.e., low lighting conditions, no GNSS signal available. The mission will push the system to its boundaries.	Telemetry to be analysed afterwards
Realistic	Autonomous flying in a real scenario and environment	Telemetry to be analysed afterwards

UC2 – D2 - FUN05 - Autonomous detection and avoidance of obstacle while flying.

Environment	Goal	Output
Laboratory	Fully autonomous detection and avoidance of obstacles. The avoidance of the obstacles will incorporate the real-time re-planning of the trajectories or, at least, the system will stop once an obstacle is detected.	Telemetry to be analysed afterwards, including the detection sensors data gathered
Outdoor controlled	Fully autonomous detection and avoidance of obstacles, using mock-ups, installed for the purpose of the tests. The avoidance of the obstacles will incorporate the real-time re-planning of the trajectories. Flying tests will be performed in indoor environments to validate this functionality (although for logistics reasons the environment will be less complex than in the case of the laboratory environment).	Telemetry to be analysed afterwards, including the detection sensors data gathered
Realistic	During the inspection of the tunnel, the detection and avoidance system will be activated. In case of an obstacle is detected, the UAV will re-plan the initial trajectory or it will stop and notify the GCS to the unexpected problem.	Telemetry to be analysed afterwards, including the detection sensors data gathered

UC2 – D2 - FUN06 - Data logger

Environment	Goal	Output
Laboratory	The capacity of the system matches the specified one, as well as the velocity of logging of the system.	Files filled, according to the system's capacity
Outdoor controlled	Correct performance of the logger in real conditions (wind, temperature, drone speed, etc.)	Files to be loaded in a computer for further analysis
Realistic	Correct performance of the logger in real scenario	Files to be loaded in a computer for further analysis

UC2 – D2 - FUN08 -Indoor Positioning

Environment	Goal	Output
Laboratory	• Proper optimal deployment and algorithms development. • Medium access control and ranging protocols developed/selected have proper performance. • Electrical Validation of Anchor&Tag Platforms	• Simulations endorsing performance for selected deployment and algorithms. • Simulations for MAC and ranging protocols. • Data measured in lab on electrical behaviour of platforms.
Controlled	• Measure range accuracies and robustness on the underlying communication protocol. • Assess positioning accuracy on different controlled scenarios (with/without obstacles, with/without failure of anchors) in lab scaled-down scenarios, with the possibility to add outdoor scenarios for accurate realistic reference on dynamic conditions.	• Reference Rage data Measurements (e.g. laser) For each tested scenario: • Data logs with range data • Data logs with output estimated position • Reference data
Realistic	• Validate positioning performance accuracy of IPS with tag mounted on drone, with actual drone dynamics on indoor tunnel scenario.	• Data logs with estimated position and range data. • Reference data • Position accuracy assessment

6.8.3. System Validation

To perform the system validation a set of flights will be done inside the tunnel. There have been defined two main data acquisition campaigns. In the first, correct operation will be verified and in the second, the necessary optimizations will be made to ensure compliance with the KPIs. Next table summarized the main verification methods and campaigns tests.

KPI	Definition and measurement of Indicator	Description and enhancements	Verification Method	Campaign tests
Project construction using Virtual Construction Technology (BIM)	Monitoring of the work progress in real time,	Measurement deviations < 10%	Generation of a 3D model of work progress in continuous flight along the flight path. The deviation will be verified with the comparison of topography bases and control points.	Set of flights inside the tunnel. 2 data acquisition campaigns will be carried out.
Self-Recognition of work elements through AI	Auto-detection of main work elements through point cloud.	Accuracy less than 20cm	Carry out flight campaigns to recognize simple elements (targets, spheres ...) that have previously been georeferenced by means of conventional topography.	Carry out a comparison of the real positions measured in the field with the post-processed images after the flights.
Position available at the tunnel to enable autonomous, way point based fly of the drone.	Position integrity for all the flight areas of the drone defined for the indoor facilities, with enough accuracy	Position error (CEP) <30cm in significant drone trajectories, <50cm in all the indoor infrastructure.	Using the initial card (applanix plate) to compare the autonomous path with the actual path stored on the plate.	Set of flights inside the tunnel. 2 data acquisition campaigns will be carried out.
Autonomous navigation inside the tunnel.	The drone is able to fly autonomously along a tunnel capturing data and avoiding collisions with the obstacles.	90% of flight mission of the drone is done autonomously	Perform a flight with a known trajectory by using waypoints. These waypoints are established as coordinates relative to two successive emission nodes. Carrying out the triangulation with the nodes, we establish the position of the aircraft within the tunnel.	Placement of nodes inside the tunnel and flight between nodes.

Table 44 UC1 D2 System validation plan

7 UC3-Demo1 Logistics:

7.1 Current state of the technology

Seismic acquisitions objective is to build a precise and reliable image of the earth underground at kilometric scales to identify or monitor hydrocarbon prospects.

Among other features, land acquisition involves planting thousands of seismic sensors on the ground, with a spatial sampling (at least in one dimension) of some 10’s of meters over several 10’s of square kilometres. In easy to access area this triggers very significant efforts, but in hard to access areas the associated logistic tends to become hardly tractable and involves very high costs, HSE risks and potential environmental footprints.

One of the most emblematic examples is the Papua-New Guinea foothills area, where a dense forest and severe slopes make human progression very complex, slow and hazardous. Moreover, the opening of necessary corridors across the forest is detrimental from the environmental point of view.

Despite those inconvenient, human work for the sensor dispatch is currently the only option available. This in turn involves transportation of material and security elements by helicopter to be dispatched at selected areas previously prepared to accommodate this logistics. Also, in terms of HSE, emergency procedures and not straightforward to conduct, for example in case of injuries.

Several steps are necessary to deploy such a complex operation, and it usually expands over several months. Depending on the steps, 500 persons or more can be simultaneously working on the field, HSE and logistics shall accommodate those specificities. On the global scale the budget size of such operation amounts for several tens of million dollars.

Other areas, such as oil field in the desert can also be problematic for seismic acquisition. Indeed, they are constrained by existing installations (pipes, buildings...) and human progress across high dunes can be slow and inefficient.

For those reasons, Total developed the METIS project where the abovementioned logistic constraints are lower by deploying the acquisition devices from the air, through the use of a fleet of drones.

Using an unmanned deployment system allows to significantly reduce the number of people on the field and therefore to reduce the operational risks associated with human operations in harsh environments.

Dropping systems for sensor deployment also allows simplification in the ground preparation and contributes to the reduction of environmental footprint of such operation.

Altogether with a reduction of personal on the field and improvement of deployment efficiency, a UAV based system is expected to reduce turnaround and budget of this type of acquisitions

In the domain of fleet operations, Scalian has improved the existing system, increasing its reliability. The first successful dropping operation has been conducted with 5 dropping UAVs and a surveillance UAV. The fleet was able to drop around a hundred sensors. The operations were completely autonomous, pilots were present only for legal reasons and never had to take control.

The fleet system allows the UAVs to share their knowledge: their status, their progress on the mission and safety information (e.g. presence of intruders). The UAVs are able to plan optimal flight path taking into account the others’ flight plan and while respecting the geocage and geofences (both static and dynamic).

Figure 11 Fleet ready for take-off.

The system has carried out the complete mission while relying on 4G LTE communications, there is still work to do on communications to achieve the Comp4Drones objectives.

Finally, the clearance and precision landing components have been implemented are in a fine-tuning phase. They can be embedded but need improvement of their respective precision.

The current version of the GCS enables the monitoring of 10 Dropping UASs and 1 Surveillance UAS simultaneously with a crew of two operators, one for the fleet management and another for the dropping phase management. It is composed of a ruggedized, two 4K screens and a dedicated interface to allow the drop of DARTs.

Figure 12: UC3 demo 1 GCS current state of the art

The main modifications that are expected for the new GCS are:

- Scale up the solution to the management of more drone,
- Allow the management of heterogeneous types of agents (rolling, flying, floating),
- Allow the remote work of the operators.

7.2 Use Case Concept of Operation

UC3 demo 1 consists in dropping seismic sensors automatically from a fleet of UAS for geophysics operations including oil exploration, volcanology, or mining. Typically, the sensors will be deployed every 50 m, in other words 400 sensors per km².

The system for UC3 demo 1 operations can cover wide areas of ground from 1km^2 to more than 100km^2. Due to the current architecture and equipment limitation, the operations are divided into missions centered on a GCS Base which is moved to a new location once a mission has been completed. The demo itself will be limited to a small surface of few hundreds square meters, and around a hundred sensors, due to area availability limitations.

7.2.1. Description of the system components

The system deployed by the UC3 demo 1 can be described by the picture below:

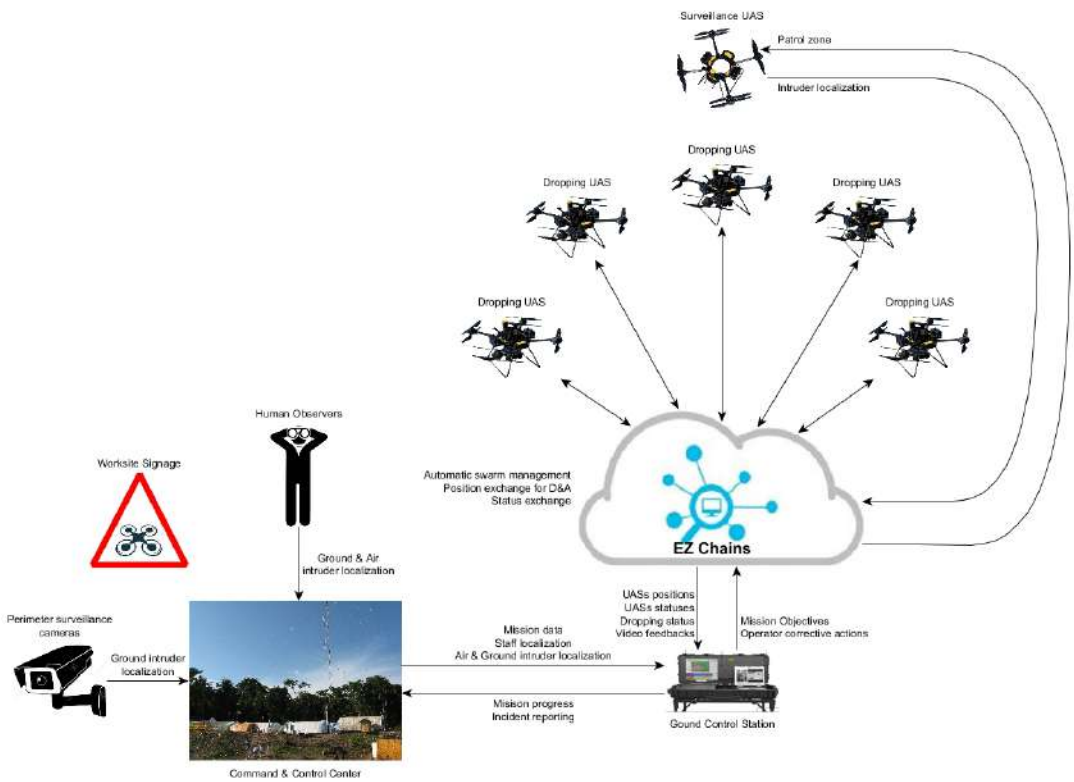


Figure 13: UC3 demo 1 system description

It is composed of:

- 5 UASs (but it may go up to 10 UASs) flying as a cooperative fleet, each with a "cassette" (containing the DART sensors) and referred hereafter as "Dropping UAS" or "dropper".
- A UAS dedicated to the detection of intruders in the zones where each Dropping UAS is going to drop a DART referred hereafter as "Surveillance UAS".
- A flight management system called EZ Chain that determines in real time the trajectory of each UAS and takes into account geo-fencing and avoidance of other stakeholders (other UASs, staff, vehicles or intruders).
- A single Ground Control Station monitoring all UASs.

- A C&C Camp where the Command & Control Center is managing operations

7.2.2. Level of automation

One of the aims of the METIS project is to automate the dropping operations as much as possible. The global philosophy of the system is to automate all operations, including automatic responses for abnormal situations. Nonetheless, human is kept in the loop to detect abnormal situations and monitor the system behaviour.

In particular, the following functions will be automated:

- Flight phases:
  - Take-off.
  - Landing.
  - Flight and dropping operations.
  - Avoidance manoeuvre:
    - Of other UAS in the fleet,
    - Of geofenced areas,
    - Of vehicles and humans that are geofenced.
- UAS state monitoring:
  - Communication loss:
    - With the GCS.
    - With the remote controller.
  - Low level of batteries and reaction activities.
  - GPS loss.
  - Engine failure.

On the contrary, the following functions will be performed by humans:

- Interface with the local authorities (RSES-D and Party Chief).
- Interface with local air traffic (by the GCS Manager).
- Input of the mission data (by the Mission Superintendent via the Command and Control).
- Monitoring of the UAS fleet behaviour (by the GCS Manager).
- Modification of the UAS fleet behaviour in case of problem (by the GCS Manager).
- UAS control take-over in case of unexpected behaviour (by the team of UAS Pilots).
- Termination of the flight if a UAS is out of control (by either the Ground Control Station Manager or the team of UAS Pilots, termination order is such that it will start at the first request)

Only the decision to drop a DART will be done by combining automation and human decision. The reason is that although one of the objectives of the system is to test automation of missions, the automatic detection of humans by camera has not been judged mature enough for the moment. We choose to complete it with human counter checks to be certain of the reliability of the system.

Note: all operations are done under BVLOS conditions.

7.3 System Requirements, KPI´s and Metrics

7.3.1. Technical KPI`s and Metrics

Business KPIs

KPI ID	Description	Goal	Metrics
UC3-D1-KPI-1	Reduce the durations of operations in dense forests.	3 times faster to complete operations.	Operations at equivalent cost: • Time to prepare the operations • Time to operate on daily basis • Time to store system and stop operations • Total time to complete operations
UC3-D1-KPI-2	Reduce the environmental footprint of operations in dense forests.	10 times less ground surface alterations to carry out operations, CO2 emissions and waste production.	Operations at equivalent cost: • Surface (in m²) altered by the operations: measure impact on a scale, estimate recovery time
UC3-D1-KPI-3	Be competitive for operations in accessible locations.	Equivalent duration and/or workload and/or cost than human based solutions.	Operations with equivalent results: • Cost in human resources • Time necessary to complete operations

Table 45 - UC3 D1: Business KPIs

Technical KPIs

KPI ID	Description	Goal	Metrics
UC3-D1-KPI-4	Reduction of lost-time injuries, impact with infrastructures and airspace disturbances per hour of operations.	Less than 10^{-6}.	Demonstration through SORA process.
UC3-D1-KPI-5	Allow to operate the system easily and worldwide.	System compatible with transport, local constraints (temperature, humidity) and local authorities.	Measure time to obtain permit-to-fly. Number of countries where system can operate

Table 46 - UC3 D1: Technical KPIs

7.3.2. Main requirements (functional, interface, performance, security, usability…)

Requirement ID	Short Description	Description	Priority	Source	KPI
UC3-OPR-002	Worldwide operations	It shall be possible to transport the system via container	L	Total	UC3-D1-KPI-5
UC3-FNC-002	Safe dropping	The dropping agents shall ensure, with a dedicated software, the clearance of a drop location before dropping a sensor.	H	Total	UC3-D1-KPI-4
UC3-FNC-003	Human validation for drops	If the fleet manager has enabled dropping operations, when a dropping agent has ensured the clearance of the dropping point, it will automatically drop without any further human validation.	H	Total	UC3-D1-KPI-4
UC3-FNC-008	Clearance logging	The clearance algorithm shall log: the video frames used, the decision and bounding boxes. This shall be used to do post-mission performance analysis.	M	Scalian	UC3-D1-KPI-4
UC3-FNC-009	Clearance training	The clearance algorithm may have to be trained for a particular region of the world, or type of background.	L	Scalian	UC3-D1-KPI-4
UC3-PRF-004	Precision landing	An UAV agent shall land precisely on its helipad, within a 50 cm radius to the target position even with a bad GPS signal.	H	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-FNC-010	External positioning system	An UAV agent shall use a dedicated external positioning system giving it its position relative to the dronepad. This system must be attached to the dronepad	M	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-FNC-011	Precision landing technology	The landing positioning system can be based on radar or infra-red-beacon technologies.	L	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-FNC-012	Precision landing interferences	The landing positioning system of a particular UAV shall not interfere with the landing positioning system of the other UAVs.	M	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-PRF-005	Precision landing conditions	The landing positioning system shall be able to provide the UAV with its position when the UAV is	L	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3

		located on a 10m-radius disc at 20m altitude above the dronepad.			
UC3-INT-004	Safe communications	The communication link shall be secure to prevent cyber-attacks.	M	Scalian	UC3-D1-KPI-4
UC3-INT-005	Agent identification	The agents shall be uniquely identified in the communication link so that an attacker trying to communicate would not be taken into account.	L	Scalian	UC3-D1-KPI-4
UC3-INT-006	Message encryption	The messages exchanged in the communication link shall be encrypted so that a Man-in-the-middle attack can be either prevented or detected.	L	Scalian	UC3-D1-KPI-4
UC3-FNC-017	Cyber-defense	The system shall integrate safety procedures when a cyber-attack is detected. (e.g. UAV return to their dronepads.)	L	Scalian	UC3-D1-KPI-4
UC3-INT-008	KB Update	The mobile agents shall be able to update their status (current action and position) to the shared knowledge base periodically.	M	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-FNC-023	Navigation planning based on KB	The mobile agents (UAV and UGV) shall be able to plan their navigation and decisions based on the knowledge base.	H	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-FNC-024	Adapted monitoring services	The GCS shall provide different services for Flight Managers responsible for the airspace management and the Operation Managers responsible for the correct handling of the agents payloads.	H	Altran	UC3-D1-KPI-4
UC3-USB-001	Monitoring workload allocation	The GCS shall allocate to a given Flight Manager a given airspace volume.	M	Altran	UC3-D1-KPI-4
UC3-USB-002	Monitoring workload definition	The airspace volume allocated to a Flight Manager or Operation Manager by the GCS shall be sized taking into account the maximum volume of information a human can handle.	M	Altran	UC3-D1-KPI-4
UC3-USB-003	Monitoring workload backup	The GCS shall modify airspace allocation when a Flight Manager or Operation Manager becomes unavailable.	M	Altran	UC3-D1-KPI-4
UC3-FNC-027	Deconfliction warnings	The GCS shall display warning messages to a given airspace	H	Altran	UC3-D1-KPI-4

		Flight Manager about the conflicts and unauthorized behaviours it has detected.			
UC3-FNC-028	GCS data recorder	The GCS shall be able to record data exchanged between itself and the agents and system of agents.	M	Altran	UC3-D1-KPI-4
UC3-FNC-029	GCS voice recorder	The GCS shall be able to record the verbal exchanges between the Flight Managers and the agents or system of agents pilots.	M	Altran	UC3-D1-KPI-4
UC3-USB-004	GCS authentication procedure	The GCS handover of an airspace to a Flight Manager or Operation Manager shall have verification and authentication procedure.	L	Altran	UC3-D1-KPI-4

Table 47 UC3 D1 List of Main Requirements

7.3.3. Drone integration requirements

Requirement ID	Description	Priority	Source	KPI
UC3-INT-002	The dropper agents shall allow to change its payload (for refill) without requiring a software reboot.	L	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-FNC-005	The clearance algorithm shall rely on visual camera.	H	Scalian	UC3-D1-KPI-4
UC3-FNC-006	The clearance algorithm should be able to use thermal camera.	L	Scalian	UC3-D1-KPI-4
UC3-FNC-007	If the clearance algorithm can use thermal camera, it should combine and correlate the two inputs: visual and thermal.	L	Scalian	UC3-D1-KPI-4
UC3-PRF-002	The clearance algorithm shall run on an embedded computer inside the UAVs. It shall not impact the capability of the UAVs to operate their mission.	M	Scalian	UC3-D1-KPI-4
UC3-PRF-003	The clearance algorithm shall take its decision in less than 10s. During this time, it can integrate its decision over time.	H	Scalian	UC3-D1-KPI-4
UC3-FNC-013	An UAV agent shall use a computer vision to land precisely: it should descend with a close-loop controlling its position to the dronepad during the descent and adjust it.	M	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-PRF-006	The landing vision algorithm shall be able to detect the dronepad when the UAV is near the vertical above the dronepad and up to 20m in height.	M	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3

UC3-FNC-014	The landing vision algorithm may rely on visual cues placed on the dronepad to allow its detection. The algorithm shall be able to detect the orientation of the UAV compared to the dronepad.	L	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
UC3-FNC-016	The clearance algorithm shall be capable of working during take-off and landing phases.	M	Scalian	UC3-D1-KPI-4
UC3-FNC-019	The UAV agents shall be able to land precisely even without the communication system, relying on the vision algorithm and the landing positioning system.	M	Total	UC3-D1-KPI-4
UC3-FNC-025	The GCS shall detect trajectory conflicts between different agents	H	Altran	UC3-D1-KPI-4
UC3-FNC-026	The GCS shall detect unauthorized behaviour by any of the handled agents	H	Altran	UC3-D1-KPI-4
UC3-DSG-004	The system shall maintain a temperature inside its hull that allows its electronics to properly function.	H	Total	UC3-D1-KPI-5
UC3-FNC-032	The UAV should resist to aggressive flight conditions	L	Scalian	UC3-D1-KPI-4
UC3-FNC-033	The stabilization block should be activated only in non-nominal conditions	L	Scalian	UC3-D1-KPI-4

Table 48 UC3 D1 List of Drone Integration Requirements

7.3.4. Regulatory requirements

Requirements related with SORA analysis (Reference to the methodology in D2.5.)

Requirement ID	Short Description	Priority (H/M/L)	Source	Success Criteria, KPI´s or metrics
UC3-P&E-001	The clearance algorithm shall be compliant with the local regulations on personal data. It may involve to blur faces onboard.	H	Scalian	UC3-D1-KPI-4
UC3-FNC-030	The GCS shall allow Flight Managers to check that the agents or systems of agent's usage of the airspace is compliant with U-Space and their declared mission.	H	Altran	UC3-D1-KPI-4

Table 49 UC3 D1 List of Regulatory Requirements

7.4 Functionalities identification

ID	Functionality	Description	System function
UC3-D1-FUN-01	Fleet operations	A generic embedded architecture that controls UAVs to allow them to work cooperatively	2.5.2 Swarm formation and cooperation
UC3-D1-FUN-02	Shared knowledge	A mean to share the knowledge between the UAVs in the fleet and also with the GCS	2.5.2 Swarm formation and cooperation
UC3-D1-FUN-03	Tactical anti-collision and watchdog	A system that allow UAVs to declare their flight plan, and compute their trajectory according to others' flight plan preventing collisions. The GCS has a watchdog to detect any incoming conflict to trigger emergency operations	2.2.6 Deconfliction
UC3-D1-FUN-04	Dynamic geofences and watchdog	A system to forbid certain flight areas, preventing UAVs to enter them. The dynamic aspect should allow the geofences to move (e.g. following a vehicle or operator for safe operations). The GCS has a watchdog to ensure enforcement of the geofences	2.3.2 Geofencing
UC3-D1-FUN-05	Safe precision landing	The UAVs must land precisely on their pad to allow easier operations for the operators performing the reloading. It must be safe by detecting humans near the pad, to prevent landing on operators.	2.2.2 Landing
UC3-D1-FUN-06	Safe dropping – clearance	The UAVS, when dropping, must first ensure that the drop zone is free from human, animals or vehicle to prevent any damage during operations	3.1.2 Passive Optical
UC3-D1-FUN-07	Safe communications	The communications required by the shared knowledge (UC3-D1-FUN-02) must be safe and secure. Any intrusion or failure could make operations dangerous.	2.6 Communication
UC3-D1-FUN-08	GCS external communication	The GCS operators communicate with ATM, UTM, agent pilots and agent operators.	1.1.5 Communication, Navigation and Surveillance
UC3-D1-FUN-09	GCS monitoring extent	The GCS operators can send orders to agents (automated or piloted), including but not limited to, entry access validation, mission pause, re-	1.1.6 Command and control

		routing, emergency landing, payload blocking.	
UC3-D1- FUN-10	GCS main display	The agents planned trajectory and separation volume are represented on the GCS	1.3.3 Detect and Avoid
UC3-D1-FUN-11	Worksharing management	In case of interface failure or operator leave, impacted workload is automatically transferred to other operators	2.2.4 Fail-safe Mission
UC3-D1-FUN-12	GCS alarm display	Conflicts, agent caused or payload caused, trigger alarms on the GCS	2.2.6 Deconfliction
UC3-D1-FUN-13	Heterogeneous management	The GCS allows operators to manages any type of agents connected to it as well as their payloads	2.5.1 Drone and Rover
UC3-D1-FUN-14	GCS monitoring consistency	Swarm of agents are tracked by a single GCS operator at a time and the swarm is identified as such.	2.5.2 Swarm formation and cooperation

Table 50 UC3 D1 List of Functionalities

7.5 Components

This section describes the components in the use case that allow to implement the functionalities listed in the previous section. The descriptions are short, for more details see the appropriate technical workpackage.

- **COMPONENT WP4-6 – GCS**

Altran has developed a concept for heterogeneous fleet of agents (sea, ground air) monitoring. It allows to monitor any number of agents with their payload as long as there is enough operator. Worksharing is automated and focuses on different topics: traffic management and its safety, payload use and its respect of safety (delivery cases) and privacy (filming cases).

This component is operation agnostic and can connect to any type of agent as long as it can exchange using a common protocol. It can be used either for complex mission monitoring (like METIS) or traffic management over cities.

- **COMPONENT WP3-16_1 – Generic Mission Controller**

Scalian has developed a generic architecture for UAVs. The main goal of this architecture is to allow a fleet of UAVs to cooperate when achieving missions. The architecture comprises all the required functionalities to sense, plan and act. This component improves the genericity and robustness of the planning and acting phase.

The development will allow new types of missions, and should allow new types of agents. This component should be able to control and use new components: it should allow to integrate work for partners proving its genericity.

- **COMPONENT WP3-16-2 – Knowledge Base**

Scalian has developed an architecture for a fleet of UAVs (see above), in order to allow coordination, they need to share their knowledge on the mission status, their individual progress, their position, their status and their planned trajectory (reserved air-space). Considering that the architecture will be improved to allow controlling new types of mission it is necessary to also improve the Knowledge base accordingly. Additionally, new types of agents should be integrated in the system (UGV, weather station …) each of which must connect and report to the KB. Hence it is mandatory to enhance it with new agent models.

- **COMPONENT WP4-2 – Precision Landing**

In order to carry out safe operations, Scalian is developing a component that will allow precision landing. This precision is necessary to reduce risks for UAVs operators (persons in charge of refuelling the UAV). This component must use several types of sensors to ensure that if one fails or is not precise enough due to the conditions (lighting …) the UAV still achieve precise landing.

This component should also connect to the clearance component (see below) in order to detect human operators when they are too close to the landing pad, thus stopping the landing phase.

- **COMPONENT WP4-5 – Clearance**

The UC3 demonstrator 1 aims at dropping sensors over large areas. One of the main focus of the operations is to be safe. In order to ensure that the dropping operations are safe, the UAVs have to verify that the drop points are clear of humans, animals and vehicles (the absence of infrastructure is guaranteed by the mission preparation).

This component, developed by Scalian, uses deep learning techniques to detect intruders and prevent the drop on that location. The challenge with this component is that it must offer a high reliability (it should never miss the detection of an intruder) while also being close to real-time and embedded on a UAV.

- **COMPONENT WP4-42 – AI Stabilization**

This component is not directly related with the demonstrator, it is part of Scalian R&D. Its goal is to do a premature study of the feasibility of using AI to stabilize UAVs. The long-term goal is to leverage AI capability to reinforce itself to increase reliability of UAV flight controllers. It will be demonstrated outside the scenarios of the demonstrator, but is taken into account in the architecture (mentioned above). Should the results be satisfactory at the end of the project, it might become a component in future implementations of the architecture.

- **COMPONENT WP5-03 – Safe fleet communication**

This component is developed by Scalian and is the backbone of its UAV-fleet architecture. Indeed, the UAVs, when cooperating on mission, require a reliable communication mean. In this case, reliable means both safe and secure: it must transfer all messages to prevent collision and issues in the system and it also must resist cyber-attack tentative.

This component is developed with two aspects: change the communication mean from private 4G LTE bubble to a new communication mean to allow easier deployment, but also the selection of an appropriate network architecture that support the usage: fast and reliable messages between the UAVs, and video feedback to the ground when required (high throughput).

Partner	Work Package	Component ID	Components	Demo	KPI	Criteria	Measurable Outcome	Objective
Altran	WP 4	WP4-6	GCS	DEMO5, DEMO6	Improve Safety, mission autonomy	SC2.1	MO2.1	O2
Scalian	WP 3	WP3-16_1	Generic Mission Controller	DEMO5	Improve system autonomy	SC1.2	MO1.1	O1
Scalian	WP 3	WP3-16_2	Knowledge base	DEMO5	Improve system autonomy	SC1.2	MO1.1	O1
Scalian	WP 4	WP4-2	Precision landing	DEMO5, DEMO6	Improve precision	SC2.2	MO2.1	O2
Scalian	WP 4	WP4-5	Clearance	DEMO5	Improve safety	SC2.2	MO2.1	O2
Scalian	WP 4	WP4-42	AI Stabilization	DEMO5	Improve reliability	SC2.2	MO2.1	O2
Scalian	WP 5	WP5-03	Safe fleet communication	DEMO5	Improve safety and security	SC3.1	MO3.1	O3

Table 51 UC3 D1 List of <components

7.6 Tools

Siemens provides a co-simulation framework relying on Simcenter Amesim and Simcenter Prescan. The former is a software tool dedicated to modelling and simulation of dynamic and multi-physics systems. It can effectively model and simulate the UAV energy storage, propulsion, and dynamics performance. The latter provides perception sensors (lidars, radars, cameras...) and environment modelling and simulation capabilities.

The co-simulation framework allows to create relatively high fidelity “plant” models that can effectively support the continuous development, testing, verification and validation of Guidance, Navigation, and Control algorithms. The framework and its methodology will provide the following contributions: reduction of the implementation (models integration) effort (UC3-DTC-62), reduction of the modelling effort (UC3-DTC-64, UC3-DTC-63), and reduction on verification efforts of GNC algorithm (UC3 – DTC -94).

Partner	Work Package	Components	Demo	WP6 Req.	Criteria	Measurable Outcome	Objective
Siemens	WP6	Modeling and simulation	UC3	**UC3-DTC-64**	SC4.1	MO4.3	O4

Table 52 UC3 D1 List of Tools

7.7 Traceability matrices

7.7.1. Requirements vs. functionalities

Requirement	Short description	FUN-01	FUN-02	FUN-03	FUN-04	FUN-05	FUN-06	FUN-07	FUN-08	FUN-09	FUN-10	FUN-11	FUN-12	FUN-13	FUN-14
UC3-OPR-002	Worldwide operations	X	X												
UC3-FNC-002	Safe dropping						X								
UC3-FNC-003	Human validation for drops						X								
UC3-FNC-008	Clearance logging						X								
UC3-FNC-009	Clearance training					X	X								
UC3-PRF-004	Precision landing					X									
UC3-FNC-010	External positioning system					X									
UC3-FNC-011	Precision landing technology					X									
UC3-FNC-012	Precision landing interferences					X									
UC3-PRF-005	Precision landing conditions					X									
UC3-INT-004	Safe communications							X							
UC3-INT-005	Agent identification							X							
UC3-INT-006	Message encryption							X							
UC3-FNC-017	Cyber-defense							X							
UC3-INT-008	KB Update	X	X					X							
UC3-FNC-023	Navigation planning based on KB	X	X	X	X										
UC3-FNC-024	Adapted monitoring services													X	

UC3-USB-001	Monitoring workload allocation									X					
UC3-USB-002	Monitoring workload definition											X			
UC3-USB-003	Monitoring workload backup														X
UC3-FNC-027	Deconfliction warnings										X		X		
UC3-FNC-028	GCS data recorder								X						
UC3-FNC-029	GCS voice recorder								X						
UC3-USB-004	GCS authentication procedure														X

Table 53 UC3 D1 Requirements and functionalities traceability matrix

7.7.2. Functionalities vs. Components

FUNCTIONALITY	Short description	COMP WP4-6	COMP WP3-16_1	COMP WP3-16_2	COMP WP4-2	COMP WP4-5	COMP WP4-42	COMP WP5-03
UC3-D1-FUN-01	Fleet operations		X					X
UC3-D1-FUN-02	Shared knowledge			X				
UC3-D1-FUN-03	Tactical anti-collision and watchdog		X	X				X
UC3-D1-FUN-04	Dynamic geofences and watchdog		X	X				
UC3-D1-FUN-05	Safe precision landing				X			
UC3-D1-FUN-06	Safe dropping – clearance					X		
UC3-D1-FUN-07	Safe communications							X
UC3-D1-FUN-08	GCS external communication	X						
UC3-D1-FUN-09	GCS monitoring extent	X						
UC3-D1- FUN-10	GCS main display	X						
UC3-D1-FUN-11	Worksharing management	X						
UC3-D1-FUN-12	GCS alarm display	X						
UC3-D1-FUN-13	Heterogeneous management	X						
UC3-D1-FUN-14	GCS monitoring consistency	X						

Table 54 UC3 D1 Components and functionalities traceability matrix

7.8 Validation plan

7.8.1. Components Verification

- **COMPONENT WP4-6 – GCS**

Test description	*Run in simulator with different type of agents and payloads. Test with multiple interfaces and operators. Vary the number of agents to test worksharing and simulate issues (intrusion, misuse...)*
Planned inputs	*Description of test missions*

Expected results	*Display clarity, workload management, connectivity between interface and web server*

- **COMPONENT WP3-16_1 – Generic Mission Controller**

Test description	*Run in simulator with different fleet size, different missions, and different agent types. Several tens or hundreds or hours of simulated missions.* *Followed by run on the real system, with 5 dropping UAVs and 1 surveillance UAV.*
Planned inputs	*Description of new mission and usages for UAV fleets.*
Expected results	*Demonstration of reliability and genericity.*

- **COMPONENT WP3-16_2 – Knowledge base**

This component will be demonstrated through the test of the Generic Mission Controller (COMPONENT WP3-16_1 above).

- **COMPONENT WP4-2 – Precision landing**

Test description	*Simulated flights then real flights. During real flights, try to have a variety of conditions: light reflection, low luminosity, wind …*
Planned inputs	*List of possible conditions to could impact the landing.*
Expected results	*Demonstration of both high precision (<15cm) and high reliability (no failure)*

- **COMPONENT WP4-5 – Clearance**

Test description	*Test with fake dropping operations, and intruders near the drop point in some cases (human operator, human intruders, animals and vehicles).*
Planned inputs	*Training video dataset in an environment close to the target operation field.*
Expected results	*Measure of precision, accuracy and recall to assess reliability and safety of the component.*

- **COMPONENT WP4-42 – AI Stabilization**

Test description	*Simulated flights, and if time allows it real flights. With variety of command: smooth flights, aggressive flights …*
Planned inputs	*Model for UAV dynamic.*
Expected results	*Measure of position, speed and acceleration control, allowing to estimate quality and reliability of the control command.*

- **COMPONENT WP5-03 – Safe fleet communication**

Test description	*Carry out usual operations with the new communication mean.*
Planned inputs	*Description of the network usage of a usual mission.*
Expected results	*Measure of network latencies, number of lost messages, and other network-oriented metrics.*

7.8.2. Functionalities Verification

UC3-D1-FUN-01 – Fleet operations

Environment	Goal	Output
Laboratory	Simulated missions, with 5 to 10 UAVs with different roles.	Demonstration of reliability: no software crash, predictable and stable behaviour of the UAVs,

		autonomy of the system when facing unexpected issues
Outdoor controlled	A dropping mission with 5 UAVs and a surveillance UAV, dropping over small area.	Same as above
Realistic	A dropping mission with 5 UAVs and a surveillance UAV, with real dropping operations over large area (>1km²). Real roll-out of operations.	Same as above. Measure of productivity and other aspects required to assess the business KPIs.

UC3-D1-FUN-02 – Shared knowledge

This functionality will be demonstrated though the test of the fleet operations (UC3-D1-FUN-01 above).

UC3-D1-FUN-03 – Tactical anti-collision and watchdog

Environment	Goal	Output
Laboratory	In addition to the tests described in UC3-D1-FUN01, specific tests will be created to demonstrate that the anti-collision watchdog trigger correctly when there is a collision risk due to a flight deviation.	Measure of trigger time for watchdog, measure of reliability of the anti-collision feature (measure of number of flight plan with collision risk)
Outdoor controlled	A UAV will fly in a controlled environment, during this flight a simulated UAV will create a collision risk.	Same as above.
Realistic	The controlled test will be enough to demonstrate this functionality. It is too much risk for real operations.	N/A

UC3-D1-FUN-04 – Dynamic geofences and watchdog

Environment	Goal	Output
Laboratory	In addition to the tests described in UC3-D1-FUN01, specific tests will be carried out where simulated object will move in the operation area. The corresponding dynamic geofence will be update.	Analysis of the behaviour of the UAVs with the moving dynamic geofence. Measure of the number of times UAVs enter geofences, duration of the intrusion, behaviour when fleeing the geofence.
Outdoor controlled	A controlled operation will be carried out, a simulated intruder will move its geofence in the operation area.	Same as above.
Realistic	During a real operation, an intruder (real or simulated) will be tracked and its geofence updated.	Same as above.

UC3-D1-FUN-05 – Safe precision landing

Environment	Goal	Output
Laboratory	Perform landing in a simulator	Measure precision (distance between target and final pose).
Outdoor controlled	In a controlled area perform several landings. In a particular case, trigger a modified landing phase, where the UAV thinks it is landing but is in fact stationary. In the meantime, an operator moves under the UAV.	Same as above. In the case where there is an intruder, verify that the landing phase is aborted.
Realistic	For the final demo, the algorithm will be used for the landing phases. No demonstration of intruder detection will be carried out for safety reasons.	Same as first.

UC3-D1-FUN-06 – Safe dropping – clearance

Environment	Goal	Output
Laboratory	The trained system will be tested on validation datasets.	Measure of precision, accuracy and recall.
Outdoor controlled	A dropping UAV with a dropping-sensor mock-up will perform fake dropping operations. Different types of intruders will be near some of the dropping points.	Same as above.
Realistic	During real operations, it is not expected to allow operators to be near the dropping points.	If a real intruder interrupts the operations, the logs will be analysed to verify that the clearance has detected the intruder.

UC3-D1-FUN-07 – Safe communications

Environment	Goal	Output
Laboratory	Demonstration of the different hypothesis and network architecture.	Measure of usual network metrics (throughput, delay, lost messages …)
Outdoor controlled	On a controlled mission, replace the current network configuration with the selected architecture.	Same as above. Measure of operational aspects: time to setup, complexity of setup …
Realistic	The final system has a private 4G LTE bubble to prevent any risk. The operations are too dangerous to allow real test of the new communication architecture.	N/A

UC3-D1-FUN-08 – GCS external communication

Environment	Goal	Output
Laboratory	Connect and test the GCS and its interfaces to the various communication means (link to external services for traffic management, intrusion, pilots, operators).	Successful integration of external communication means
Outdoor controlled	Repeat extract of previous test plan. Add test for physical components	No failed test
Realistic	Extract of previous test	No failed test

UC3-D1-FUN-09 – GCS monitoring extent

Environment	Goal	Output
Laboratory	Comprehensive testing of every command of the GCS operators (simulated).	Every command is taken into account and deliver the expected result
Outdoor controlled	Extract of previous test list (HITL).	No regression
Realistic	Extract of previous test list.	No regression

UC3-D1- FUN-10 – GCS main display

Environment	Goal	Output
Laboratory	Have the CGS used by various operators on several missions presenting a comprehensive list of use cases (simulation)	Report indicating the level of approval of the GCS display (average, dispersion, bocking points...)
Outdoor controlled	Check the interfaces tuning for outdoor use are correct	Same as above (but not limited to this function test plan)
Realistic	Repeat the most challenging use cases from laboratory tests (workload, alarm triggering).	Same as above (but not limited to this function test plan)

UC3-D1-FUN-11 – Worksharing management

Environment	Goal	Output
Laboratory	Simulate operation with large number of agents and several GCS managers. Modify the number of agents and GCS managers. Meanwhile, test each GCS manager workload by triggering various events	GCS managers confirms that the distributed workload is acceptable at all time.
Outdoor controlled	Same as above but include external source of disturbance (noise, light)	Same as above
Realistic	Same as above on a reduced set of missions	Same as above

UC3-D1-FUN-12 – GCS alarm display

Environment	Goal	Output
Laboratory	Same test plan as UC3-D1-FUN-09	Report on alarm efficiency (reaction time, filtering, classification...)
Outdoor controlled	Extract of test plan above with the addition of external source of disturbance (noise, light...)	Same as above (but not limited to this function test plan)
Realistic	Extract of test plan above	Same as above (but not limited to this function test plan)

UC3-D1-FUN-13 – Heterogeneous management

Environment	Goal	Output
Laboratory	Same test plan as UC3-D1-FUN-09	Report focusing on differences between agents and payloads (information, discrimination, specificities...)
Outdoor controlled	Non-regression	No difference
Realistic	Non-regressions	No difference

UC3-D1-FUN-14 – Display – clarity

Environment	Goal	Output
Laboratory	Same test plan as UC3-D1-FUN-09	Check that each time a swarm appears in a test, it is treated by a single operator
Outdoor controlled	Non-regression	No difference
Realistic	Non-regressions	No difference

7.8.3. System Validation

The verification strategy for the integrated demonstrator relies on an extended test campaign during which the system will conduct an **acquisition-sensors deployment mission** in a representative location.

A fleet of dropper drones, coordinated by a ground control station, will navigate over an easy-to-reach (*hard-to-reach for measuring set-up 3*) area delimited by geofences and drop batches of darts acting as acquisition-sensors.

These operations will not cover the acquisition and analysis of the data.

The ability of the demonstrator to answer its technical and business objectives will be assessed through different measuring set-ups and extrapolations:

Measuring set-up 1

Measuring set-up 1 will verify the main requirements identified (functional, interface, performance, security, usability…) for the integrated demonstrator through specific test scenarios.

Measuring set-up 2

Measuring set-up 2 will verify that the technical and business objectives of the demonstrator are met during the test campaign.

Parameters such as the cost and time required to complete the operations or the surface of land altered by the operations will be measured and compared to the objectives.

Measuring set-up 3

Measuring set-up 3 will verify that the technical and business objectives of the demonstrator are met during a particular phase of the test campaign. The aforementioned acquisition-sensors deployment mission will be partly conducted on a **hard-to-reach** (e.g. a forest) limited area.

By extrapolating the measured operational data, the completion of the objectives related to operations in hard-to-reach locations will be assessed.

8 UC3-Demo2 Logistics: Logistics in urban areas

8.1 Current state of the technology

Worldwide logistics uses different types of vectors. Boats, planes, trucks, transport cars and even bikes, are included in a super logistical network coordinated throughout the world. Each type of vector has a specific range of operation. The last-mile delivery is an increasingly studied field, as the number of business to consumer (b2c) deliveries is growing especially due to the increase of e-commerce. Some challenges of last-mile delivery include minimizing cost, improving infrastructure and developing new vectors to replace or complete the utility vehicles in charge of the last mile delivery today.

Figure 14: UC3 demo 2 logistic worldwide state

source: www.eslsca.fr

To fill this market gap, the drone vector is considered as the current best solution. But the regulatory framework has to be created to ensure the safety of drone logistic operations. That's why, since 2010, the authorities have been working actively, to put in place these safety measures.

Atechsys, a company created in 2008, is working with the French civil aviation authorities to define the safest process to do logistic operations by drone. In 2016, the company created the first worldwide logistical parcel delivery line by drone in France. These missions are done in full autonomy. But, because drone technologies and operations are still an emerging sector, the regulation authorities have limited these types of operation to rural areas.

Since 2013, Atechsys is deeply involved in the creation of all the logistic framework needed around the drone vector, to ensure parcel delivery by drone. New technologies are appearing on the market to increase the safety level of the drone, and allow new activities like parcel delivery in peri-urban areas. The legislation is also constantly adapting to these new technologies, and taking them into account in new types of scenario and open specific domains of activities.

For these reasons, Atechsys is implementing an experimental mission, thanks to new technologies from the French consortium C4D. To do so, we are trying to implement a demonstration, promoting the technologies of the project partners, and showing the osmose between these technologies with a common goal: to deliver a parcel between two buildings of the same institution. The final demonstration will take place in a hospital environment. The mission planed will synchronies the ground rovers and flying UAS, the goal is to transport the parcel with the most reduced human proximity.

Increase the automation of this type of transport will increase the speed of the delivery and reallocate wasted time of the health team from transporting the parcel to real health activities.

This system of system allows the UAV and the rover to share their knowledge: their status, their progress on the mission and safety information (e.g. presence of intruders). The UAV are able to follow the flight path defined in the MAP and take into account the geocaging zone limiting the drone.

8.2 Use Case Concept of Operation

UC3 demo 2 consists in transporting a parcel between 2 buildings thanks to 2 types of unmanned systems: an aerial (drone) and a ground (rover) system. Typically, the rover will transport the parcel from inside the first building to the planned landing zone outside the building. Then the parcel will be transferred to the drone (landed on the rover). It will flight to the second landing zone and do the reverse operation on the rover 2. The second rover will then deliver the parcel inside the second building.

The system of systems will be able to deliver a parcel between 2 buildings 2.5km apart. The demo itself will be limited to a small corridor forbidden to public due to legal restrictions.

8.2.1. Description of the system components

The system deployed by the UC3 demo 2 is described in the figures below:

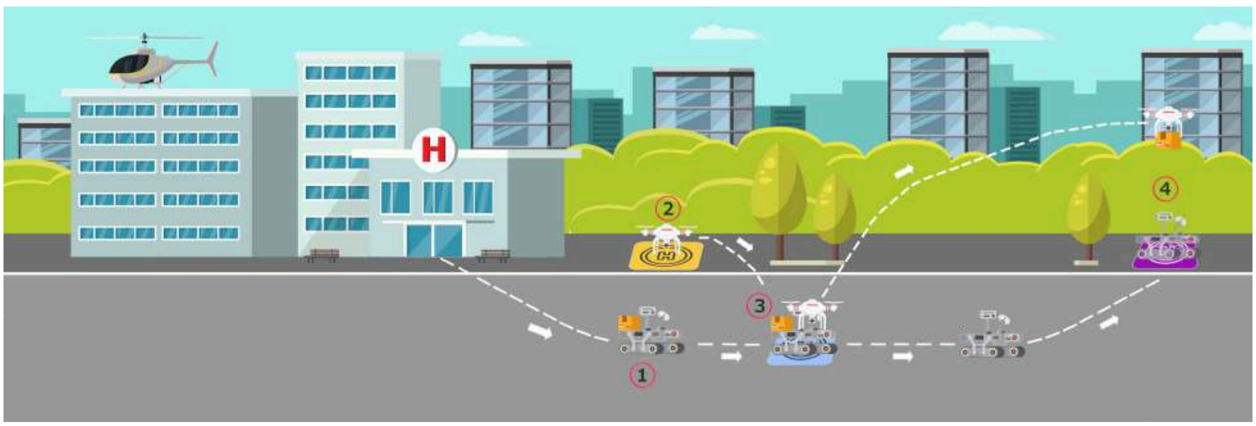


Figure 15: UC3 demo 2 1rs part system description

Figure 16: UC3 demo 2 2nd part system description

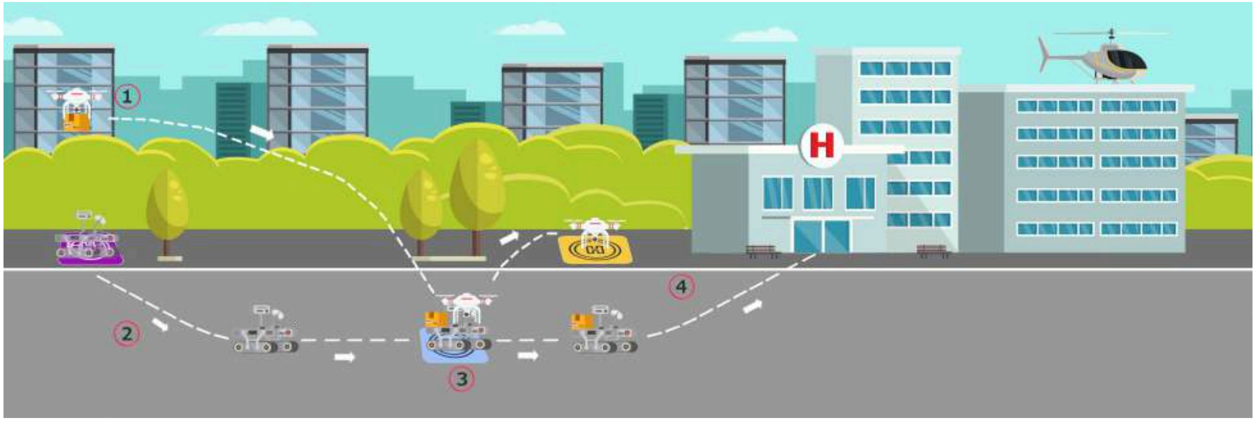


Figure 17: UC3 demo 2 3rd part system description

The system is composed of:

- A drone with a parcel catching-transfer system, automatic landing, and safeguard technologies
- Two rovers with parcel catching-transfer system, safeguard technologies to evolve in populated environments
- A flight management system.
- A single Ground Control Station to monitor the flight.
- A pilot who can regain control of the system in order to respect the regulation in an experimental environment
- Command & Control Center

8.2.2. Level of automation

One of the aims of the mission is to automate the parcel transfer operations between drone and rover as much as possible. The global philosophy of the system is to automate the entire operation, including an automatic travel of the rover inside the hospital building, automatic landing of the drone on the rover/ on the landing pad, automatic parcel transfer between the 2 vector types, and automatic control of the drone position during its flight.

In particular, the following functions will be automated:

- Flight phases:
    - Take-off
    - Automatic landing
    - Flight
    - Parcel transfer
    - A flight away will be avoided to the maneuver forbidden
    - the geocaging technology which will forbid the drone intruding
        - geofenced areas,
- UAS condition and failures monitoring:
    - Communication loss:

  - With the GCS.
  - With the remote controller.
- Low level of batteries
- GPS loss.
- Engine failure.
- Geocaging position and alerts

- Rover condition and failures monitoring:
  - Communication loss:
    - With the GCS.
    - With the remote controller.
  - Low level of batteries
  - GPS loss.
  - Engine failure.

On the contrary, the following functions will be performed by human beings:

- Interface with the local authorities (RSES-D and Party Chief).
- Interface with local air traffic control (by the GCS Manager).
- Input of the mission data (by the Mission Superintendent via the Command and Control).
- Monitoring of the UAS flight behaviour (by the GCS Manager).
- Check of UAS simulation before the flight (simulation includes the current flight path and weather conditions)
- Modification of the UAS fleet behaviour in case of problem (by the GCS Manager).
- UAS control take-over in case of unexpected behaviour (by the team of UAS Pilots).
- Termination of the flight if the UAS or the rovers are out of control

Only the flight stage will be monitored/managed by a pilot to guaranty the safety of the operation. The reason is that although one of the objectives of the system is to test automation of missions, the automatic detection of humans by camera on the rover and the limitative flight away technology have not yet been certified? in an industrial or populated environment. We choose to complete the system with human counter checks to be absolutely certain of the reliability of the system.

Note: all operations are done under BVLOS conditions.

8.3 System Requirements, KPI´s and Metrics

8.3.1. Technical KPI`s and Metrics

Technical KPi

ID	Description	Goal	Metrics
UC3-D2-KPI-1	Ability to carry out a logistic mission in multimodal autonomous	Collaborative mission with drone and droid done in autonomy	Full mission with the coordination between drone, rover and humans with error under 10^{-5}

UC3-D2-KPI-2	Ability to achieve industrial deployment of such logistics solution	Adaptation of the standard mission to an industrial environment and POC	Time used to adapt the mission to a new scenario, modification to do on drone and rover are easy to put in place and for a small budget
UC3-D2-KPI-3	Ability to carry out these transportations in complete safety while respecting the rules and standards	All limitative technologies implemented inside drone and droid. These technologies are able to work in parallel and together	No latency above 50ms detected du to technologies coordination during each step they are used

Table 55 UC3 D2 List of Business KPIs

Business KPi

ID	Description	Goal	Metrics
UC3-D2-KPI-4	Perform tests with manufacturers to measure their palatability and the given value	Prove of concept: done-droid in hospital environment + release.	Repeatability of the demo, in the weather limits defined, without error (<10^{-5} error/hour)

Table 56 UC3 D2 List of Business KPIs

8.3.2. Main requirements (functional, interface, performance, security, usability…)

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
High-FNC-System-008	Drone-Rover exchange (parcel)	The drone and the rover must be able to exchange the parcel automatically (Rover1 to Drone, and Drone to Rover 2)	H	TwinswHeel -Atechsys	UC3-D2-KPI-1
High-DSG-Drone-011	Rover: Parcel – maximal size and weight (rover constraint)	The maximum transport weight in the rover must not exceed 2 kg and fit in a cube of 20 * 20 * 20 cm	H	TwinswHeel	UC3-D2-KPI-1
High-FNC-Drone-018	Landing performance:	Considering the landing area, and the drone dimension, the drone shall land with high accuracy	H	TwinswHeel + Scalian+Sherpa	UC3-D2-KPI-2
High-OPR-System-022	Landing technologies	The drone shall use a combination of several technologies to land precisely. The nature of these technologies shall be different enough so that they complement each other.	H	TwinswHeel + Scalian+Sherpa	UC3-D2-KPI-1

		Redundancy of sensors/ sources to get a precise relative position between drone and rover			
High-FNC-Rover-001	Rover mission	The rover shall contribute to the mission at the 1st phase (transport the parcel to the drone to the transfer pad), and the last phase (transport of the parcel to the final recipient)	H	TwinswHeel	UC3-D2-KPI-1 UC3-D2-KPI-3
High-FNC-Rover-002	Rover Minimal service req. (distance)	The Rover shall be able to transport the parcel on a distance of 500 m (from 300 to 800m)	M	TwinswHeel	UC3-D2-KPI-2 UC3-D2-KPI-3
High-PRF-Rover-003	Rover Localization performance	Localization at +/- 5 cm in an already scanned space	M	TwinswHeel	UC3-D2-KPI-1
High-OPR-Rover-004	Rover localization technology	The rover shall use a combination of technologies to be localized. The nature of these technologies shall be different enough so that they complement each other. (minimum 2 redundancies)	H	TwinswHeel	UC3-D2-KPI-1
High-FNC-Rover-009	Rover control & Path planning (without obstacles)	The rover shall navigate in its environment, considering a virtual route and its mission	H	TwinswHeel	UC3-D2-KPI-3 UC3-D2-KPI-4
High-FNC-Rover-014	Obstacle detection	The rover shall detect fixed and moving obstacles	H	TwinswHeel	UC3-D2-KPI-2 UC3-D2-KPI-3
High-FNC-Rover-024	Obstacle avoidance	The rover shall avoid fixed and moving obstacles	H	TwinswHeel	UC3-D2-KPI-2 UC3-D2-KPI-3
High-FNC-Com-001	System communication	The system (drone / rover / operator / GCS) shall be able to exchange information (position, path planning...)	H	CEA, TwinsWheel, Atechsys	UC3-D2-KPI-1
High-FNC-Com-009	Communication monitoring	the communication must be monitored	H	CEA, TwinsWheel, Atechsys	UC3-D2-KPI-1
High-PRF-Com-015	Communication performance	The system must have a performant communication: - low Latency < 50 ms (for	H	CEA(drone) TwinsWheel (rover)	UC3-D2-KPI-1

		simple variable such as control information) - Large bandwidth to bring up all the necessary sensor information - monitored (to Know the status of the network permanently)			
High-FNC-Com-029	Drone Remote control	The operator must be able to control the drone or the rover in remote control.	H	TwinswHeel	UC3-D2-KPI-1

Table 57 UC1 D1 List of Main Requirements

8.3.3. Drone integration requirements

Requirement ID	Short Description	Description	Priority (H/M/L)	Source
Low-DSG-Drone-006	drone floor area constraint	Considering the rover landing diameter, the drone floor area must be =< 60x60 cm	H	Atechsys
High-DSG-Drone-011	Rover : Parcel – maximal size and weight(rover constraint)	The maximum transport weight in the rover must not exceed 2 kg and fit in a cube of 20 * 20 * 20 cm		TwinswHeel
High-FNC-Drone-012	Drone: Weight to support	For Perception & localization functions, the drone shall also support: - extra mass (sensors, SBC: Onboard computer) for Perception & localization functions, - battery mass for energy requirement	H	Atechsys
Low-DSG-Drone-013	Sensor & SBC Mass	The mass dedicated for Perception & localization functions ((sensors, SBC: Onboard computer) shall be limited to 150 grams	M	Atechsys
Low-OPR-Drone-014	Battery energy and mass	Considering mission (parcel Weight, distance & Altitude, number of deliveries without being charged), the minimal Energy to stock in Drone is X (Ex: 2500) mAh (battery approximative weight=X (Ex: 400 grams)	M	Atechsys
High-FNC-Drone-015	Environment (drone)	The drone shall evolve (fly, take off, landing) outside, up to X meter altitude	M	All
High-FNC-Drone-017	Drone dimensions	Considering - - weight of "utile Charge" (Parcel: 800g, Battery: 400g, sensors, SBC:150g)	H	Atechsys

	considering requirements	- the parcel size - the drone floor area constraint, the drone dimensions constraint shall be: - Drone floor area > 60 cm - quadri-hexa copter - total weight of drone + parcel =< 5kg		
High-FNC-Drone-018	Landing performance	Considering the landing area, and the drone dimension, the drone shall land with high accuracy	H	TwinswHeel+ Scalian+Sherpa
Low-PRF-Drone-019	Landing precision (on rover)	Considering the drone floor area (60cm), and the rover diameter (70cm), the drone shall land precisely on the rover pad, within a (70cm-60cm)/2= 5 cm radius to the target position	H	TwinswHeel+ Scalian+Sherpa
Low-PRF-Drone-020	Landing precision (on Heli pad)	Considering the span of the drone (60cm), and the Heli-pad diameter (100cm), the drone shall land precisely on the Heli-pad, within a (100cm-60cm)/2= 20 cm radius to the target position	M	TwinswHeel+ Scalian+Sherpa
Low-FNC-Drone-021	Localization – approach phase	The drone is connected with the droid to send sensors data and receive positioning order to land precisely on the rover (<5cm)	H	TwinswHeel+ Scalian+Sherpa
Low-OPR-Drone-030	Drone - Localization – autonomous flight	The drone is localized thanks to its GPS with an accuracy under 5m during the automatic flight	H	Atechsys
Low-FNC-Drone-031	Precision navigation	The drone shall navigate in its environment, considering a virtual route and its mission, with a determined accuracy under 5m	M	??
Low-FNC-Drone-032	Geocaging	The drone flight needs to restricted to an allowed corridor (geo-caging)	H	??
Low-OPR-Drone-033	Localization – auto mode	The drone checks its position during all the flight to correspond to its flight path with <5m accuracy	H	Atechsys
High-OPR-Drone-034	Drone Localization	The drone shall use a combination of technologies to be localized during the fly phase. The nature of these technologies shall be different enough so that they complement each other. (minimum 2 redundancies)	M	Atechsys + SLAM partner
Low-OPR-Drone-035	Drone Localization	1st redundancy of localization shall be GPS-RTK	M	Atechsys
Low-OPR-Drone-037	Drone Localization	2nd redundancy of localization can be Video SLAM	L	??

Low-OPR-Drone-038	Localization – compare-2-trajectories	The ground station or the rover compare the current video from the drone and do a relative localization that give more accuracy for the final landing phase	M	??
High-FNC-Drone-039	Drone Obstacles perception	The drone shall perceive its environment 30m around it (fixed and moving obstacles, including other aircraft and humans) (The drone must be able to dynamically detect and consider other aircraft on the area: bird.)	H	??
High-FNC-Drone-040	Drone path planning	The drone must follow the virtual trajectory defined by the pre-established macro route corrected by the local trajectory to avoid fly away	H	Atechsys
Low-OPR-Drone-041	Drone - PathPlanning-route	Define a virtual route on the map established by the simulation validation in the rover. The drone must only follow this virtual route. The route must have safe points to land the drone in case of emergency	M	Atechsys
Low-OPR-Drone-042	Drone - PathPlanning-control repeated trajectory	The trajectory of the drone is compared to the pre-recorded sensors trajectory done by the drone to localize its own position with more accuracy	M	Atechsys
Low-OPR-Drone-043	Pathplanning – new type of flight	The drone path has to be checked by the operator before each new kind of flight	M	Atechsys
Low-OPR-Drone-044	Drone - Simulation flight	Thanks to sensors and weather condition, simulate the flight and be able to validate the conditions to launch the flight. This module is integrated on the ground station or droid	M	Atechsys
High-FNC-Drone-045	Detect and avoid	The drone shall be able to detect predefined objects.	L	??
High-FNC-Drone-046	Detect and avoid	The drone shall be able to avoid collision with fixed obstacle	L	??
High-P&C-Drone-049	Norms	The drone must be allowed to fly in one (and, hence, all) of the countries of Europe.	H	Atechsys

Table 58 UC3 D2 List of Regulatory Requirements

8.3.4. Regulatory requirements

Requirements related with SORA analysis (Reference to the methodology in D2.5.)

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	Success Criteria, KPI´s or metrics
High-P&C-System-048	Camera regulation for drone/rover	The system shall be compliant with the GDPR regulation since its uses a camera.	M	ATE	UC3-D2-KPI-3
High-P&C-Drone-049	Flight regulation	Norms: The drone must be allowed to fly in one (and, hence, all) of the countries of Europe.	H	ATE	UC3-D2-KPI-3
High-P&C-GCS-007	GCS regulation compliance (U-Space)	The GCS shall be compliant with U-SPACE requirements	H	Altran	UC3-D2-KPI-3
High-P&C-GCS-010	The GCS regulation compliance (EU)	The GCS shall be compliant with European Union regulations	H	Altran	UC3-D2-KPI-3

Table 59 UC3 D2 List of Regulatory Requirements

8.4 Functionalities identification

These functionalities could be either **hardware functionalities, software functionalities, modules, etc**. All of them together will define the final system. As it was done for the requirements, **¡Error! No se encuentra el origen de la referencia.**show the functionalities identified for the drone, the rover and all the ground systems needed for UC3 demo 2.

ID	Functionality	Description	System function
FNC-System-009	rover - Drone - Parcel – transfer	The rover, after landing validation received from the drone, shall order the drone to grab or drop the package	6.2.1 Flight Control (.1)
FNC-Drone-018	Landing performance	Considering the landing area, and the drone dimension, the drone shall land with high accuracy	6.2.2 Flight Nav (.1)
FNC-Rover-001	Rover mission	The rover shall contribute to the mission at the 1st phase (transport the parcel to the drone to the transfer pad) , and the last phase (transport of the parcel to the final recipient)	6.2.2 Flight Nav (.3)
FNC-Rover-002	Rover Minimal service req. (distance)	The Rover shall be able to transport the parcel on a distance of 500 m (from 300 to 800m) (The rover is capable of a few km of autonomy)	6.2.7 Regenerative energy storage (.3)
FNC-Rover-009	Rover control & Path planning	The rover shall navigate in its environment, considering a virtual route and its mission	6.2.2 Flight Nav (.3)

	(without obstacles)		
FNC-Rover-023	Droid - PathPlanning-fixed obstacle	The road must allow the droid to avoid fixed obstacles without endangering other road users	6.2.4 Sys and environment status (.1)
FNC-Rover-027	Droid - Control – local obstacle avoidance	During planning phase, a local trajectory is established according to the obstacles, but if an obstacle appears or which has moved or which was not detected in the previous stage, then it must still be avoided	6.2.2 Flight Nav (.7)
FNC-Com-001	System communication	The system (drone / rover / operator / GCS) shall be able to exchange information (position, path planning...)	6.2.5 Coordination (.2)
FNC-Com-009	Communication monitoring	the communication must be monitored	6.2.6 Communication (.1)

Table 60 UC3 D2 List of Functionalities

8.5 Components

This section describes the components in the use case that allow to implement the functionalities listed in the previous section. The descriptions are short, for more details see the appropriate technical work package.

- **COMPONENT WP3-16_1 – Flight Mission Controller**

Component description is included in the UC3·D1

- **COMPONENT WP3-16-2 – Knowledge Base**

Scalian has developed an architecture for a fleet of UAVs (see above), in order to allow coordination, they need to share their knowledge on the mission status, their individual progress, their position, their status and their planned trajectory (reserved air-space). Considering that the architecture will be improved to allow controlling new types of mission it is necessary to also improve the Knowledge base accordingly. Additionally, new types of agents should be integrated in the system (UGV, weather station …) each of which must connect and report to the KB. Hence it is mandatory to enhance it with new agent models.

- **COMPONENT WP3-16_3 – Generic Mission Controller**

Scalian has developed a generic architecture for UAVs. The main goal of this architecture is to allow a fleet of UAVs to cooperate when achieving missions. The architecture comprises all the required functionalities to sense, plan and act. This component improves the genericity and robustness of the planning and acting phase.

The development will allow new types of missions, and should allow new types of agents. This component should be able to control and use new components: it should allow to integrate work for partners proving its genericity.

- **COMPONENT WP3-32 – Traffic by TSE**

On the drone, it is expected that communications between different components could be supported by a TSN Network (Time-Sensitive Network). TSN is a group of IEEE Standards that targets support of deterministic communications over standard Ethernet. Several traffic Queues can be defined to support different levels of TSN support (determinism, controlled latency, best efforts, etc.). This software is in charge of setting up the TSN queues and the routing rules so that Traffic with specific QoS requirements can be handled as expected in the TSN network (on-board)

- **COMPONENT WP3-35 – Determinism and qualification for autopilot**

The qualification of the drone is mainly determined thanks to a heavy flight tests campaign. Depending of the weight and altitude of the drone, the level of power impact will be established to estimate how much hours of simulated and real tests European comity will need to allow a new vector.

- **COMPONENT WP3-38 – Simulation for drone**

The goal here is to, before the flight, simulate the behaviour of the flight, based on the flight path and the weather conditions. If the results give a 95% success mission or above, then the flight can be done.

- **COMPONENT WP4-2 – Precision Landing**

In order to carry out safe operations, Scalian is developing a component that will allow precision landing. This precision is necessary to reduce risks for UAVs operators (persons in charge of refuelling the UAV). This component must use several types of sensors to ensure that if one fails or is not precise enough due to the conditions (lighting …) the UAV still achieve precise landing.

2 other partners are developing precision landing technology: Altran and Sherpa. Thanks to the plurality of the landing technology, we will be able to match the requirement of different landing pad limits to the performances of the landing tech.

This component should also connect to the clearance component (see below) in order to detect human operators when they are too close to the landing pad, thus stopping the landing phase.

- **COMPONENT WP4-6 – GCS**

Altran has developed a concept for heterogeneous fleet of agents (sea, ground air) monitoring. It allows to monitor any number of agents with their payload as long as there is enough operator. Work-sharing is automated and focuses on different topics: traffic management and its safety, payload use and its respect of safety (delivery cases), new functionalities like landing procedure or stop-function-start flight and privacy (filming cases).

This component is operation agnostic and can connect to any type of agent as long as it can exchange using a common protocol. It can be used either for complex mission monitoring or traffic management over cities.

- **COMPONENT WP4-12 – Safe monitoring components**

Drone safety will be addressed in runtime to face with the limited computation resources by analysing the behaviour of the algorithms. Certain failure scenarios have been anticipated, together with potential reconfigurations that assure that critical functionality remains assured. However, it is not possible to anticipate all failures, in particular not the combination of failures, as the required database would become too big (combinatorial explosion). Therefore, some failures have to be handled at runtime; the system should autonomously take a suitable action. The COMP4DRONES architecture shall use safety monitors looking at past and current states, in order to verify correctness and validate the system; or focus on future states, with prediction algorithms and actively diminish risk by assessing threats. To ensure correct runtime functionality in a drone/robot component, its execution will be monitored according to predefined invariants that essentially specify a contract for the dynamic behaviour of the component. In the case in which it is not possible to find a feasible solution before that a decision must be made, a safety mechanism will need to take place.

- **COMPONENT WP4-18 – Transponder for drone rover**

The component WP4-18-TEK provides the drone and the rover anti-collision and identification functionalities. WP4-18-TEK consists of Ultra-Wideband transceivers and the controlling and data processing embedded software. WP4-18-TEK is capable of cooperative ranging (internodal distance measurement based on the propagation time of the radiofrequency signals); when multiple transceivers participate in the ranging procedure it is capable of localization with respect to a relative frame. The drone is equipped with one transceiver, the rover can be equipped with two or more transceivers, optional fixed beacons can be used according the mission needs. The solution is explored by simulation and preliminary realization during the project year 1, developed and verified in laboratory environment during the year 2, and field validated during year 3.

- **COMPONENT WP4-41 – Design tools**

The main goal of this component is to provide functionality to generate a mission profile (altitude and speed definition for different flight phases). The development of the component for coaxial propeller performance will improve fidelity of the signal. This component will also improve aerodynamics submodule for UAV applications and, with dedicated developments or through methodologies, the integration with other tools for environment simulation, sensors simulation and flight simulators. The goal is to provide a comprehensive simulation framework to address autonomous drone's simulation. The Industrialization of the market will be helped by this component to understand the software capabilities and provide a starting point for UAV system simulation analysis.

- **COMPONENT WP5-01 – Intrusion detection system**

This component will provide a lightweight anomaly-based intrusion detection system (IDS) for drones. It will work on network traffic patterns and on carried data plausibility, for both drones to drone and drone to ground central station links. When possible, the IDS will extract information on the detected attacks to notify the experts and might propose some countermeasures if the feature is made available.

- **COMPONENT WP5-18 – Reliable radio communication system**

This component WP5-18-CEA provides communication capabilities from a drone to a pilot, to the cloud, and/or other drones in an efficient and reliable way. By aggregating the capacity of multiple radio interfaces, this component is able to increase the available bandwidth for applications. By using multiple radio interfaces, it offers the capability to switch the traffic from one interface to the other as soon as a disconnection or a drop of performance is detected.

Partner	Work Package	Component ID	Components	Demo	KPI	Criteria	Measurable Outcome	Objective
Scalian	WP3	16-1	Flight Mission Controller	Demo	Improve safety, mission autonomy	SC1.1	MO1.1	O1

Scalian	WP3	16-2	Knowledge Base	Demo	Improve safety, mission autonomy	SC1.1	MO1.1	O1
Scalian	WP3	16-3	Generic Mission Controller	Demo	Improve safety, mission autonomy	SC1.1 SC4.1	MO1.1 SC4.1	O1 O4
CEA	WP3	32	Traffic by TSE	Demo	Improve safety, mission autonomy	SC1.1	MO1.3	O1
Atechsys engineerin g	WP3	35	Determinism and qualification for autopilot	Demo	Improve mission planning	SC2.2	MO2.1	O2
Siemens	WP3	38	Simulation for drone	Demo	Improve safety, mission planning	SC4.1	MO4.2	O4
IMEC-NL	WP4	2	Precision Landing	Demo 8	Improve safety, mission autonomy	SC2.1	MO2.1	O2
UNIVAQ	WP4	5	Clearance	Demo 10	Improve mission autonomy	SC2.1	MO2.1	O2
ALM	WP4	6	GCS	Demo 8	Improve autonomy	SC2.1	MO2.1	O2
CEA	WP4	12	Safe monitoring components	Demo 6	Improve safety	SC2.2	MO2.3	O2
IMCS	WP4	18	Transponder for drone rover	Demo 6	Improve safety, mission autonomy	SC2.2	MO2.3	O2
ALTRAN	WP4	41	Design tools	Demo 6	ease of integration, ease of customization	SC2.2	MO2.3	O2
CEA	WP5	01	Intrusion detection system	Demo	Improve anomaly-detection	SC3.1	MO3.2	O3
CEA	WP5	18	Improved communicatio n	Demo	Improve communication capabilities	SC3.1	MO3.3	O3

Table 61 UC3 D2 List of components

8.6 Tools

Enable implementation of the requirements.

Partner	Work Package	Compon ents	Demo	WP6 requirem ent	Criteria	Measura ble Outcom	Objectiv e
Siemens/ Sherpa	WP6	Modeling and simulation	UC3	**UC3-DTC-64**	SC4.1	MO4.3	O4

Siemens	WP6	Modeling and simulation	UC3	**UC3-DTC-62**	SC4.1	MO4.3	O4
Siemens/ Sherpa	WP6	Modeling and simulation	UC3	**UC3-DTC-52**	SC4.1	MO4.2	O4
Siemens	WP6	Modeling and simulation	UC3	**UC3-DTC-63**	SC4.1	MO4.3	O4
Sherpa	WP6	Modeling and simulation	UC3	**UC3-DTC-53**	SC4.1	MO4.3	O4
Sherpa	WP6	Modeling and simulation	UC3	**UC3-DTC-51**	SC4.1	MO4.3	O4
CEA/Sherpa	WP6	Modeling and simulation	UC3	**UC3-DEM02-DTC-24**	SC4.1	MO4.1	O4
CEA/Sherpa	WP6	Modeling and simulation	UC3	**UC3-DEM02-DTC-25**	SC4.1	MO4.1	O4
UNICAN	WP6	Modeling and simulation	UC3	**UC3-DEM02-DTC-26**	SC4.1	MO4.1	O4
UNICAN	WP6	Modeling and simulation	UC3	**UC3-DEM02-DTC-27**	SC4.1	MO4.1	O4
UNICAN	WP6	Modeling and simulation	UC3	**UC3-DEM02-DTC-28**	SC4.1	MO4.1	O4
UNICAN	WP6	Modeling and simulation	UC3	**UC3-DEM02-DTC-77**	SC4.1	MO4.2	O4
UNICAN	WP6	Modeling and simulation	UC3	**UC3-DEM02-DTC-78**	SC4.1	MO4.2	O4

Table 62 UC3 D2 List of Tools

Siemens provides a co-simulation framework relying on Simcenter Amesim and Simcenter Prescan. The former is a software tool dedicated to modelling and simulation of dynamic and multi-physics systems. It can effectively model and simulate the UAV energy storage, propulsion, and dynamics performance. The latter provides perception sensors (lidars, radars, cameras...) and environment modelling and simulation capabilities.

The simulation will be used, at first, before the operation starts. During this phase, the main goal is to identify if the drone could do the mission in simulation, with a high level of approval, based on the previous flight data, state of the drone-droid (battery, position, errors) and weather conditions.

The simulation will be also used to ensure a safe landing and experiment upstream, all the landing possibilities (in the presence of people in the landing zone, with a fast wind or a lot of sunshine...).

Thanks to these tests, we will be able to define the weather, drone, rovers' limits to get safest operation possible.

The simulations will also be used to model the drone and its components, to evaluate the time used to implement on the drone, a new component.

COMPONENT WP4-5 – Clearance

The UC3 demonstrator 2 aims at transporting parcel over a defined path. One of the main focus of the operations is to be safe. In order to ensure that flight is done in safe environment, the rovers have to verify that the landing places are clear of humans, animals and vehicles (the absence of infrastructure is guaranteed by the mission preparation).

This component, developed by Scalian, uses deep learning techniques to detect intruders and prevent unsafe landing on that location. The challenge with this component is that it must offer a high reliability (it should never miss the detection of an intruder) while also being close to real-time and embedded on a rover.

8.7 Traceability matrices

8.7.1. Requirements vs. functionalities

Requirement	FNC-System-009	FNC-Drone-018	FNC-Rover-001	FNC-Rover-002	FNC-Rover-009	FNC-Rover-023	FNC-Rover-027	FNC-Com-001	FNC-Com-009
High-FNC-System-008	X	X	X					X	
High-DSG-Drone-011		X							
High-FNC-Drone-018		X							
High-OPR-System-022	X	X	X						
High-FNC-Rover-001			X						
High-FNC-Rover-002				X					
High-PRF-Rover-003			X	X					
High-OPR-Rover-004					X				
High-FNC-Rover-009					X				
High-FNC-Rover-014				X	X				
High-FNC-Rover-024						X	X		
High-FNC-Com-001		X	X					X	
High-FNC-Com-009		X	X						X
High-PRF-Com-015		X	X					X	
High-FNC-Com-029		X	X					X	

Table 63 UC3 D2 Requirements and functionalities traceability matrix

8.7.2. Functionalities vs. Components

Components	Short description	FNC-System-009	FNC-Drone-018	FNC-Rover-001	FNC-Rover-002	FNC-Rover-009	FNC-Rover-023	FNC-Rover-027	FNC-Com-001	FNC-Com-009
WP3-16_1	Flight Mission Controller	X								
WP3-16-2	Knowledge Base	X								
WP3-16_3	Generic Mission Controller		X	X		X				
WP3-32	Traffic by TSE	X							X	
WP3-35	Determinism and qualification for autopilot		X							
WP3-38	Simulation for drone		X				X			
WP4-2	Precision Landing		X							
WP4-5	Clearance	X	X							
WP4-6	GCS	X	X			X	X		X	X
WP4-12	Safe monitoring components									X
WP4-18	Transponder for drone rover	X							X	
WP4-41	Design tools		X	X						
WP5-01	Intrusion detection system					X	X	X		
WP5-18	Improved communication	X							X	

Table 64 UC3 D2 Components and functionalities traceability matrix

8.8 Validation plan

8.8.1. Components Verification

- ***COMPONENT*** **WP3-16_1** Flight Mission Controller

Test description	*Run in simulator with different weather conditions, different missions, and different landing approach. Several tens or hundreds or hours of simulated missions.* *Followed by run on the real system, with 2 rovers and 1 UAVs and 1 flighting drone*
Planned inputs	*Description of new mission and usages for UAV and rovers.*
Expected results	*Demonstration of reliability and genericity.*

- **COMPONENT WP3-16_2 Knowledge Base**

This component will be demonstrated through the test of the COMPONENT WP3-16_1 above.

- **COMPONENT WP3-16_3** Generic Mission Controller

This component will be demonstrated through the test of the COMPONENT WP3-16_1 above.

- **COMPONENT WP3-32 Traffic by TSE**

Test description	Test the redundancy of the communication system thanks to another transport canal (internet instead of radio) and compare the results at the end of the communication
Planned inputs	Radio communication, fusion of communication data at the end (on the vector for a communication to the vector, on the GCS for the other way)
Expected results	The data sent by this technology are the same than radio one, and the latency is reasonable (to be able to compare with radio ones) (<15ms)

- **COMPONENT WP3-35** Determinism and qualification for autopilot

Test description	Integrate on a new vector, the autopilot and verify if the behaviour of the drone, after calibration, is stable and reliable.
Planned inputs	Autopilot and vector, simulations
Expected results	Demonstration of flight capabilities and repeatability

- **COMPONENT WP3-38** Simulation for drone

Test description	*Simulated flights then real flights. During real flights, try to have a variety of conditions: light reflection, low luminosity, wind …*
Planned inputs	*List of possible conditions to could impact the landing.*
Expected results	*Demonstration of both precision (<4m) and high reliability (no failure) during the flight*

- **COMPONENT WP4-2** Precision Landing

Test description	*Simulated landing phases then real ones. During real landing, try to have a variety of conditions: light reflection, low luminosity, wind …* These operations are done on each type of landing pad
Planned inputs	*List of possible conditions to could impact the landing. Landing type, landing length, landing target type*
Expected results	*Demonstration of both high precision (<10cm) and high reliability (no failure), for the less performance ones, precision <1m high reliability*

- **COMPONENT WP4-5** Clearance

Test description	*Test with fake landing and transfer parcel operations, and intruders near the landing point in some cases (human operator, human intruders, animals and vehicles).*
Planned inputs	*Training video dataset in an environment close to the target operation landing site.*
Expected results	*Measure of precision, accuracy and recall to assess reliability and safety of the component.*

- **COMPONENT WP4-6 – GCS**

Test description	Ensure that each step of the demo can be implemented in an autonomous mission (ex: landing, start mission, pause mission, transfer parcel …)
Planned inputs	The steps to do for the demo 6

Expected results	A fully automatic mission with all the step and consigns implemented and sent to the vectors

- **COMPONENT WP4-12** Safe monitoring components

Test description	Push the behaviour of the drone-rover in its limits and ensure the safe and trusted monitoring components
Planned inputs	Components selected to demo 6 + vectors + communications
Expected results	The components are still monitored in any worst cases

- **COMPONENT WP4-18** Transponder for drone rover

Test description	Ensure a stable and reliable communication between all platforms
Planned inputs	Exhaustive list of command control for the planned mission of demo 6
Expected results	Simulation then on-site tests with no loss of data

- **COMPONENT WP4-41** Design tools

Test description	Fast integration of new technology bricks in the vectors' simulations or 3D models
Planned inputs	Components on the vectors
Expected results	Diminution of the time used to do this task and reliability of the simplified model proposed compare to the reality

- **COMPONENT WP5-01** Intrusion detection system

Test description	Close to the landing pad solution, observe the behaviour of the drone without intrusion near the pad, then with intrusion
Planned inputs	Landing pad, landing software, detection system, flighting vector
Expected results	The drone easily lands on the pad when there is no intrusion, do a static flight if there is intrusion near the pad, until disappearance of the threat, then continues its mission

- **COMPONENT WP5-18** Improved communication

Test description	Ensure efficient and reliable communication between the rovers, the drone, the pilot and the GCS
Planned inputs	The vectors (drone-droid-radio) and GCS
Expected results	No loss data and continuity of the signal in the range of the demo 6

8.8.2. Functionalities Verification

- **UC3-D2-FUN-System-009 Flight control parcel transfer**

Environment	Goal	Output
Laboratory	The drone placed on the rover is capable of catching the parcel, hold it, and give it back to the rover. The rover transfers the parcel out the drone landing zone	Repeatability, the drone is able of holding the parcel after the transfer.
Outdoor controlled	Same than above, but with variable weather condition, sunlight …	Even if the rover is bumped because of the road, the drone is still able to catch the parcel

- **UC3-D2-FUN-Drone-018 Landing perform**

Environment	Goal	Output
Laboratory	The drone is able to land on the landing pad with the tag in any case, The drone is able to detect the tag on the drone and to land on it	10-7 landing test error for the landing pad operation and 10-5 for the land on the rover with higher precision
Outdoor controlled	The drone is able to land on the landing pad with the tag in any case, The drone is able to detect the tag on the drone and to land on it or decide to abort the mission and go back to its landing pad	Same than above but with variable weather condition to determinate the weather limits for the drone

- **UC3-D2-FUN-Rover-001 Mission management**

Environment	Goal	Output
Laboratory	Every aspect (step) of the Use case can be defined in the mission and is able to be interpreted by the vectors (start, pause, stop, abort, land, parcel transfer, way-point…)	Simulate the mission in a planner mission software with all the steps. Simulation of the flight with all these steps to verify the correct mission
Outdoor controlled	A UAV will fly in a controlled environment, during this flight a test of the flight behaviour between the step where the rover brings the parcel to the special landing zone (and the drone is waiting on its landing pad), and when the parcel has been given by the drone to the rover and has taken off to land on its landing pad	The mission is correctly repeated without any out-system perturbation.
Realistic	The controlled test will be enough to demonstrate this functionality.	N/A

- **UC3-D2-FUN-Rover-002**

Environment	Goal	Output
Laboratory	The autonomy of the rover and the drone are enough to do their task with a power margin	After a full mission, the drone and the rovers have still more than 20% of batteries charge.
Outdoor controlled	Same than above, but with variable weather conditions and lightning	Same as above. Gives the limits of the operational weather conditions
Realistic	Experimentation in situ	Same than above

- **UC3-D2-FUN-Rover-009 Mission environment interpretation**

Environment	Goal	Output
Laboratory	In addition to the tests described in UC3-D2-FUN-Rover-001, the rover will be tested on a travel path (preview and after the steps tested in function Rover-001)	The rover can orientate itself in a building and outdoor, and is able to follow its mission
Outdoor controlled	Same than above, but with intruders on its mission	No risk of collision with intruders
Realistic	Experimentation in situ	Same than above

- **UC3-D2-FUN-Rover-023 Path planning**

Environment	Goal	Output
Laboratory	In addition to the tests described in UC3-D2-FUN-Rover-001, the rover will be tested on a travel path (preview and after the steps tested in function Rover-001)	The rover can orientate itself in a building and outdoor, and is able to follow its mission
Outdoor controlled	Same than above, but with intruders on its mission	No risk of collision with intruders
Realistic	Experimentation in situ	Same than above

- **UC3-D2-FUN-Rover-027 Obstacle supervision**

Environment	Goal	Output
Laboratory	In addition to the tests described in UC3-D2-FUN-Rover-001, the rover will be tested on a travel path (preview and after the steps tested in function Rover-001) and can detect new obstacle on its usual path	The rover can orientate itself in a building and outdoor, and is able to follow its mission
Outdoor controlled	Same than above, but with obstacle on its mission	No risk of collision with intruders
Realistic	Experimentation in situ	Same than above

- **UC3-D2-FUN-Com-001 Coordination drone-rovers**

Environment	Goal	Output
Laboratory	Test in laboratory the communication stability between drone and rover	No loss of data
Outdoor controlled	Test in an outdoor controlled environment, the communication stability between drone and rover	No loss of data under 500m
Realistic	Experimentation in situ	Same than above

- **UC3-D2-FUN-Com-009 Monitoring Mission**

Environment	Goal	Output
Laboratory	Test in laboratory the communication stability between drone with GCS, and rover with GCS + test redundancy	No loss of data, combination of data to verify the redundancy
Outdoor controlled	Test in an outdoor controlled environment, the communication stability between drone with GCS, and rover with GCS. The drone is able to be controlled by the remote control wherever the place of the drone. Test also standard perturbation in simulation (WIFI (2.4-5.1GHz)-3g-4g-5g, radio…)	- No loss of data under 500m, - Low Latency < 50 ms (for simple variable such as control information) - Large bandwidth to bring up all the necessary sensor information - Monitored (to Know the status of the network permanently)
Realistic	Experimentation in situ with the present signal perturbation	Same than above

8.8.3. System validation

Finally, the table below shows the verification method for each of the technical KPIs:

KPI ID	KPI	Verification Method
UC3-D2-KPI-1	Ability to carry out a logistic mission in multimodal autonomous	The synchronisation between drone and rover are established and stable.
UC3-D2-KPI-2	Ability to achieve industrial deployment of such logistics solution	Experiment the mission in industrial site, and evaluate the time to adapt the Demo 6 to this use case
UC3-D2-KPI-3	Ability to carry out these transportations in complete safety while respecting the rules and standards	Ensure a high level of safety for the full mission, in accordance with the European limitations
UC3-D2-KPI-4	Perform tests with manufacturers to measure their palatability and the given value	Same result of system of system stability than UC3-D2-FUN-Rover-001

Table 65 UC3 D2 system validation plan

9 UC4-Demo1 Surveillance and Inspection: Inspection of offshore turbines structure with hyperspectral technology carried by autonomous drones

9.1 Current state of the technology

Drones are already used today to collect data for accurate volume measurements of stockpiles or earth movement sites. The drone, e.g. Airobot Mapper will collect accurately georeferenced images.

Figure 18 UC4 – D1 demonstrator's UAV drone platform

These images are converted to 2D orthomosaics and 3D pointclouds using photogrammetry software (e.g. AiroCollect). In these 3D pointclouds the volumes can be measured.

Figure 19 UC4 – D1 Construction site mapping

On large earth movement sites, it is important to trace different types of soil, for example to not mix polluted soil with other soils. Additionally, soil containing the roots of certain invasive plant species (e.g. Japanese Knotweed) has to be treated differently and cannot be spread to other sites.

However, on RGB images, it is not easy to differentiate between different types of material or detect if certain plants are present before starting the excavation.

Preliminary tests have been done with a hyperspectral camera on the terrain of an asphalt factory. For example, the on the RGB picture below look very similar. However, the hyperspectral image below shows that both materials have a different spectral response.

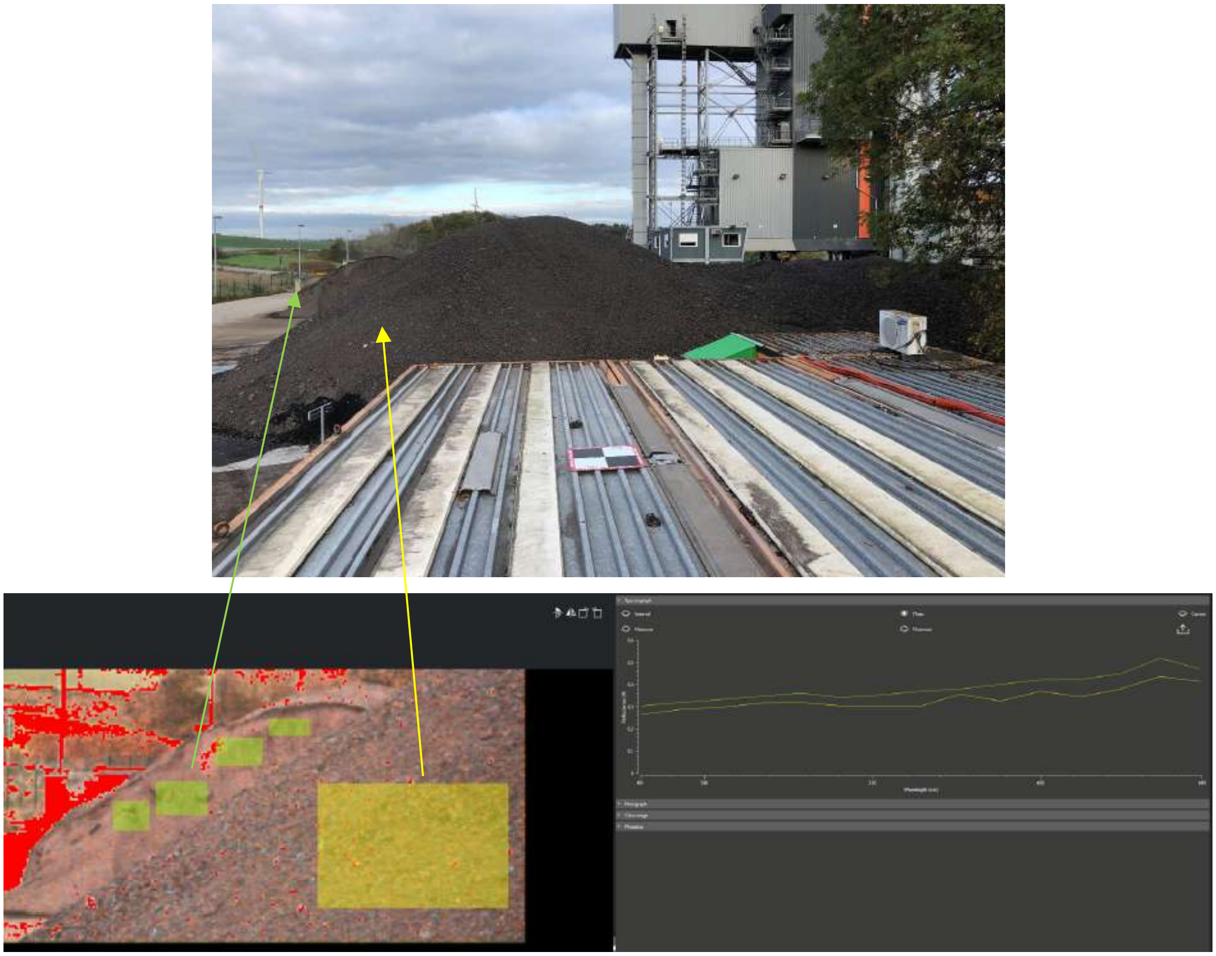


Figure 20 UC4 – D1 demonstrator's preliminary test images

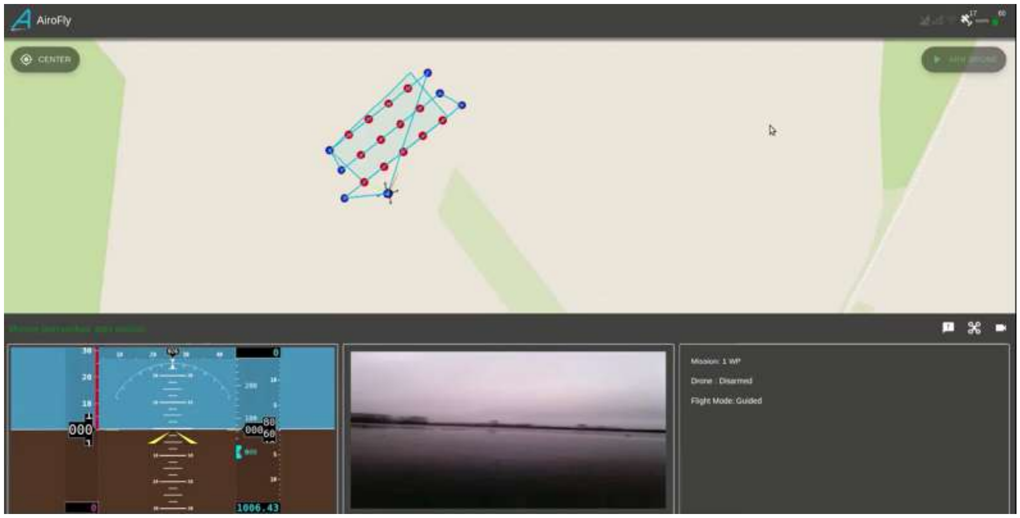
To correctly interpret hyperspectral data, it is important that the spectral content of the incoming light is known. Today, reference tiles are used to calibrate the processing. A limiting factor for use in the field is that when the light conditions change, e.g. clouds, etc. a new image of the reference tile needs to be taken

9.2 Use Case Concept of Operation

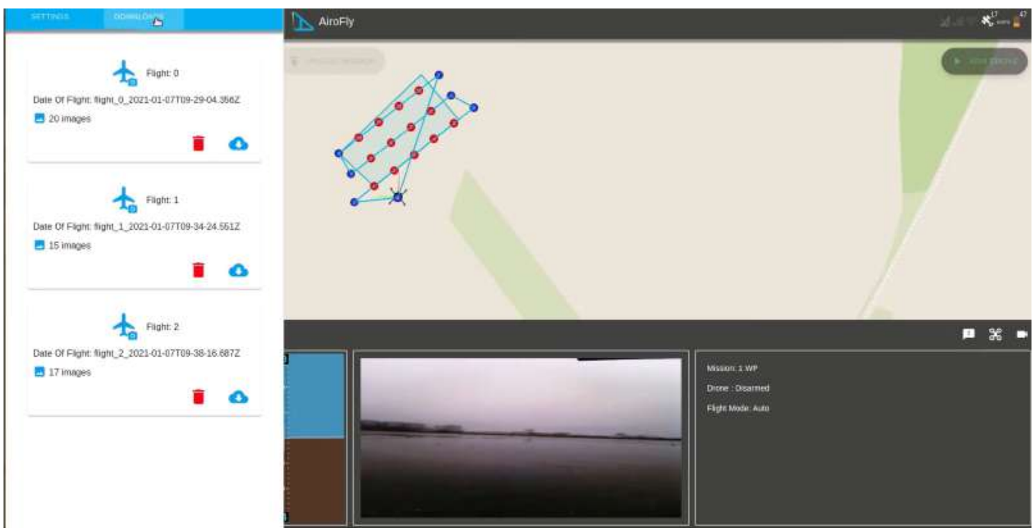
In this use case following modes of operation will be demonstrated:

Automated Mapping of Stockpiles (UC4-SCN-1)

- A multirotor drone will be used to collect the data on a stockpile. An employee on the site will take the drone out of storage and insert a battery.
- Remotely, an operator will enter the mapping flight plan and give the command to take off.



- The drone will execute the mapping flight and return to the home position. During the mapping flight georeferenced RGB and hyperspectral images will be recorded.
- After the flight, the RGB & hyperspectral data will be downloaded and transferred to the AiroCollect software



- In the AiroCollect software, the RGB images will be used to create a 3D pointcloud to perform the volume measurements.
- The hyperspectral images will be processed and used to identify the type of soil.

Automated Mapping of Large Sites (UC4-SCN-02)

A multirotor (or VTOL) drone will be used to collect the data on a large construction site. An employee on the site will take the drone out of storage and insert a battery.

- Remotely, an operator will enter the mapping flight plan and give the command to take off.
- The drone will execute the mapping flight and return to the home position. During the mapping flight georeferenced RGB and hyperspectral images will be recorded.

- After the flight, the RGB & hyperspectral data will be downloaded and transferred to the AiroCollect software
- In the AiroCollect software, the RGB images will be used to create a 3D pointcloud to perform the volume measurements.
- The hyperspectral images will be processed and used to identify the type of soil and detect the presence of the invasive plant species.

9.3 System Requirements, KPI´s and Metrics

9.3.1. Technical KPI`s and Metrics

KPI ID	Description	Goal
Business KPIs		
UC4-D1-KPI-01	Demonstrate that the platform is able to complete a hyperspectral mapping of a 1 Ha site within 30min	Value to reach
UC4-D1-KPI-02	Demonstrate the software workflow to manage the mapping process; organize and geo-reference the collected hyperspectral data with an accuracy less than 10cm.	Value to reach
UC4-D1-KPI-03	Demonstrate automatic hyperspectral image-based soil classification using AI technology with an accuracy of 80% compared to human classification.	Percentage to reach
Technical KPIs		
UC4-D1-KPI-04	Demonstrate the added value of hyperspectral measurements for automatic classification of soil types on construction sites in realistic conditions (wind up to 5 Beaufort, minimum temperature of -10°C, changing light conditions).	Value to reach
UC4-D1-KPI-05	Demonstrate that the drone with an integrated hyperspectral payload is capable to perform safe automated mapping flights and provide geo-referenced hyperspectral data with an accuracy of 5cm	Value to reach
UC4-D1-KPI-06	Demonstrate the integration of algorithms to restore hyperspectral images by removing image degradations caused by vibrations, wavelength dependent fading and spectral changes due to lighting conditions.	Functionality to demonstrate

Table 66 UC4 D1 List of KPIs

9.3.2. Main requirements (functional, interface, performance, security, usability…)

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC4-PRF-01	Perform automated	Perform an automated (3D) flight plan above a terrain.	M	Airobot	UC4-D1-KPI-05

	(3D) flight plan				
UC4-SEC-01	Perform manual flight	Perform a manual flight to test sensor technology	M	Airobot	UC4-D1-KPI-05
UC4-PRF-04	Collect RGB & hyperspectral data	Collect RGB & hyperspectral data simultaneously.	H	Airobot & imec.be	UC4-D1-KPI-02
UC4-PRF-05	Create 3D model based on RGB images	Create a 3D model based on collected RGB images.	M	Airobot & imec.ipi	UC4-D1-KPI-02
UC4-INT-04	Annotation	Have the possibility to annotate hyperspectral data (select areas of soil & assign type).	M	Airobot	UC4-D1-KPI-02
UC4-PRF-07	Local processing	Process the data locally, in near real-time, near where the drone is operated to have fast results.	H	Airobot & imec.ipi	UC4-D1-KPI-04

Table 67 UC4 D1 List of Main Requirements

9.3.3. Drone integration requirements

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC4-PRF-02	Geo-referencing	Provide the estimated 3D coordinates of the hyperspectral & RGB images	H	Airobot	UC4-D1-KPI-02
UC4-INT-03	Easy transfer of recorded data and logs to server	Have an easy way to transfer the recorded hyperspectral data from the drone to the server.	H	Airobot	UC4-D1-KPI-04
UC4-INT-07	View output of hyperspectral camera in real-time	View output of hyperspectral camera in real-time so the operator can verify that the systems is correctly working.	H	imec.be	UC4-D1-KPI-04
UC4-INT-08	Hyperspectral settings	Allow operator to change the settings of the hyperspectral camera remotely.	H	imec.be	UC4-D1-KPI-04
UC4-PRF-13	Weather – wind	Be able to execute the flight in winds of up to 5 beaufort.	H	Airobot	UC4-D1-KPI-05

UC4-PRF-14	Offshore weather temperature	Be able to execute flights in temperatures of -10°C to +45°C.	H	Airobot	UC4-D1-KPI-05

Table 68 UC4 D1 List of Drone integration Requirements

9.3.4. Regulatory requirements

Requirements related with SORA analysis (Reference to the methodology in D2.5.)

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	Success Criteria, KPI´s or metrics
UC4-PRF-03	Safe BVLOS flight	Perform safe BVLOS flights under STS-02 conditions	H	Airobot	UC4-D1-KPI-02

Table 69 UC4 D1 List of Regulatory Requirements

9.4 Functionalities identification

ID	Functionality	Description	System function
UC4-D1-FUN – 01	Hyperspectral camera Payload	Collecting and storing spectrally corrected hyperspectral data.	Passive Optical Sensor (KET 3.1.1)
UC4-D1-FUN – 02	Accurate Georeferencing of data	Store accurate position and orientation of the drone, gimbal to estimate location on ground.	Tracking (U2) Positioning (KET 2.4.1)
UC4-D1-FUN - 03	Onboard Hyperspectral Cube generation	Automated generation of hyperspectral cube based on raw sensor data.	Data Fusion & Processing (KET 2.4.1)
FUN - 04	Offline detailed data processing	Detailed offline processing of the data to classify the results	Data Fusion & Processing (KET 2.4.1)
UC4-D1-FUN - 05	Accurate (3D) flight planning	Perform an accurate, pre-programmed, (3D) Flight using RTK GNSS technology.	Operation plan preparation/optimisation (U2) Geo-awareness (U1) Flight Planning and Scheduling (KET 2.2.3)
FUN – 06	Remotely managed BVLOS flight	Perform a remotely managed BVLOS flight according to European Drone Legislation	Flight Planning and Scheduling (KET 2.2.3)

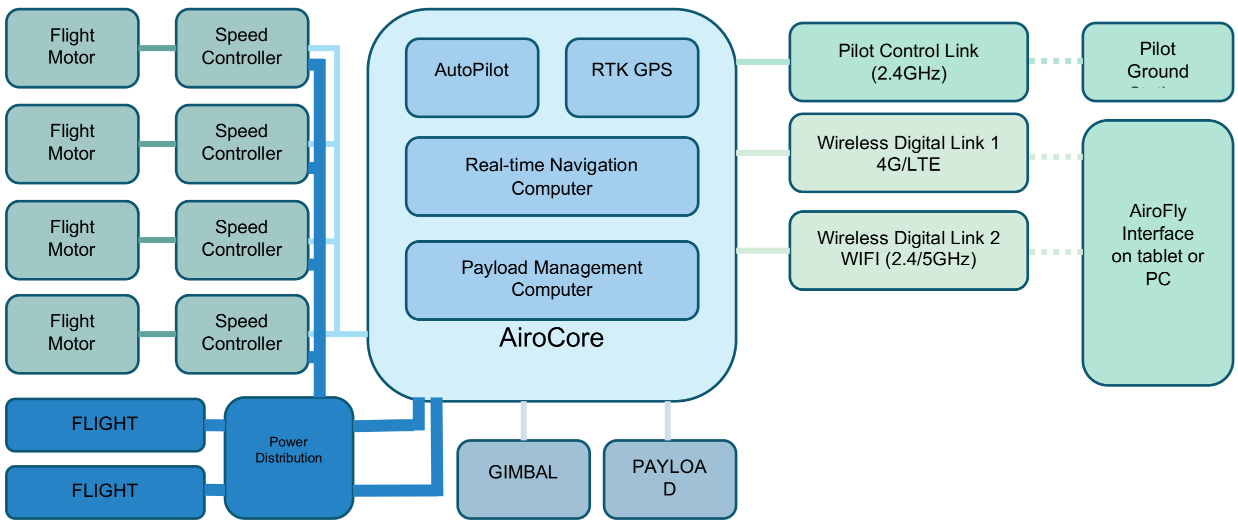
Table 70 UC4 D1 List of Functionalities

9.5 Components

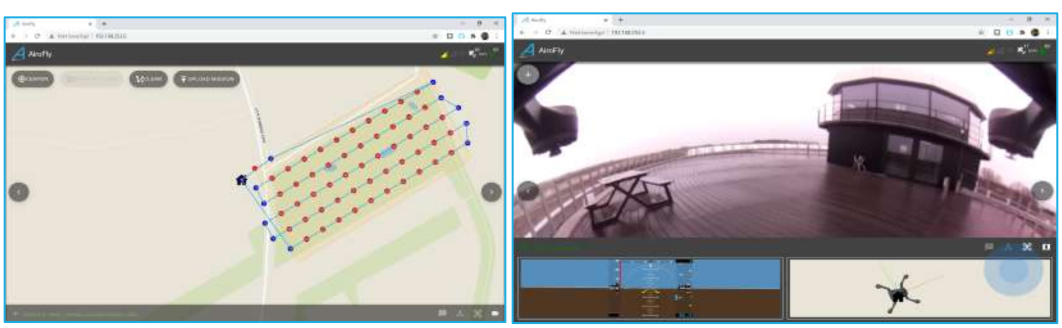
- **Component 1 - Airobot Mapper with AiroCore**

The Mapper drones is based on the AceCore ZOE all-weather drone platform. It is an all-weather platform (max wind speed 27 knots, 33 knots gusts) which can also be operated in moderate rain conditions. It has an autonomy of 30min. By default, it carries a Sony UMC-R10C camera with 23.2mm x 15.4mm APC-C size Exmor APS HD 20.1MP CMOS sensor.

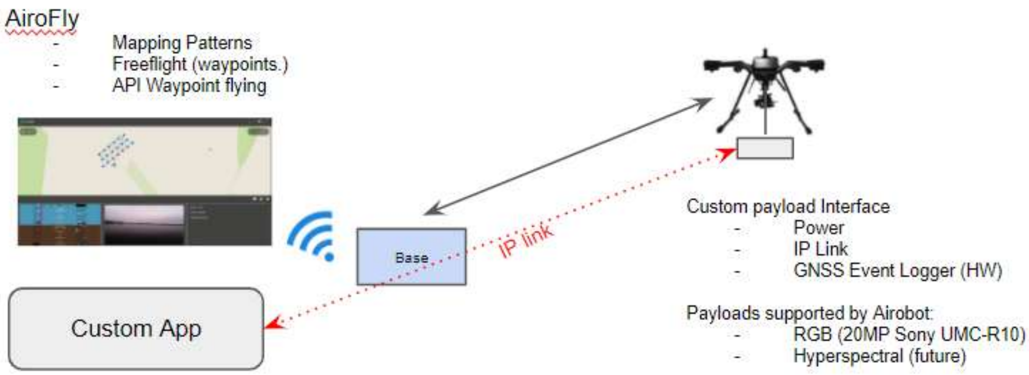
Airobot adds the AiroCore and other features to turn this drone into an automated BVLOS drone, controlled via 4G. After power on, the drone automatically creates a secure link via 4G to a server hosted by Airobot. Only an operator with the right credentials can get access to the drone via the same server.



Via a secure remote IP connection, the operator gets access to the onboard AiroFly software. In the AiroFly software, the operator can plan a flight (e.g. a mapping flight) and monitor the drone during the flight. The drone features several cameras (front, aft, top & bottom) to give the operator a complete view of the situation around the drone.



On the Airobot Mapper, it is possible to have a direct secure IP link from a custom application to the payload to support custom interfaces. The AiroFly software also has a waypoint flying API for custom flight patterns.



- **Component 2 - Airobot VTOL Mapper with AiroCore**

The Mapper VTOL is currently under construction and is based on a standard VTOL platform to which the AiroCore is added to turn it into a mapping solution which can cover larger surfaces. It has the same features as the Airobot Mapper as described for component 1.

It is expected to have an autonomy of 1-2 hours and will be suitable to cover large areas.

During the flight, all parameters of the drone will be monitored remotely.

- **Component 3 - IMEC Hyperspectral Payload**

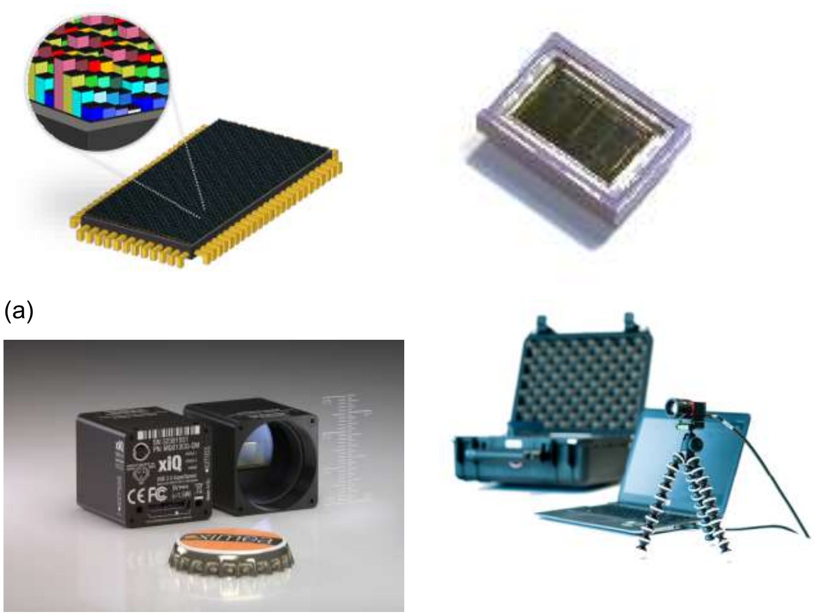
Hyperspectral cameras can improve detection of material imperfections. The hyperspectral payload will be based on imec's UAV platform: (dual) mosaic sensors/cameras with Ximea breakout board and Jetson TX2 board. Regarding the software blocks, we will reuse Airobot's server-based interface for ground controller with imec's camera commands.

State of the Art:

Currently, there are no real lightweight hyperspectral UAV cameras which have more than 4/5 bands. Such a camera would be a real breakthrough in the domain of UAV precision agriculture. Parrot's sequoia multispectral camera with about 4-5 spectral bands is the leading state of the art in this domain. However, with 4-5 spectral bands only simple agriculture indices like NDVI can be extracted. Tetracam's 3-filter camera or multi-camera systems supporting up to 12 bands are other alternatives. However, multi camera systems lead to much more bulkier systems with additional complexity of software to register images from different cameras to obtain the same spatial field of view, which could potentially lead to loss in image quality. For our target applications more, spectral information would be required (>10 bands in VISNIR) to provide accurate diagnostic and actionable information. Our proposed camera can enable such applications. Headwall's micro-hyperspec is another camera intended for UAV platforms, which uses conventional grating-based solutions for the spectral unit. This leads to a bulkier camera than our proposed solution, making this unsuitable for lightweight drones. Micro-hyperspec cameras can weigh up to 1kg or more, making this perhaps more suitable for larger drones/UAVs.

Improvements

IMEC-BG has developed a unique integrated hyperspectral filter/imager technology, where the spectral filters are monolithically deposited/integrated on top of CMOS image sensors at wafer level. The materials of the filters are chosen such that they are compatible with the production flows available in most CMOS foundries. This is achieved using a set of CMOS compatible production steps, like deposition, patterning and etching, which allows pixel level accuracies in filter alignment. The result is a compact & fast hyperspectral imager made with low-cost CMOS process technology. This technology has been demonstrated on multiple instances, few of them are shown below and an overview is shown in the link: https://www.imec-int.com/en/hyperspectral-imaging



(a) (c) (b)

Spectral range	470-620nm/630-1000nm
# Spectral /bands	16/25
FWHM	< 10nm, using collimated light
Filter transmission efficiency	~ 85%
Imager	CMOSIS CMOS CMV 2000 imager
Imager resolution	2Mpixel
Resolution per tile/band	512 x 272 pixels 410 x 218 pixels
Frame rate in # hypercubes/sec	340

Figure 21 (a) concept of mosaic layout (filter heights exaggerated for illustration), (b) a packaged mosaic sensor and a USB3 hyperspectral camera (c) on-market XIMEA camera integrated with IMEC sensors; Table with key specifications of mosaic based spectral imager

This hyperspectral UAV camera will be integrated with other compute enabled features of the AiroCore platform to provide a complete UAV hyperspectral payload that is light weight and spans visible and NIR spectral ranges (450-970nm) with about 32 spectral bands. An overview of the architecture is shown in the figure below. This architecture will be further worked out between imec-BG and Airobot to make a prototype payload system that is compatible with the Airocore platform.

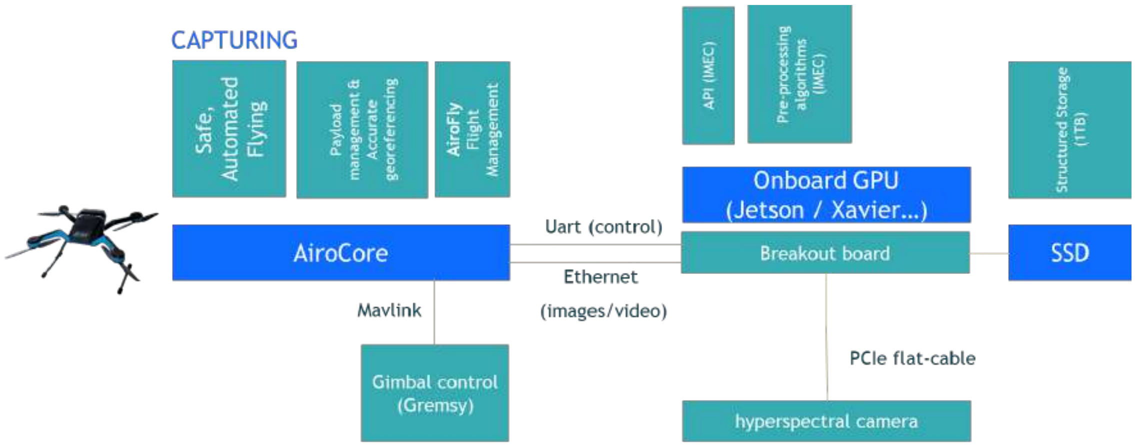


Figure 22: System architecture of UAV playload with compute enabled system

An example architecture integration with a DJI M600 drone platform is also shown in a figure below

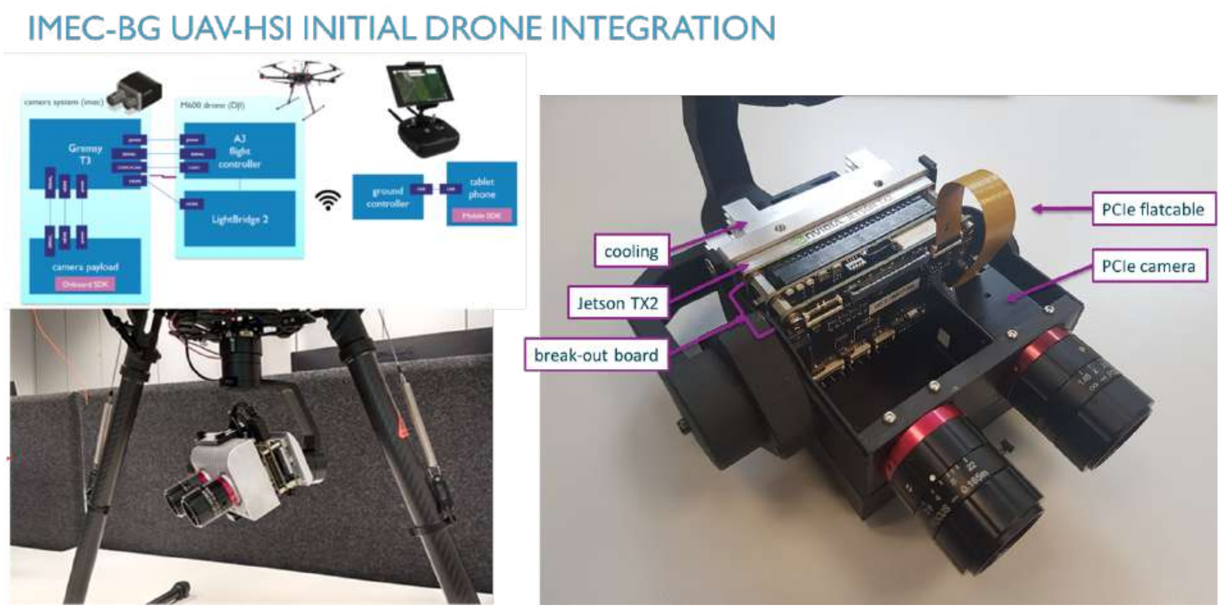


Figure 23: Example prototype payload and a possible integration with a DJI M600 drone

- **Component 4 -IMEC Hyperspectral Processing Chain**

The goal of this component is to design a processing pipeline based on hyperspectral imagery to perform soil classification. Imec will further develop its current pipeline and rely on its expertise to efficiently deploy algorithms on the NVidia Jetson boards.

Currently, there exists many hyperspectral image processing algorithms (e.g. demosaicking for mosaicked sensor layouts or deep learning-based detection, segmentation or classification). However, they are developed and designed for (off-board) PC platforms and are totally not optimized for the imec's hyperspectral dual camera payload, integrated nor run on embedded hardware platforms such as the Jetson TX2 board.

Classic deep learning frameworks rely on massive amount of annotated data, over which we will not dispose (and are not able to collect ourselves). Therefore, we rely on recently developed few-shot learning techniques, which are trained with only a limited number of annotated samples. However, the robustness under various noise conditions and few-shot learning performance needs further research. In the case of hyperspectral imaging, this will also impact the acquisition: e.g. the varying incident sun light will create different appearances of the same physical material. Proper normalization procedures are needed to be developed.

The entire pipeline is made up of three main modules: pre-processing, on-board analysis and post-processing, as can be seen in the Figure below.

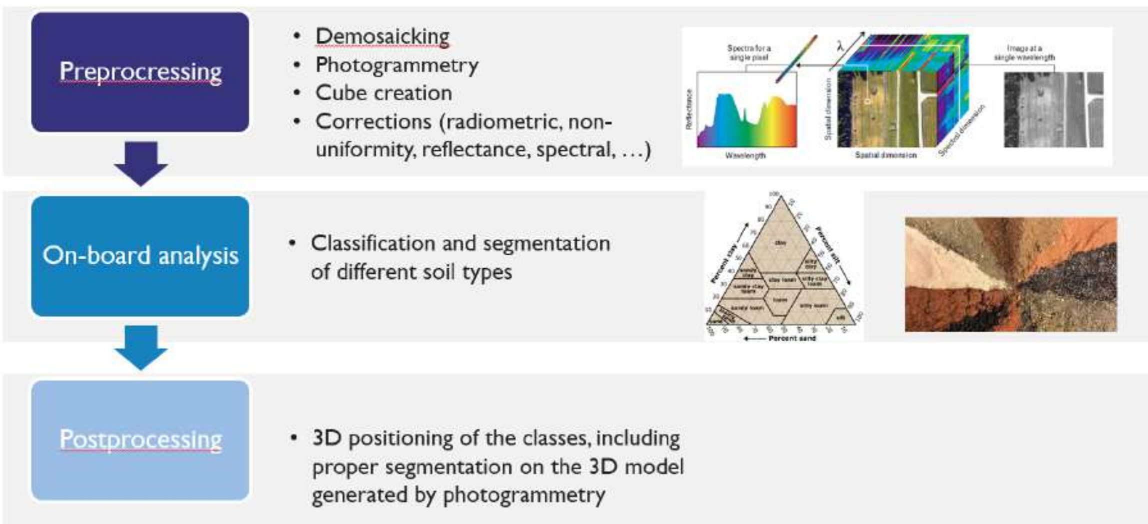


Figure 24: The hyperspectral imaging processing pipeline.

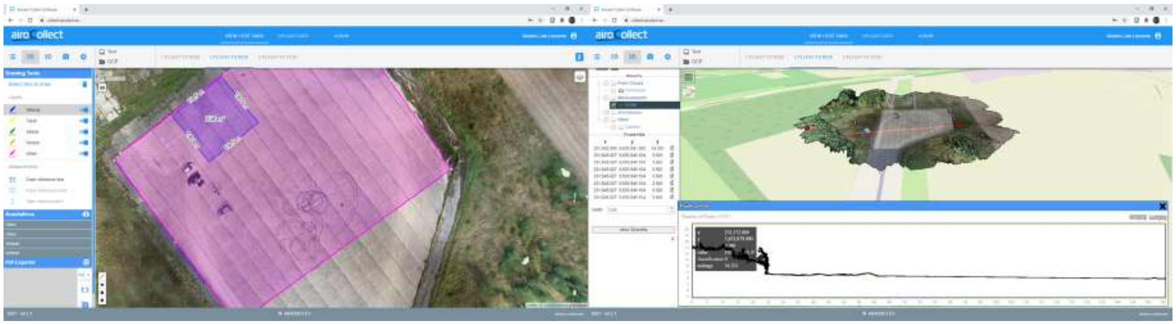
The pre-processing consists of four different sub-modules. First, a demosaicking algorithm is developed to estimate a multispectral image with full spatial-spectral definition. Second, a hyperspectral image cube is created. Third, several corrections are carried out: radiometric, non-uniformity, reflectance, spectral (varying lighting conditions) and corrections coping with degradations due to vibrations, fading, etc. Finally, the hyperspectral images are stitched together and a 3D model is constructed.

The on-board analysis is dealing with the actual classification of the soil, e.g. into silt, clay, sand or mixtures of several types. Special attention will be given to the presence of certain roots, such as the Japanese Knotweed.

CNN-based AI-algorithms are therefore being developed. The purpose is to implement the algorithms on the Jetson TX2 board in order for them to be executed in real-time. This way the soil types of main interest are identified and located online and the drone can be instructed to fly towards the most interested areas in order to limit fly-time and avoid that relevant areas remain uncaptured. The final goal is to achieve automatic HS-image-based classification and segmentation of soil using AI technology with an accuracy of 80% compared to human inspections.

- **Component 5 - Airobot AiroCollect cloud processing infrastructure**

The AiroCollect is a scalable cloud-based software to process, store and share data collected with drones. Today, users can upload RGB images, which are used to automatically generate pointclouds and orthomosaics. This software will be expanded with the IMEC hyperspectral processing chain to quickly process large amount of data.



Partner	Work Package	Components ID	Demo	KPI	Criteria	Measurable Outcome	Objective
AIROBOT	WP4	Component 1 WP4-34	UC4-SCN-1 UC4-SCN-2	UC4-D1-KPI-01 UC4-D1-KPI-01 UC4-D1-KPI-02 UC4-D1-KPI-04	SC2.1	MO2.1	O2
		Component 2 WP4-34			SC2.1	MO2.1	O2
		Component 5 WP4-35			SC2.1	MO2.1	O2
IMEC-BE	WP4	Component 3 WP4-34	UC4-SCN-1 UC4-SCN-2	UC4-D1-KPI-01	SC2.1	MO2.1	O2
IMEC-IPI	WP4	Component 4 WP4-35	UC4-SCN-1 UC4-SCN-2	UC4-D1-KPI-02 UC4-D1-KPI-03	SC2.1	MO2.1	O2

Table 71 UC4 D1 Components List

9.6 Traceability matrices

9.6.1. Requirements vs. functionalities

Requirement	Short description	FUNC 1	FUNC2	FUNC 3	FUNC 4	FUNC 5	FUNC 6
UC4-PRF-01	Perform automated (3D) flight plan					X	X
UC4-SEC-01	Perform manual flight					X	X

UC4-PRF-04	Collect RGB & hyperspectral data	X		X		X	
UC4-PRF-05	Create 3D model based on RGB images				X		
UC4-INT-04	Annotation				X		
UC4-PRF-07	Local processing	X		X			
UC4-PRF-02	Geo-referencing	X	X				
UC4-INT-03	Easy transfer of recorded data and logs to server	X					
UC4-INT-07	View output of hyperspectral camera in real-time	X					
UC4-INT-08	Hyperspectral settings	X					
UC4-PRF-13	Weather – wind					X	
UC4-PRF-14	weather temperature					X	
UC4-PRF-03	Safe BVLOS flight					X	X

Table 72 UC4 D1 Requirements and functionalities traceability matrix

9.6.2. *Functionalities vs. Components*

FUNCTIONALITY	Short description	COMP 01	COMP 02	COMP 03	COMP 04	COMP 05
UC4-D1-FUN – 01	Hyperspectral camera Payload			X		
UC4-D1-FUN – 02	Accurate Georeferencing of data	X	X	X		
UC4-D1-FUN - 03	Onboard Hyperspectral Cube generation			X	X	
UC4-D1-FUN - 04	Offline detailed data processing				X	X
UC4 - D1-FUN - 05	Accurate (3D) flight planning	X	X			
UC4 - D1 - FUN – 06	Remotely managed BVLOS flight	X	X			

Table 73 UC4 D1 Components and functionalities traceability matrix

9.7 Validation plan

9.7.1. *Components Verification*

COMP01 – WP4-34 - Airobot Mapper with AiroCore

Test description	A flight test will be performed at DronePort to demonstrate that a remotely managed, automated mapping flight is possible. The drone will be prepared by an operator in the field. After he clears the area, he will pass on control to a remote operator, who will be in the DronePort building behind his desk (about 1 km away). The remote operator will enter the mapping flight pattern and launch the drone if everything is safe. The drone will perform its mission and collect georeferenced RGB data. After the flight, the remote operator will download the logged images and transfers them to the AiroCollect software.

	Once completed, the operator in the field will remove the propellors and batteries from the drone and take it back inside.
Planned inputs	Airobot Mapper Drone Flight Plan
Expected results	A set of georeferenced images, collected in a mapping pattern, which can be used to generate orthomosaics and pointclouds. Proof that a remotely managed mapping flight can be performed safely.

COMP02:- WP4-34 - Airobot VTOL Mapper with AiroCore

Test description	A flight test will be performed at DronePort to demonstrate that a remotely managed, automated mapping flight is possible. The drone will be prepared by an operator in the field. After he clears the area, he will pass on control to a remote operator, who will be in the DronePort building behind his desk (about 1 km away). The remote operator will enter the mapping flight pattern and launch the drone if everything is safe. The drone will perform its mission and collect georeferenced RGB data. After the flight, the remote operator will download the logged images and transfers them to the AiroCollect software. Once completed, the operator in the field will remove the propellors and batteries from the drone and take it back inside.
Planned inputs	Airobot VTOL Mapper Drone Flight Plan
Expected results	A set of georeferenced images, collected in a mapping pattern, which can be used to generate orthomosaics and pointclouds. Proof that a remotely managed mapping flight can be performed safely.

COMP03 – WP4-34 - IMEC Hyperspectral Payload

Previous test requirements	Component 1 & Component 2 which can perform remotely managed, automated mapping flights
Test description	The IMEC Hyperspectral payload will be mounted on Component 1 and Component 2. A similar mapping mission will be flown.
Expected results	The imec hyperspectral payload will generate hyperspectral cubes which can be used for further processing.

COMP04 – WP4-35 - IMEC Hyperspectral Processing Chain

Previous test requirements	Functioning Component 3
Test description	The hyperspectral cubes generated by component 3 will be used as input for this component.

Expected results	

COMP05 – WP4-35 - Airobot AiroCollect cloud processing infrastructure

Previous test requirements	Functioning components 1,2,3 & 4
Test description	A hyperspectral cube collected with component 3 will be uploaded to the AiroCollect software. The AiroCollect software will pass this data to component 4 and will display the results afterwards.
Expected results	The AiroCollect software will be able to accept the hyperspectral cubes generated by the IMEC hyperspectral payload and show the results from the IMEC hyperspectral processing chain.

9.7.2. Functionality Verification

UC4-D1-FUN – 01 – Hyperspectral Camera Payload

Environment	Goal	Output
Laboratory	Be able to collect hyperspectral images with a non-flying payload.	Hyperspectral raw images
Outdoor controlled	Collect hyperspectral images from flying drone on DronePort	Hyperspectral raw images of terrain at DronePort
Realistic	Collect hyperspectral images on a construction site	Hyperspectral raw images of stockpiles of a construction site

UC4-D1-FUN – 02 Accurate Georeferencing of data

Environment	Goal	Output
Laboratory	Have cm-accurate georeferencing of standard RGB images	RGB images with cm-accurate position embedded in the exit data
Outdoor controlled	Have cm-accurate georeferencing of hyperspectral raw data,	CSV file with a list of positions of the hyperspectral raw data
Realistic	Have cm-accurate georeferencing of hyperspectral cube	CSV file with a list of positions of the hyperspectralcubes

UC4 –D1-FUN- 03 Onboard hyperspectral cube generation

Environment	Goal	Output
Laboratory	Be able to generate a hyperspectral cube on a PC environment	Hyperspectral cube
Outdoor controlled	Be able to generate a hyperspectral cube one Jetson Nano	Hyperspectral cube
Realistic	Be able to generate a hyperspectral cube onboard a flying drone	Hyperspectral cube

UC4-D1-FUN – 04 Offline detailed data processing

Environment	Goal	Output
Laboratory	Load the hyperspectral cube into a manual processing chain and classify the soil types	Validation that different soil types can be classified based on hyperspectral technology
Outdoor controlled	Load hyperspectral cubes into an automated processing chain, generate a 2D orthomosaic & 3D point-cloud	2D orthomosaic & 3D pointcloud including the hyperspectral data
Realistic	Load hyperspectral cubes into AiroCollect software to generate 2D orthomosaics & 3D pointclouds and provide a classification of the data	2D orthomosaic & 3D pointcloud including automated classification of the soil.

UC4-D1-FUN – 05 Accurate (3D) Flight Planning

Environment	Goal	Output
Laboratory	Perform a standard mapping flight pattern at DronePort (simulate stockpile mapping)	Demonstration of mapping flight of area that corresponds to a typical stockpile
Outdoor controlled	Perform a mapping of a large site in multiple flights at DronePort (stimulate large worksite mapping	Demonstration of mapping flights above a large worksite
Realistic	Perform stockpile & large site mapping on an actual construction site	Demonstration of stockpile & large site mapping on real construction sites

UC4-D1-FUN -06 Remotely Managed BVLOS flight

Environment	Goal	Output
Laboratory	Perform a VLOS flight at DronePort where the pilot operates the drone at the test site, using the complete technology chain,	VLOS flight controlled by pilot using BVLOS technology stack
Outdoor controlled	Perform a BVLOS flight at DronePort where the pilote operates the drone from the office. An operator will be at the testsite to take control for safety reasons	BVLOS flight at DronePort, with local operator as back-up
Realistic	Perform a BVLOS flight at an actual construction site	BVLOS flight at DronePort, with local operator as back-up

9.7.3. System Validation

The complete system will be tested on a real construction site to proof all the interfaces and functionalities.

The results of the tests done will be evaluated according to the technical KPI´s defined in for the demonstrator and the compliance of the main functionalities, that allow to verify the features and requirements defined at end user level in the D1.1

For the digitalization of the construction site the validation will be defined into two scenarios: (1) data acquisition of a real stockpile on a construction site and (2) data acquisition on a large earth movement site.

KPI ID	Description	Target Value	Verification Method
Business KPIs			
UC4-D1-KPI-01	Demonstrate that the platform is able to complete a hyperspectral mapping of a 1 Ha site within 30min	Duration of mapping flight < 30min	Measure the time of flight and check that the results cover at least 95% of the complete site
UC4-D1-KPI-02	Demonstrate the software workflow to manage the mapping process; organize and geo-reference the collected hyperspectral data with an accuracy less than 10cm.	Absolute accuracy of 10cm	Collect reference data using traditional GNSS survey
UC4-D1-KPI-03	Demonstrate automatic hyperspectral image-based soil classification using AI technology with an accuracy of 80% compared to human classification.	80% accurate classification	Perform a manual classification of the soil.
Technical KPIs			
UC4-D1-KPI-04	Demonstrate the added value of hyperspectral measurements for automatic classification of soil types on construction sites in realistic conditions (wind up to 5 Beaufort, minimum temperature of -10°C, changing light conditions).	Perform a flight	Perform a flight in wind conditions of 5 Beaufort
UC4-D1-KPI-05	Demonstrate that the drone with an integrated hyperspectral payload is capable to perform safe automated mapping flights and provide geo-referenced hyperspectral data with an accuracy of 10cm	Absolute accuracy of 10cm	Collect reference data using traditional GNSS survey
UC4-D1-KPI-06	Demonstrate the integration of algorithms to restore hyperspectral images by removing image degradations caused by vibrations,	Functionality to demonstrate	Collect reference data in different

	wavelength dependent fading and spectral changes due to lighting conditions.		lighting conditions

Table 74 UC4 D1 system validation plan

10 UC4-Demo2 Surveillance and Inspection: Fleet of multi robot navigating and mapping in an unknown environment

10.1 Current state of the technology

Imagine a large, partially damaged, building in a disaster area: a shopping mall, a hospital, or an industrial complex. Before rescue workers enter the building, a fleet of drones has mapped the area, monitored hazardous gasses, found safe passage ways, and identified human victims that should be rescued, providing the rescue workers with indispensable information. A challenge here is that in this indoor environment there is no GPS, or the GPS is unreliable. The fleet consists of small, lightweight drones; larger drones with processing capabilities, and wheeled rovers. The focus here is on multi-drone collaboration in a GPS denied environment where collaborating drones create a common model of the environment, including automatic detection of points of interest.

This challenge requires a number of advances with regard to the state of the art. The current state of the technology and the improvement steps for the state of the art are described below. We address these by means of the following areas : Simulations allowing for HW in the loops, Sensors and tightly constrained platforms, Test and development platform realisation, Communications, Battery management system.

Simulations allowing for HW in the loop (ALM)

(ALM) A complex demo requires simulations allowing for HW in the loop. Current simulation systems are limited in the sense that TBD. In this project we extend this in the following way. With regard to attractor-based navigation: the current state-of-the-art is: AR tags with ranging based on size, Radio beacons using signal strength as ranging, in the aviation sector, there is the concept of VOR (radio-beacon with ranging based on echo delay).

Attractor-based navigation (ALM). When flying drones inside a building (or e.g. underground) there is no access to GNSS positioning information. However, autonomous drones are currently highly dependent on GNSS. We are looking into alternative navigation aids, with some focus on “carry-in” tools. In this specific component, we are looking at trying to navigate around a centralized beacon (potentially mounted on a rover). This can be done through radio, visual, and mechanical means. Radio beacons currently used are based on various technologies, including BLE, WIFI and Ultra-wide-band antennas. Visual methods can be based on pre-taken pictures, machine-learning, and basic visual markers, e.g. QR-like markers. The most commonly used example of mechanical navigation aids is “tethered” drones.

Within the demonstrator, there will be multiple drones working on the shared exploration task. Given the cluttered environment, it is assumed there will be no global communication capabilities, where all drones can know the same as all others. This lack of global knowledge invalidates many of the planning approaches in the current scientific literature. Through the usage of a “cooperative planner” component, we’re going to cope with this challenge, making use of local, partial communication where possible. In the research fields of game-theory, multi-agent systems, and service orchestration, several strategies for cooperation have been developed. Most of these strategies have not yet been applied within a robotic environment, nor has there been much focus on cooperating robots. An exception to this is the field of Robotic Soccer and similar competitions and challenges, which apply voting-based planning through shared playbooks and role-assignment.

Sensors and tightly constrained platforms (TUD, IMEC-NL, EDI, DEMCON, BUT)

Current state-of-the-art **HDR imaging algorithms** typically target on images/videos captured from stationary cameras. Our algorithms overcome this limitation by application of novel HDR merging and tone-mapping algorithms. We developed a novel robust algorithm for HDR images acquisition based on merging standard frames. The algorithm can be used in power-limited environment for real-time computing. The main idea is based on fusing individual frames into HDR images using advanced weighing functions, which are robust and suitable for acquisition of high-quality HDR in UAV application. The method achieves, despite the low requirements on resources, results comparable to state-of-the-art de-ghosting methods.

(TUD) Micro Air Vehicles (MAVs) are increasingly being used for complex or hazardous tasks in enclosed and cluttered environments such as surveillance or search and rescue. Despite important efforts, it is quite disconcerting to note how difficult it is to autonomously achieve one of the most essential tasks for drones, namely, obstacle detection and avoidance. The complexity is essentially due to the difficulty to detect obstacles in the focus of expansion, where the optic flow is close to zero. This problem gets even harder in real environments where, for instance, the light intensity can change, sometimes abruptly, making it impossible to ensure the robustness of autonomous systems for obstacle detection and avoidance. In this project we extend the state of the art by developing cutting-edge neuromorphic solutions based on event-based cameras and radars to achieve robust and reliable obstacle detection and avoidance in challenging environments (e.g., dim light conditions, smoky environment).

(IMEC-NL) **Spiking Neural Networks (SNNs).** State-of-the-art components rely on single sensor (LiDar / Radar / Camera / ToF) for collision avoidance and do not rely on event-based sensing technologies. However, cameras and radar are complementary sensors that can augment each other. The radar has the capability to directly measure an object’s range and radial velocity. While classical signal processing can be applied efficiently to detect large objects, discriminating people, or others, from clutter in traffic environments remains a difficult task. This is mainly due to the fact that people are poor radar energy reflectors and they move slowly relative to the static environment. Additionally, the effects of multipath propagation of radar signals are difficult to model explicitly due to the unknown and ever-changing scene geometry, especially in moving platforms. Yet, detecting moving people in radar data can be performed based on the unique pattern of motion of the human body and on their camera images.

(EDI) Bio-inspired localization algorithms. A first step is to replicate the experiments in [Banino 2020] while also trying to determine and generalize the conditions that lead to the emergence of grid cell-type neurons. We are also currently preparing the virtual environments, where the grid cell agent will perform reinforcement learning and navigation-related tasks. To go beyond SoA, EDI plans to add a third movement dimension to the simulated agent. We will try to demonstrate the emergence or the lack of grid cell-type neurons in agents that move in 3D since we are interested in using this bio-inspired navigation approach for drones.

(EDI) Hardware accelerated Optical flow and SLAM. In many aspects, the component builds on the previous work of Angelopoulou & Boudanis [Angelopoulou 2011, Angelopoulou 2014]. The two main advancements are that the accelerator adopts BRIEF feature descriptor (and Hamming distance for feature matching) which is more suitable for hardware implementation, and the accelerator is tailored for heterogeneous processing, i.e. it is fully pipelined and adopts streaming interfaces for more efficient (DMA-based) communication with the processor. The solution would make it more feasible to calculate SLAM algorithms on drone's on-board computer.

The **Simultaneous Localization and Mapping (SLAM)** problem is a well-known problem in robotics, where a robot has to localize itself and map its environment simultaneously. A computational problem of constructing and updating a map of an unknown environment while simultaneously keeping track of its location within it. The traditional and most commonly used methods for solving "the SLAM problem" are with: the Kalman filter, particle filter, graph, and bundle adjustment-based methods. Kalman filters such as EKF (Extended Kalman Filter) and UKF (Unscented Kalman Filter) have provided successful results for estimating the state of nonlinear systems and integrating various sensor information. However, traditional EKF-based methods suffer from the increase of computation burden as the number of features increases. To cope with this problem, particle filter-based SLAM approaches (such as FastSLAM) have been used. While particle filter-based methods can deal with a large number of features, the computation time still increases as the map grows. Graph-based SLAM methods have recently received considerable attention, and they can provide successful real-time SLAM results in complex and large (urban) environments. The origin of SLAM can be traced way back to the 1980s and 1990s when the robotics industry was building up robots for industrial automation. Developing robots that can operate or navigate with-out colliding into other objects. Anno 2020/2021 preliminary forms of SLAM are commercially implemented in indoor cleaning robots for mostly more structured environments. SLAM capabilities for complex, dynamic and large (urban) environments, like autonomous cars/planes/vessels, are not yet commercially and industrially available and are at a TRL5+ level.

Utilizing ROS/ROS2 in **safety-critical embedded applications with real-time requirement** is challenging because of C1) Non-real-time underlying hardware, C2) No control on the host OS scheduler, C3) Unpredictable dynamic memory allocation, C4) High resource requirement, and C5) Unpredictable execution model for ROS nodes. In this project, we address these limiting factors by proposing a hardware-software architecture -CompROS- for ROS2 based robotic development in a Multi-Processor System on Chip (MPSoC) platform. Comparing to the state of the art, we believe that ComnpROS is the first framework which aims predictable and composable robotic development in both hardware and software level.

Communications (TNL, ANYWI)

(TNL) The possibilities of collecting sensor observations in areas where the connectivity between drones and base stations is difficult is limited. In a scenario where communication can be routed through intermediate drones, the communication mechanisms of Disruption Tolerant Networking (DTN) can be of use. However, they need adaptation as currently DTN is designed for a non-ad hoc situation where connectivity is possible on a time-scheduled basis. Moreover, currently streaming communication (such as for video) is not possible with DTN.

(Anywi) Multi-link (-path/-home) networking has several decades of history, and offers reliability via fail-over mechanisms. Existing technologies exhibit several limitations: either built-in reliability measures interfere with tunnelling arbitrary drone-to-ground or drone-to-drone communications, or one must forego security features. AnyWi proposes a novel protocol unifying these requirements, and focuses in particular on timely discovery and quality estimation of available links based on e.g. 5G/LTE, Wi-Fi or similar technologies.

Battery management system (UWB, SM)

A DronePort equal autonomous battery swap system is not available on the market currently. The main idea of the DronePort system: "autonomous battery management for a fleet of drones" is novel and any suitable hardware, software or approach to do that is not available. Also, the main subsystems of our solution are not ready to be taken over from another existing projects. Main subsystems are: 4DOF robotic actuator, battery module with automatic high power and data connectors, battery gripper to handle the battery module and DronePort base module. Only the 4DOF DronePort robotic actuator could be substituted by a commercial 4 or 6 DOF robotic arm but with limitation in size, weight and availability.

10.2 Use Case Concept of Operation (2-3pg. maximum)

Inside the indoor area to be explored there are a number of «victims» modelled as heat sources.

Before rescue workers enter the building, a fleet of drones will map the area and identified human victims that should be rescued, providing the rescue workers with indispensable information. Here, there is collaboration between the flying drones, but also between the flying drones and the ground-based drones (e.g. rover) that is assisting the drones and providing processing capacity. Below is the concept of operation:

1. First, a rover (wheel-based) drone is being driven into the environment. The rover will act as a reference point for areal drones exploring the environment.
2. Then, flying aerial will enter the environment and start exploring.
3. Through this exploration the system as a whole (rover, control station and drones) will create a common model of the environment, together with points of interest, (e.g. (simulated) human victims, heat-sources) created from the individual viewpoints of the various drones. The system provides a live view of the exploration to the control station operator.
4. The system will be flexible and adaptable enough to cope with a changing environment and/or failure of part of the system (e.g. drone-loss). It is assumed that the rover will have a stable, uninterrupted communication channel with the control station.
5. Finally, this model created by the system can be used to find safe routes of access to these points of interest, for example to extract victims.

This demonstrator is aiming at TRL level 4-6 at the end of the project. This will be reflected in the chosen KPI's. The use case is focusing on major technological enhancements from the SOTA as addressed by partners. The demonstrator acts mostly as a showcase and validation tool of the progress in the state of the art of the various components the partners are creating.

A challenge here is that in this indoor environment there is no GPS, or the GPS is unreliable. The fleet consists of small, lightweight drones; larger drones with processing, and wheeled rovers. The focus here is on multi-drone collaboration in a GPS denied environment where collaborating drones create a common model of the environment, including automatic detection of points of interest. The multi-drone collaboration includes collaboration between drones with various processing constraints. This collaboration is associated with the exchange of data via communication links, therefore special attention is paid to robust communications.

To give an idea an existing collapsed fire station model has been used, which mimics the type of environments that the Use-case is targeting. See image below.

Figure 25 Collapsed building virtual recreation

10.3 System Requirements, KPI´s and Metrics

To have clear idea of the objectives and purpose of the demonstrator it is important to highlight the main metrics defined in deliverable D1.1 and that will lead to the definition of the most applicable requirements of the systems and components developed within the project.

The main technical requirements for the demonstrator are shown below and Annex 1 includes both the main requirements and all those that are considered to have an influence on the development of the systems and components that will allow the objectives of the demonstrator to be carried out. In turn, these requirements will be related to the technological KPIs defined for the demonstrated although not always all the requirements can be related, since it can be a type of requirement imposed by the boundary conditions, the regulation or by integration needs.

10.3.1. Technical KPI`s and Metrics

Technical KPIs

ID	Definition and measurement of Indicator	Target Value
UC4-D2-KPI-10	Demonstrate accelerated HW/SW able to do classification faster than SOTA and with lower power, compared to current non-accelerated solutions.	Value to reach (10 x faster, and 10 x lower power)
UC4-D2-KPI-11	Detect & avoid collisions during operations in BVLOS taking place in shared environments. Accuracy of classification, and navigation abilities in uncontrolled and novel environments.	Functionality to demonstrate
UC4-D2-KPI-12	Robust communication in cluttered environment.	Percentage to reach Target value: on average reach a 10-fold decrease in packet

	Capabilities in terms of channels used, packet delay/round trip times, bandwidth estimates and available channels employed.	loss ratio, with < 10% added overhead.

Table 75 UC4 D2 List of KPIs

10.3.2. Main requirements (functional, interface, performance, security, usability…)

Requirement ID	Short Description	Description	Priority	Source	KPI´s
UC4-DEM2-FNC-05	Common model creation	The aerial platform shall use SLAM for modelling the environment.	H	DEMCON, EDI, ALMENDE	UC4-KPI-07 UC4-KPI-11
UC4-DEM2-FNC-06	Common model creation	The System shall use SLAM for semantical rich modelling and simulation.	H	ALMENDE	UC4-KPI-07
UC4-DEM2-FNC-07	Autonomous Battery Management	The DronePort system shall provide landing spot for autonomous landing.	H	Smart Motion, UWB	UC4-KPI-09
UC4-DEM2-FNC-08	Autonomous Battery Management	The DronePort system shall autonomously exchange or charge battery of the drone.	H	SmartMotion, UWB	UC4-KPI-09
UC4-DEM2-FNC-09	Autonomous Battery Management	The DronePort system shall handle battery management.	H	SmartMotion, UWB	UC4-KPI-08 UC4-KPI-09
UC4-DEM2-FNC-11	Autonomous Battery Management	The Droneport control software shall handle battery management.	H	UWB, SmartMotion	UC4-KPI-08 UC4-KPI-09
UC4-DEM2-FNC-12	Autonomous Battery Management	The Droneport communication protocol shall support command for the refuelling process.	H	UWB,SmartMotion	UC4-KPI-11 UC4-KPI-12
UC4-DEM2-FNC-13	Autonomous Battery Management	The Droneport control software shall plan the refuelling mission.	H	UWB	UC4-KPI-08 UC4-KPI-09
UC4-DEM2-INT-03	Communication	The rover shall be able to act as a radio hub between drones and a ground station.	H	ANYWI, TUE	UC4-KPI-12
UC4-DEM2-INT-04	Communication	The system shall use standardized interfaces such as ROS2, MAVlink and Wi-Fi for communication.	H	TNL, ANYWI, TUD	UC4-KPI-12

UC4-DEM2-INT-05	Autonomous Battery Management	The Droneport communication protocol shall be based on MAVLink messaging protocol.	H	UWB, SmartMotion	UC4-KPI-12
UC4-DEM2-INT-06	Autonomous Battery Management	The drone shall communicate using MAVLink messaging protocol.	H	UWB, SmartMotion	UC4-KPI-12
UC4-DEM2-PRF-07	Autonomous Battery Management	The Droneport control software shall manage the energy refuelement requests for multiple drones.	H	UWB	UC4-KPI-09
UC4-DEM2-SEC-04	Verification and Validation	A drone system validation framework shall be provided.	H	BUT	UC4-KPI-09

Table 76 UC4 D2 List of Main Requirements

10.4 Functionalities identification

These functionalities could be either **hardware functionalities, software functionalities, modules, etc**. All of them together will intrinsically define the final system. As it was done for the requirements, Table 77show the functionalities identified for the demonstrator 2.

ID	Functionality	Description	System function
FUN – 01	Optic flow object detection and avoidance	This feature detects objects by means of optic flows.	Obstacle Detection and Avoidance
FUN – 02	Neuromorphic image processing	Image processing via neural networks combining optic flows and radar.	Obstacle Detection and Avoidance
FUN - 03	Object detection SW in drones	Object detection by means of daylight and IR cameras.	Obstacle Detection and Avoidance
FUN - 04	Aerial platform	Embedded platform with tight constraints on weight and processing power.	System and Environment Status
FUN - 05	Vehicle platform	Embedded platform with relaxed constraints on weight and processing power.	System and Environment Status
FUN -06	Robust Networking	Component to provide store and forward communications to guarantee message delivery in difficult communication situations.	Network Centric Communications
FUN - 07	Drone to Ground GW	Component to provide robust communications between drone and ground station.	Network Centric Communications

FUN - 08	Smart Control logic	Control logic to provide early detection of low energy situations.	Intelligent Vehicle System Monitoring
FUN -09	Simultaneous localization and mapping	Logic to provide localization based on images.	Simultaneous Localization and Mapping
FUN-10	Failsafe online reconfiguration	Tools to provide online reconfiguration of drone software in such a way that critical safety aspects remain guaranteed.	Intelligent Vehicle System Monitoring
FUN-11	Decision strategies for drone fleet	Logic to assign tasks to drones based on their status and the current situation.	Swarm formation and cooperation UAV and UGV

Table 77 UC4 D2 List of Functionalities

10.5 Components

The following are the components addressed in this demonstration:

1. Attractor based navigation
2. Cooperative Planner
3. Map Enhancement
4. Shared reference frame
5. Visual analytics
6. HDR & Multi Spectral Imaging
7. 3D SLAM algorithms
8. Bio-inspired localization algorithms
9. Hardware accelerated Optical flow and SLAM
10. Sensory fusion in FPGA (Vision + Radar)
11. Resilient Communication
12. Spiking Neural Networks & Sensory Fusion for drone navigation
13. Droneport traffic control
14. Path manager to monitor connection availability and quality of the different base communication channels for drone use
15. API to supply communication link state metainformation to path manager

Partner	Work Package	Components	Demo	Component ID	KPI	Criteria	Measurable Outcome	Objective
ALM	WP4	Attractor-based navigation	UC4 D2	COMP01 WP4-20	Improve autonomy	SC2.1	MO2.1	O2
ALM	WP4	Cooperative Planner	UC4 D2	COMP02 WP4-10	Improve cooperation among drones	SC2.1	MO2.1	O2

ALM	WP4	Map Enhancement	UC4 D2	COMP03 WP4-14	Improve data analytics	SC2.1	MO2.1	O2
ALM	WP4	Shared reference frame	UC4 D2	COMP04 WP4-22	Improve cooperation, mission autonomy	SC2.1	MO2.1	O2
ALM	WP4	Visual analytics	UC4 D2	COMP05 WP4-15	Improve data analytics	SC2.1	MO2.2	O2
BUT	WP4	HDR & Multi Spectral Imaging	UC4 D2	COMP06 WP4-43	Improve inspection quality	SC2.1	MO2.1	O2
DEMCON	WP4	3D SLAM algorithms	UC4 D2	COMP07 WP4-38	Improve mission autonomy and data analytics	SC2.1	MO2.1	O2
EDI	WP4	Bio-inspired localization algorithms	UC4 D2	COMP08 WP4-23	Improve mission autonomy, safety	SC2.1	MO2.1	O2
EDI	WP4	Hardware accelerated Optical flow and SLAM	UC4 D2	COMP09 WP4-24	Improve safety, mission autonomy	SC2.1	MO2.1	O2
IMEC-NL	WP4	Sensory fusion in FPGA (Vision + Radar)	UC4 D2	COMP10 WP4-01	Improve safety, mission autonomy	SC2.1	MO2.1	O2
TNL	WP5	Resilient Communication	UC4 D2	COMP11 WP5-20	Improve mission autonomy	SC2.1	MO2.1	O2
TUD	WP4	Spiking Neural Networks & Sensory Fusion for drone navigation	UC4 D2	COMP12 WP4-01	Improve safety, mission autonomy	SC2.1	MO2.1	O2
UWB	WP4	Droneport traffic control	UC4 D2	COMP13 WP4-19	Improve mission autonomy , mission safety	SC2.1	MO2.1	O2

ANYWI	WP5	Path manager to monitor connection availability and quality of the different base communication channels for drone use	UC4 D2	COMP14 WP5-12	Improve mission autonomy , mission safety	SC2.1	MO2.1	O2
ANYWI	WP5	API to supply communication link state metainformation to path manager	UC4 D2	COMP15 WP5-13	Improve mission autonomy , mission safety	SC2.1	MO2.1	O2

Table 78 UC4 D2 List of <components

10.6 Tools

Next table maps the tools to KPIs, project success criteria's, measurable outcomes and objectives.

Partner	Work Package	Description	Tool ID	KPI	Criteria	Measurable Outcome	Objective
ALM	WP6	Simulation of UC4Demo2, Single rover, multiple drones in an indoor environment, (e.g. smoke-simulation, point of interest, 3-D obstacles) Cloud hosting of the simulation for the project.	ALM Cloud-based Simulation	Although not directly a measurement tool, the tool will support: UC4-D2-KPI-10 UC4-D2-KPI-11	SC2.1	M02.1	02

Table 79 UC4 D2 List of Tools

10.7 Traceability matrices

10.7.1. Requirements vs. functionalities

Requirement	Short description	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
UC4-DEM2-INT-10	single, trained operator from the control station											x
UC4-DEM2-PRF-02	detect moving objects.	x	x	x								
UC4-DEM2-FNC-04	Reconfigure itself in real-time while maintaining operational.										x	
UC4-DEM2-FNC-05	use SLAM for modelling the environment.									X		
UC4-DEM2-FNC-06	use SLAM for semantical rich modelling and simulation.									x		
UC4-DEM2-FNC-07	provide landing spot for autonomous landing.									X		
UC4-DEM2-FNC-08	autonomously exchange or charge battery of the drone.				x				x			
UC4-DEM2-FNC-09	handle battery management.				x				x			
UC4-DEM2-FNC-11	handle battery management.				x				x			
UC4-DEM2-FNC-12	support command for the refuelling process.							x	x		X	
UC4-DEM2-FNC-13	shall plan the refuelling mission.				x				x			

UC4-DEM2-INT-03	act as a radio hub between drones and a ground station.					x	x	x			x	
UC4-DEM2-INT-04	standardized interfaces such as ROS2, MAVlink and Wi-Fi for communication.						x	x		x		
UC4-DEM2-INT-05	based on MAVLink messaging protocol.						x	x			x	
UC4-DEM2-INT-06	communicate using MAVLink messaging protocol.						x	x				
UC4-DEM2-PRF-07	manage the energy refuelement requests for multiple drones.								x			
UC4-DEM2-SEC-04	Drone system validation framework							X				
UC4-DEM2-FNC-05	use SLAM for modelling the environment.									X		
UC4-DEM2-FNC-06	SLAM for semantical rich modelling and simulation.									x		
UC4-DEM2-FNC-07	provide landing spot for autonomous landing.								x			

Table 80 UC4 D2 Requirements and functionalities traceability matrix

10.7.2. Functionalities vs. Components

The table below links all the components that are part of this demonstrator to the main functionalities defined:

FUNCTIONALITY	Short description	Wp4-20	WP4-10	WP4-14	WP4-22	WP4-15	WP4-43	WP4-38	WP4-23	WP4-24	W{P-01	WP4-19	WP5-12	WP5-13	WP5-20
FUN – 01	Optic flow object detection and avoidance							x		x					
FUN – 02	Neuromorphic image processing									x	x				
FUN - 03	Object detection SW in drones	x				x	x								
FUN - 04	Aerial platform	x			x	x				x	x	x			
FUN - 05	Vehicle platform												x	x	x
FUN - 06	Robust Networking														x
FUN - 07	Drone to Ground GW												x	x	
FUN - 08	Smart Control logic							x	x						
FUN - 09	Simultaneous localization and mapping		x	x	x			x							
FUN- 10	Failsafe online reconfiguration														
FUN- 11	Decision strategies for drone fleet		x		x										

Table 81 UC4 D2 Components and functionalities traceability matrix

10.8 Validation plan

Below the per component validation plans are provided. As described in D1.1, this use case is focused on major technological enhancements from the SOTA on the component level. The partners act as product owners, focussing on specific components. The demonstrator as a whole is aiming at TRL level 4-6 at the end of the project. For this reason, there are no system-level validation plans envisioned. In effect, the demonstrator acts as a showcase and validation tool of the progress in the state of the art of the various components.

- **COMP01- WP4-20 - Attractor based navigation**

Previous test requirements	Having a drone navigate effectively based on standard aids, e.g. GPS, IMU, audio rangers
Test description	The drone will be flying in a GNSS-limited environment, e.g. indoor. For testing purposes, a drone will fly with switched off GPS antenna, relying on the radio beacon setup for localization
Planned inputs	UWB beacon triangulation data as position estimate

Expected results	Effective localisation and navigation, allowing basic collision avoidance in a pre-known map environment. Landing navigation support close to the beacon.

- **COMP02 – WP4-10 - Cooperative Planner**

Previous test requirements	Basic autonomous navigation per drone Existing mission strategy per drone
Test description	Comparison of mission efficiency when multiple drones are working together on a similar mission, with several limitations of communication between these drones.
Planned inputs	Exploration mission definition, multiple drones
Expected results	Efficiency enhancements on the mission, e.g. shorter overall time for completing the mission

- **COMP03 – WP4-14 - Map Enhancement Service**

Previous test requirements	Drones capable of basic SLAM User interface to the SLAM results (e.g. ROS's rViz)
Test description	The map enhancement service aims at introducing semantic-rich map information, prediction maps and a novel approach to map merging between multiple drones, for the purpose of enhancing navigation strategies and more effective SLAM. It's still unclear what sort of enhancements these will be, so defining a SMART test at this stage is complex.
Planned inputs	Exploration mission definition, multiple drones, unknown cluttered environment.
Expected results	Map usage advantages (Not quantified at this stage)

- **COMP04 – WP4-22 - Shared reference frame**

Previous test requirements	Drones capable of basic SLAM
Test description	As part of the above-mentioned components (map enhancements and cooperative planner) a shared navigation reference frame is needed. Normally this is a global map, fixed by GNSS. However, during the exploration of an unknown area by multiple drones they need to share a common, potentially non-grounded, reference frame. Checking the usability and robustness of such a frame definition is done in this test.
Planned inputs	SLAM outputs of the various drones
Expected results	A common location description of the drones, through which they can perform collision avoidance, mission planning, etc.

- **COMP05.- WP4-15 - Visual Analytics**

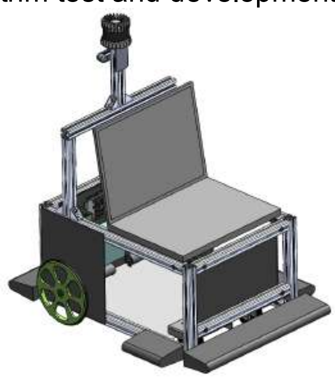
Previous test requirements	Drones capable of basic SLAM User interface to the SLAM results (e.g. ROS's rViz)

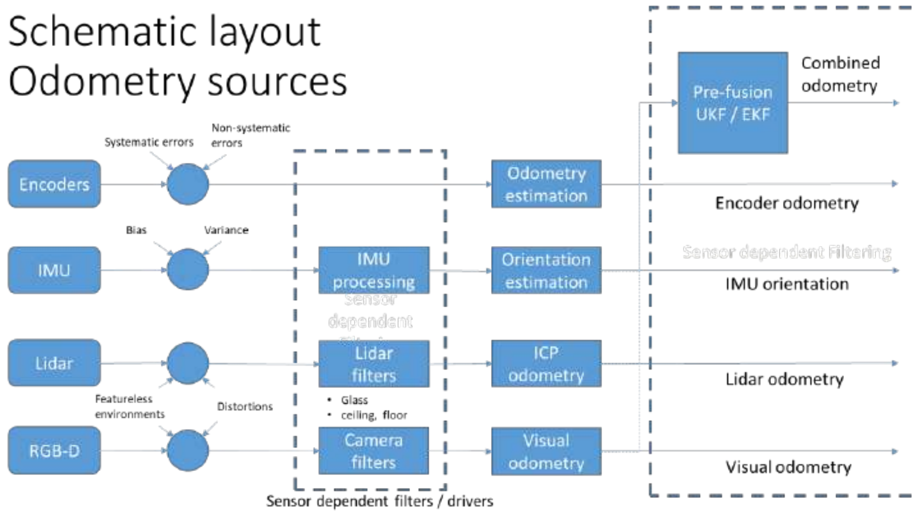
Test description	Involving the human operator of the drone system (Pilot) to provide the semantic information for the map enhancement service, and testing novel augmented reality approaches for providing information feedback to the operator.
Planned inputs	SLAM outputs of the various drones Additional (merged) sensor output of the drones Human operator inputs
Expected results	Semantic input to the map enhancement service Better situational awareness for the operator

- **COMP06 –WP4-43 - HDR & Multi Spectral Imaging**

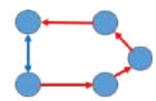
Previous test requirements	Processing of HDR images from publicly available datasets.
Test description	Raw frames will be processed by our HDR fusion algorithm and compared to the conventional state-of-the-art methods. The output will be videos that will be evaluated using state-of-the-art HDR assessment quality methods.
Planned inputs	Raw frames with varying (known) exposure times captured by the UAV.
Expected results	HDR and tone mapped video which can be displayed on conventional displays and results from HDR quality assessment methods.

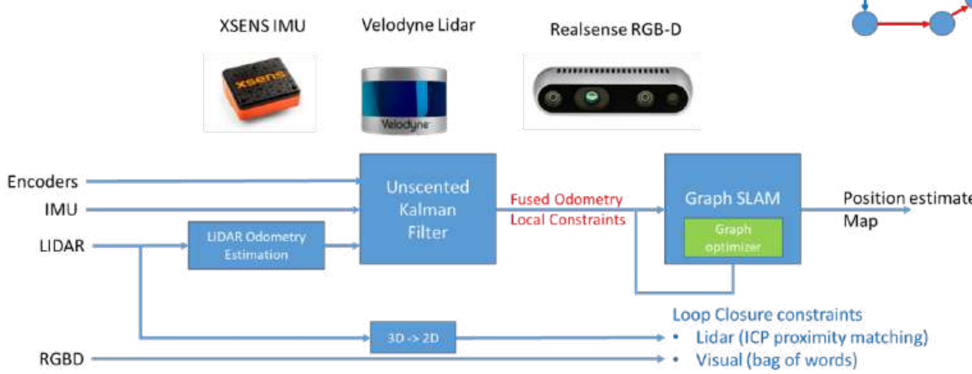
- **COMP07 - WP4-38 - Simultaneous localization and mapping**

Test description	Different navigation sensors will be fitted on a driving “test & development” platform for the SLAM algorithm test and development purposes.   The following schematic layout of the Graph SLAM model will be tested onboard the driving platform on an embedded compute module:

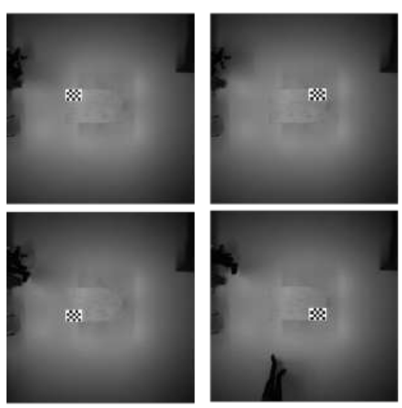


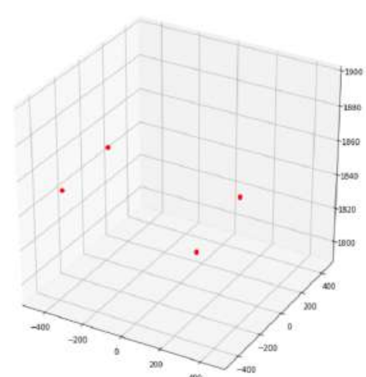
The following diagram shows the test components:





The test includes an optical tracking system made with markers placed in 4 corners:





<table>
<tr>
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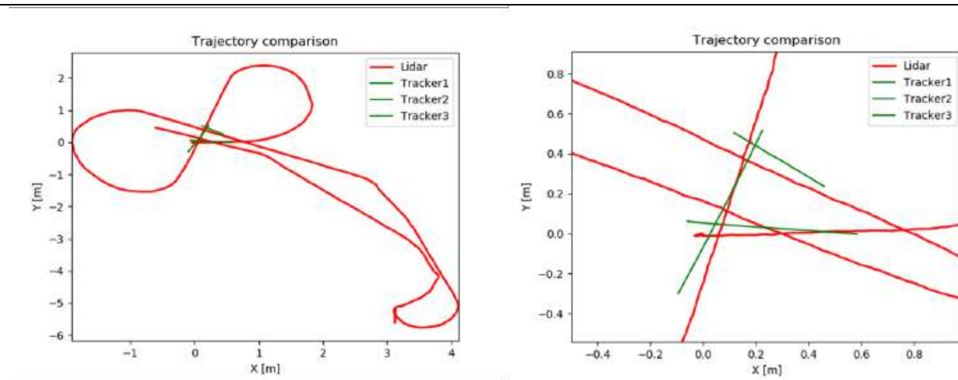
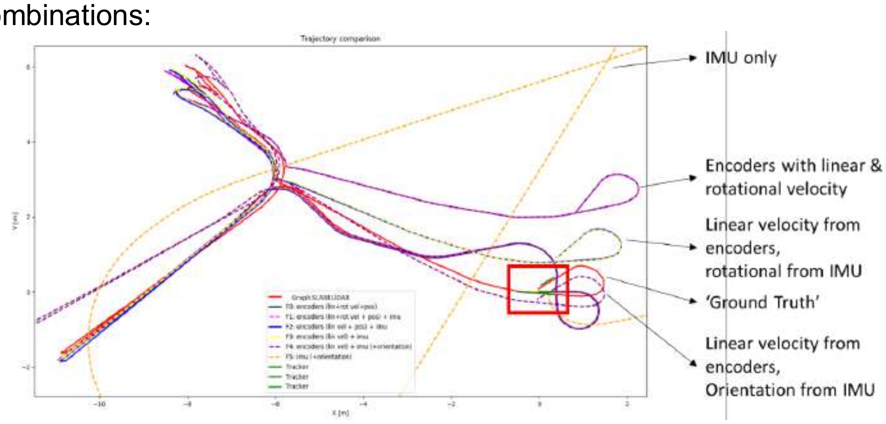
<td>


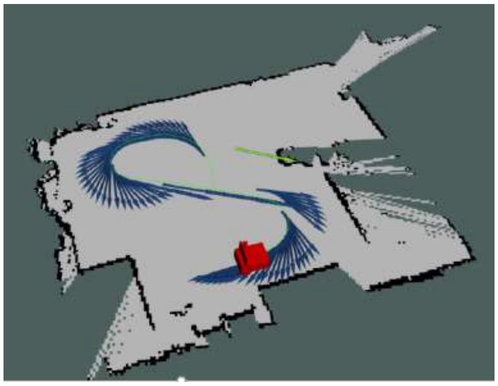
At the small green lines are the movements tracked by the optical camera for the ground truth.
The following figure shows the UKF Sensor Fusion with LiDAR including all sensors and combinations:



</td>
</tr>
<tr>
<td><u>Planned inputs</u></td>
<td>
LiDAR SLAM inputs:

LiDAR: point cloud
RGB camera: left, right and depth image
IMU: acceleration (m/s) data and rotation (deg/sec)
Encoders: counting rotation 360 deg (1024 counts per revolution) processed in a simple model between wheelbases we can extract a simple path.

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

Expected results	Quantification of the performance of our sensor fusion framework, combining different sensor input. The goal to define a reliable and robust sensor (fusion) combination for at least 10cm position accuracy. 

- **COMP08 – WP4-23 - BIO-INSPIRED LOCALIZATION ALGORITHMS**

Previous test requirements	- The bio-inspired localization component shall enable agent to localize itself in a small (2m x 2m) 2D environment. - The agent shall be able to autonomously plan its route to a given destination in a simple obstructed environment. - The agent shall be able to localize itself with a precision of 10cm after moving 4 meters. - The agent shall be able to reach destination checkpoint with a precision of 10cm. - The agent's generated trajectory shall not deviate from optimal trajectory by more than 20%.
Test description	Initially, the testing will be executed in a Gazebo/ROS simulation environment where the agent has an attached camera. First, tests will be performed using a rover, thus the localization problem will concern localizing and moving through 2D space. By the end of the project, the approach should be validated using a drone agent and thus adopting NN training procedures and methods for 3D localization. If the simulation test results are successful, the tests shall be performed with an actual drone in a controlled environment - a drone cage with a local ground-truth positioning system.
Planned inputs	Camera data generated by the simulator and ground truth data for training and comparing purposes. In a later phase of the validation, the simulated data will be switched to data from a real onboard camera and ground truth data from a visual positioning system. In both cases, the agent shall be supplied with the target location which should be reached.
Expected results	The component shall provide two outputs: (1) approximate position in the current reference frame and (2) signals for control actuators which should guide the agent towards the target position.

- **COMP09 – WP4-24 - HARDWARE -BASED OPTICAL FLOW AND SLAM**

Previous test requirements	- Drone's SLAM component shall work in real-time with control loop's duration not greater than 200 ms. - Drone's optical flow accelerator shall simultaneously track at least 20 points. - Drone's optical flow component shall be able to produce outputs with a frequency of at least 20 Hz. - Drone's optical flow component shall be able to perform with images of at least VGA (0.3 Mega Pixel) resolution.
Test description	The component is tested and validated in real-time via HiL setup, where the developed accelerator is fed with images from a host machine. The images are either generated from an industrial camera or are prerecorded with an actual drone flight. In a later phase of the project, the component shall be deployed in a heterogeneous SoC-based autonomous flight controller and its output will be used by the drone software stack for localization.
Planned inputs	Video streams from an industrial camera and a camera attached to a drone.
Expected results	The accelerator outputs more than 200 tracked points depending on the configuration which can be used for reconstructing motion from vision. Sideways to the correspondences, the component supplies feature descriptors, which can be used for onboard calculation of SLAM.

- **COMP10 – WP4-01 - Sensory Fusion in FPGA**

Previous test requirements	By exploiting complementary sensors (camera and radar) this component can detect fixed and moving obstacles in low visibility conditions, low-light conditions, and in different weather conditions (fog, rain, cluttered environment).
Test description	We have benchmarked a first version of the spiking neural network accelerator using standard machine learning datasets (such as handwritten digits and cropland classification using radar and camera images). Tests are currently being performed in the lab, using the collected datasets. The dataset will be split using 80% training and 20% testing with k-fold validation analysis. Latency, energy, accuracy, number of gates and other metrics will be measured.
Planned inputs	Complex (I/O) radar samples, Address Event Representation of contrast changes from DVS240. Camera Images. These will be streamed to our FPGA platform using a memory map interface. Neural network training and efficient implementation.
Expected results	*Object detection, classification, and tracking.* Tracking obstacles with the following quantities: distance, angle, speed, magnitude, confidence of detection in real-time and on-board of drone (using digital FPGA platforms)

- **COMP11 – WP5-20 - Resilient Networking**

Previous test requirements	DTN (Disruptive Tolerant Networking component) implemented and running for all embedded devices that are taking part in the demonstration. There should be a video source and an application able to display the video.
Test description	The Robust networking component will receive the video form a drone and will send it to the base station. We consider here the following scenarios. In all scenarios a video will be offered from the drone with as destination the base

	station. The final result will be that the video will be displayed. The following scenarios are considered. • Direct link - there is a line of sight between the video node and the base station. • Multi-hop – there is no direct link from source to destination, but there is a path to the destination via one or more nodes. • No link - there is no direct link from source to destination, and there is also not a path from source to destination. • Custody - there is no direct link from source to destination, but there is a partial path from source to destination.
Planned inputs	In all scenarios video is offered from a drone with as destination the base station.
Expected results	• Direct link – in this case the video is shown at the base station • Multi-hop – in this case the video is shown at the base station • No link - in this case the video is stored at the source node until a path to the destination becomes available and we obtain the Direct link or Multi- hop scenario • Custody - in this case the video is stored at both the source and intermediate node until a path to the destination becomes available and we obtain the Direct link or Multi- hop scenario.

- **COMP14 – WP512 - MULTIPATH COMPONENT (ANYWI)**

Test description	The validation process is based on set of tests covered by software component called toolkit. The toolkit is represented by Figure 26: Toolkit general overview where System under test (SUT) represents component 14 - *Path Manager*. The toolkit resides outside SUT and it simplifies SUT to the level of black box, without having any knowledge of its internal logic. The toolkit should cover common test scenarios, including edge-cases for multi-path networking. Tests are meant to be isolated cases, during which for each input or change of input toolkit knows what to expect at the exit of SUT as a positive outcome. Therefore, two components of toolkit should be created, one for data analyzation (DA) and another for data simulation (DS) from different sources. Assuming there is possibility for SUT to have multiple inputs and outputs (e.g. path manager having input from Connection Management API and Link Status API), here are all considered fused into only one instance. Failing any of test scenarios should mean system failed the validation process.
Planned inputs	Toolkit should be able to simulate any information exchange relevant to SUT.
Expected results	Validate robustness of *Path Manager* and demonstrate improved reliability of the data link between drone and ground compared with a single link.

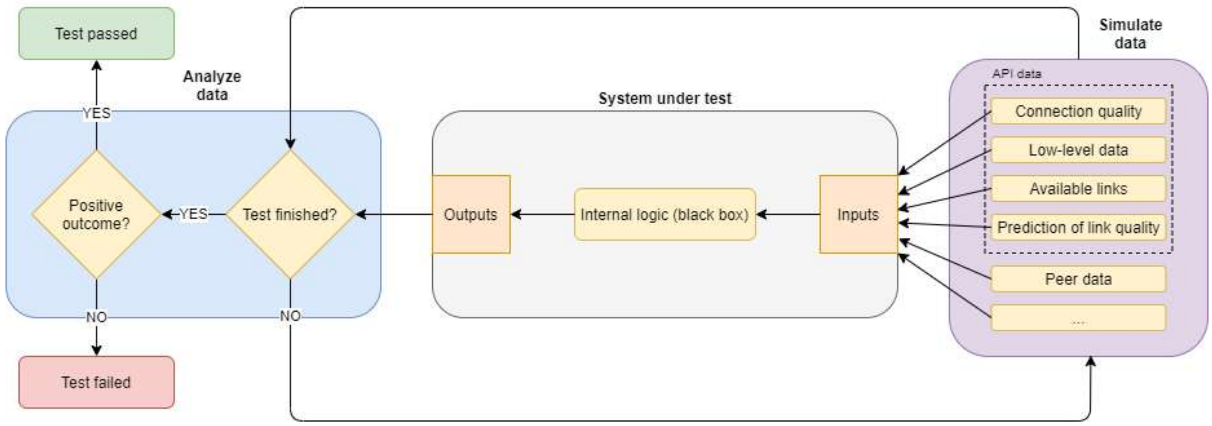


Figure 26: Toolkit general overview

- **COMP15 – WP5-13 - API to supply communication link state metainformation to path manager**

Test description	*Same as for component 14 with the difference that SUT represents component 15 - API. Additionally, there are differences in Expected results.*
Planned inputs	*Same as for component 14.*
Expected results	Validate that *API* provides accurate and precise metainformation (e.g. presence of network module, link status, link quality data, connection quality data, list of available links etc.) crucial for multi-link system.

11 UC5-Demo1: Agriculture: Wide Crop Demonstrator

11.1 Current state of the technology

The general assumption at the base of agriculture there is the concept of performing ***the correct action/treatment exactly when is needed and where is needed***. This assumption requires users to have precise knowledge of the health status and growth evolution of the crops/plants under scrutiny, which imply in turn investing a lot of effort in inspection and treatment actions that are traditionally carried out by human operators.

There are both subjective and objective reasons for manual operations to be performed. On the one hand, many operators are still convinced that manual operations are better than automatic ones, since can be easily performed exactly where needed, i.e., specific treatments with manual pumps to reduce a given infestation may allow the actions to be taken locally on the involved plants rather than on the whole field. On the other hand, it might be the case that heavy machinery cannot be used depending on the characteristics (i.e. orographic difficulties) and current conditions (i.e. flooded fields) of the fields to be treated.

Networks of sensors and IoT concepts are increasingly adopted in the agricultural sector for collecting meaningful information concerning the spatial and temporal characteristics of the soil composition and crop monitoring. UAVs enable faster and more frequent remote sensing than manual processes and are much more flexible than ground infrastructures. Moreover, aerial operation enables the acquisition of a big amount of data, under different environmental condition, that can be used by agronomists and scientist to create accurate models and to evaluate the status of vegetation indexes like the chlorophyll content, the leaf water content, the ground cover and Leaf Area Index (LAI), and the Normalized Difference Vegetation Index (NDVI). For these reasons, UAVs are already widely adopted in agriculture for monitoring processes but most of the traditional Smart-farming UAV applications still rely on the traditional pattern where the drone is principally used for data acquisition. Such data, collected by different sensors such as multi-spectral sensors, RGB, and thermal camera, LiDAR, are then elaborated offline to determine the state of the crops.

In this demonstrator the idea is to give evidence that certain manual operations can be perfectly carried out in an autonomous manner by advanced autonomous systems, reducing the impact on the environment of certain operations (i.e. precisely sizing the amount of water and pesticides to be used and acting on spot where needed, promptly activating treatments at the first symptoms on individual crops/plants), while saving human effort.

The general purpose is the development and assessment of Smart and Precision Agriculture Technologies to enable:

1. **Real-time field monitoring and inspection**, i.e. detection symptoms disease and cross-correlation of plants indexes;
2. **Prompt on-field intervention**, i.e. customized spot spraying;
3. **Improve non-real time actions**, i.e. forecast on production volume and optimized water management.

11.2 Use Case Concept of Operation

This demonstrator includes three possible operational scenarios, already described in deliverable D1.1. Each scenario consists of four phases: Observe, Orient; Decide; Act. Each phase grows incrementally along the three scenarios of execution and maps the COMP4DRONES principle of modular composability of drone technologies. For the sake of clearness, a brief description of the three scenarios and related figures is reported hereinafter:

- Scenario 5.1.1: image campaign acquisitions to determine the precise tree crowns and water needs. Intervention is manual and distributed to the shole field (see Figure 27).
- Scenario 5.1.2: smart drone to determine where actions are needed. Intervention is still manual but distributed locally (see Figure 28).
- Scenario 5.1.3: smart drone to determine where actions are needed and to communicate with a rover. Local intervention is automatically and autonomously managed by the rover (see Figure 29).

For further details on the use case concept of operation please refer to deliverable D1.1.

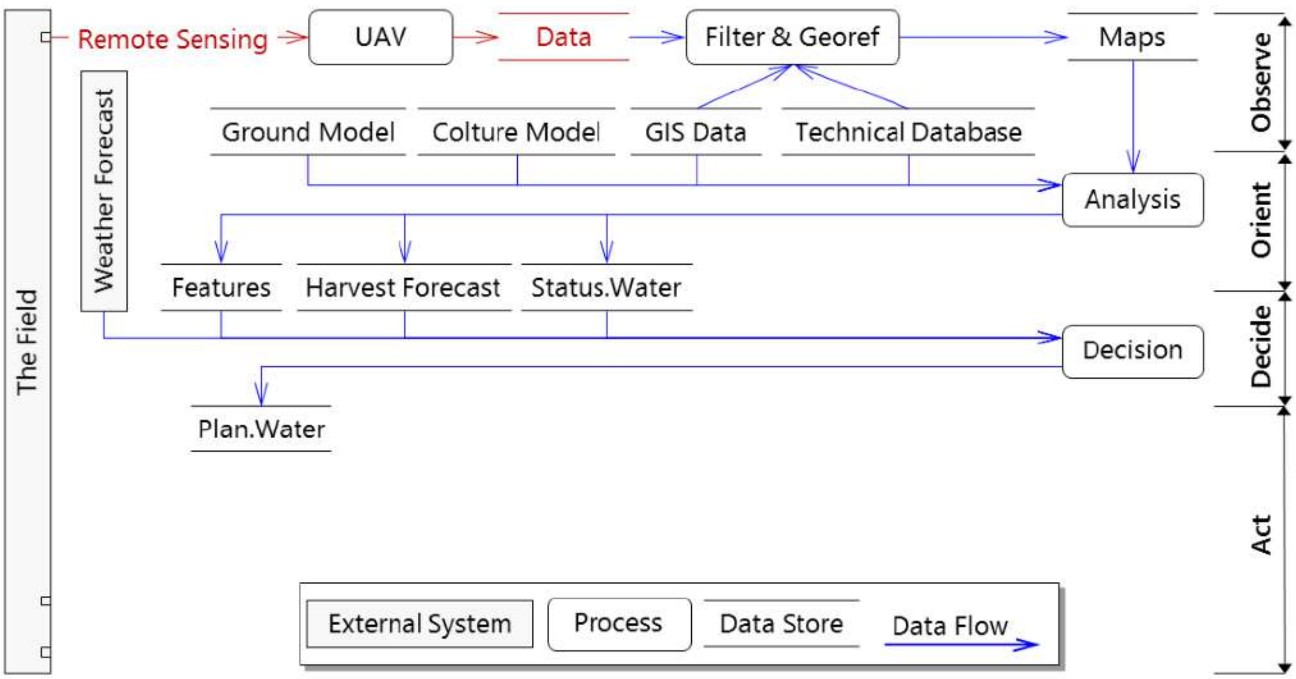


Figure 27 UC5 – D1 Scenario 5.1.1

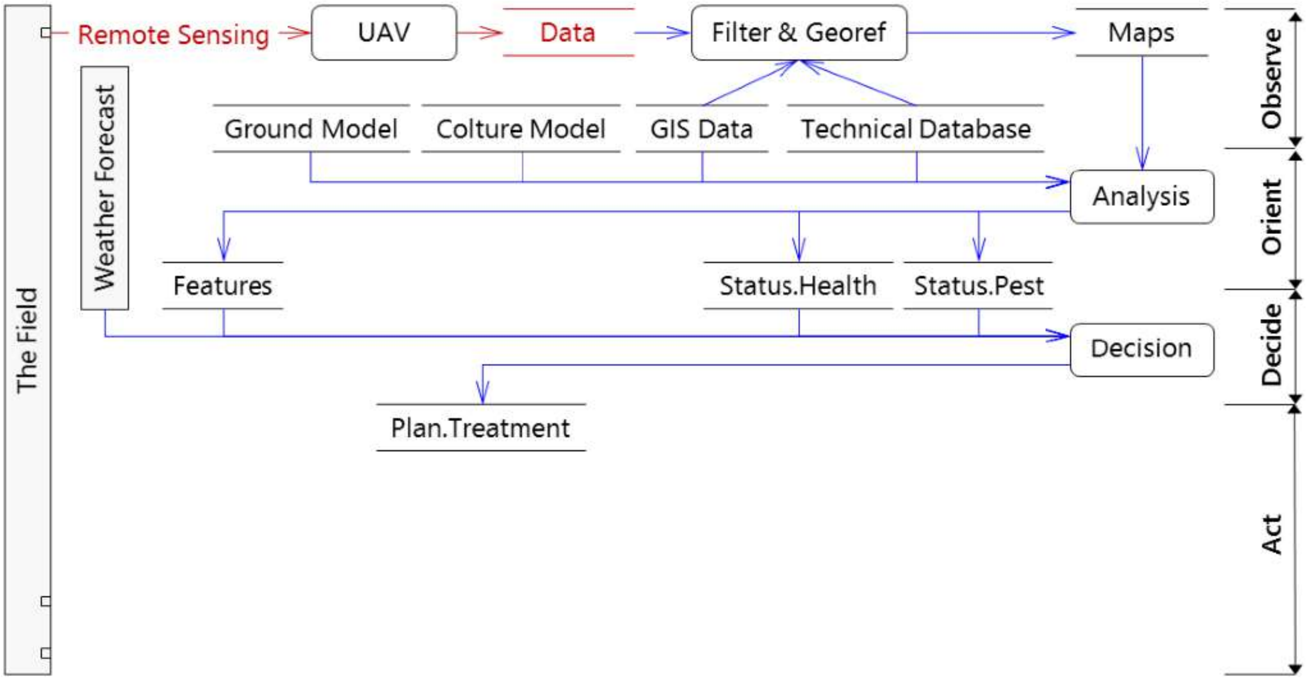


Figure 28 UC5 – D1 Scenario 5.1.2

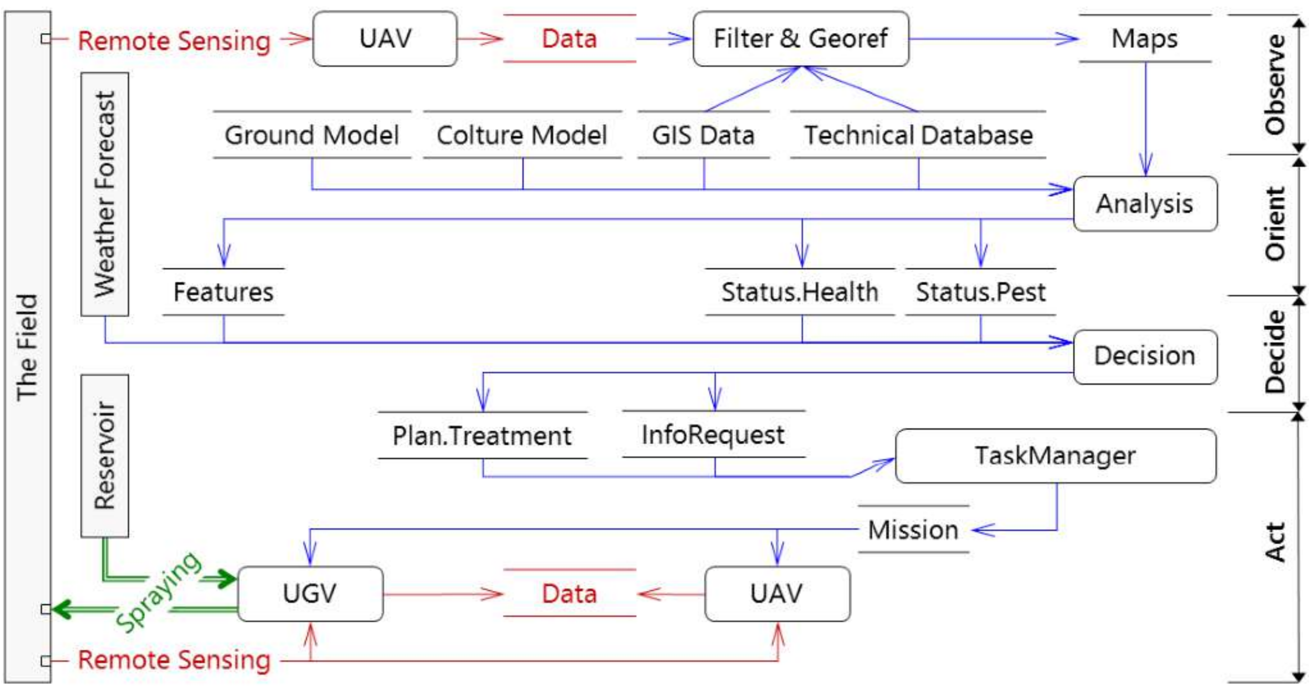


Figure 29 UC5 – D1 Scenario 5.1.3

11.3 System Requirements, KPI´s and Metrics

In order to validate the demonstrator and its components, it is important to highlight the main metrics defined in deliverable D1.1. The following sections depict the KPIs and the main technical requirements for the demonstrator, Please, consider that:

- NOT all the requirements can be related since it can be a type of requirement imposed by the boundary conditions, the regulation or by integration needs.
- The KPIs have been defined ONLY for the most innovative and advanced part of the demonstrator.

11.3.1. Technical KPI`s and Metrics

Table 82depicts the list of the Key Performance Indicators for the technology, as defined in D1.1 and here updated. It is important to note that during the elicitation phase of the requirements a new KPI has been defined.

nº	**KPI**	**Definition and measurement of indicator**	**Target value**
		Business KPIs	
KPI - B1 (UC5-DEM10-KPI-001)	Drone mission duration	Comparison between data acquisition/post-processing executed through drone mission and actual reference values in the agricultural domain.	Target are task specific, but it is expected a complete automation of traditionally manually operated tasks (i.e., grape counting and weed detection).
KPI - B2 (UC5-DEM10-KPI-002**)**	Drone and UGV mission in field for monitoring and weed/pest control	Comparison in % of reduction in resources consumption (i.e., water, fertilizers) between traditional mechanisms and distributions/sizing leveraging on C4D technologies.	A reduction in the use of pesticides using organic products is expected to vary in the estimated percentages from 5% to 10% This measure will be evaluated through indirect measures.
KPI - B3 (UC5-DEM10-KPI-003)	Availability of cooperative UGV and UAV 1. Operational communication 2. Mission accomplishment	• Energy consumption charts. • Average time among two faults in communications, CRC errors. • Localization errors charts.	1. the energy will be evaluated only in laboratory and compared to the actual value (trl very low) 2. the average time among two faults in communication between UGV and UAV lower than 5s or in any case

			doesn't provoke to stop the mission 3. localisation errors lower than the average distance between 2 field plants
Technical KPIs			
KPI - T1 (UC5-DEM10-KPI-004**)**	Comparison with approaches in the State of the Art with regards to FPGA-based acceleration (i.e., Xilinx SDSoC): • Easy to design and deploy • Easy to develop applications for heterogeneous platforms (ARM GP core + FPGA acceleration blocks) • Improvements in performance and resource consumption (FPGA slices)	• Number of lines of code. • Execution time, clock cycles and energy consumption per offloading and execution. • Other application-specific metrics (e.g., FPS, latency)	1. Simplified definition of the HW Processing Unit and automated system integration 2. Reduced effort to achieve target performance (time to solution); better use of resources (for equivalent functionality) 3. Performance and resource consumption improvements are task specific and cannot be currently estimated in terms of target.
KPI - T2 (UC5-DEM10-KPI-005**)**	Accuracy in the prediction of the behaviour of the system through SIL / HIL methodologies	Relevant parameters (e.g. mean quadratic error, peak error) for accuracy analysis of the SIL/HIL outputs with respect to real measurements.	We target to achieve mean quadratic errors and peak errors of the generated trajectories which are smaller than those achieved through model-in-the-loop approaches (e.g., Matlab).
KPI - T3 (UC5-DEM10-KPI-006)	Accurate SLAM technique implementation / no-GPS positioning system	• Localization accuracy. • Orientation capabilities with geomagnetic field mapping.	Positioning accuracy comparable to GPS performance to the level of allowing GPS-free mission in the target application.
KPI - T4 (new)	Usage of automatically captured images for inspection purposes on field using collaborative UAV and UGV	number of images correctly classified vs number of total images correctly captured	recognition accuracy of 85%

Table 82 UC5 D1 List of KPIs

11.3.2. Main requirements (functional, interface, performance, security, usability…)

Table 83maps the main requirements to the KPIs. Please, notice that some requirements are mapped to UC5-Demo1 business KPIs, not reported in this document. For details about the business KPIs see deliverable D1.1. Please, notice also that, as explained in the introduction of this section, for some requirements a mapping is not applicable.

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
Functional					
UC5-DEM10-FNC-003	System Navigation	The system shall provide a path in order to perform the image acquisition campaign.	H	UNISANNIO	KPI-B1
UC5-DEM10-FNC-004	Computational Platform	The system should enable advanced onboard computation by means of dedicated and optimized accelerators.	M	UNISS-ENG UNIMORE	KPI – T1
UC5-DEM10-FNC-07	AI Algorithms for monitoring and prediction purposes to identify leaf diseases	AI algorithms shall be designed, trained and tested to detect and identify parasite animals and to classify leaf diseases using imaging sensor data.	H	AITEK, UDANET	KPI - T4
Interface					
UC5-DEM10-INT-005	Autopilot Communication Interface	The Autopilot of target drone shall be capable to address and process conditional instructions provided by additional components (e.g. Companion on-board Computer).	H	TOPVIEW	Not Applicable
UC5-DEM10-INT-006	GNSS Receiver Interface	The Autopilot of target drone shall be capable to interface GNSS receivers with suitable positioning performance.	H	TOPVIEW	Not Applicable
Security					
UC5-DEM10-SEC-002	Intrusion Detection System module	There shall be designed a module that shall guarantee the detection of unauthorized access to the network, in order to avoid the introduction of dangerous information or the data breach.	H	ROT	KPI-B3

Table 83 UC5 D1 List of Main Requirements

11.3.3. Drone integration requirements

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC5-DEM10-FNC-008	Autonomous Navigation	The system shall integrate SLAM algorithms to allow the drones to safely navigate and interact with the environment.	H	MODIS	KPI – T3
UC5-DEM10-INT-001	On board camera	The drone shall mount an onboard camera (the type of cameras will be defined) to acquire images.	H	AITEK UDANETMODIS	KPI - T4
UC5-DEM10-INT-002	Data Storage	The drone shall be equipped with an onboard unit capable to store images.	H	ROT	KPI-T1
UC5-DEM10-INT-003	Video streaming to ground station	The drone shall stream video and images to the ground station allowing run-time or off-line (after mission conclusion) processing in the ground station.	H	AITEK UDANETMODIS ABI	KPI - T4

Table 84 UC5 D1 List of Drone Integration Requirements

11.4 Functionalities identification

The characterizing functionalities of this demonstrator are identified starting from the three scenarios identified above and are connected to the features identified in deliverable D1.1, in section "*Key Concept and Technologies*" of UC5 Demo1. Table 85depicts an extract of these functionalities and their mapping to the system functionalities. For more details, please refer to the deliverable D1.1. Please, notice that some functions, to ease their validation, have been divided into sub-functions.

The function FUN –01, Processing platform, has been divided into:

- FUN – 01 is related to the modular companion infrastructure
- FUN – 01.1 is focused on the platform performance analysis

The function FUN – 03, Drone/Rover safe cooperation, has been divided into:

- FUN – 03 embraces secure communication between the UAV and the UGV
- FUN – 03.1 is related to the actual physical cooperation UAV-UGV identification, communication, and positioning.

ID	Functionality	Description	System function
UC5-D1-FUN – 01	Processing platform: On-board processing platform	Modular companion computer infrastructure, based on COTS FPGA SoCs. **(see feature F1.2 in D1.1)**	System and Environment Status – Intelligent Data Handling
UC5-D1-FUN - 01.1	Processing platform: Advanced processing platform configuration	Processing platform performance analysis based on a model-driven approach to find alternative configuration paths. Heterogeneous HW/SW processing platform models based on COTS FPGA SoCs **(see feature F1.2 in D1.1)**	System and Environment Status – Data fusion and processing
UC5-D1-FUN – 02	On board video acquisition and processing	Video content analysis solutions based on AI to: Enabling precise tree **crowns definition** for water management and harvest forecast. Monitoring and processing to **detect exact location of un-healthy crops/plants** **(see feature F1.1 in D1.1)**	Advanced on-board information processing capabilities
UC5-D1-FUN - 03	Drone/rover cooperation: security and embedded discrete-time controller	Safe cooperation will be ensured with a secure communications framework. An Intrusion Detection System avoids malicious attacks through hybrid encryption algorithms to prevent unauthorized access in a lightweight manner. Efficient digital implementation of discrete–time controllers on FPGAs will be integrated; Compensation and rejection of environmental perturbations, measurement uncertainties, and possible faults will be ensured; Management functionalities of critical situations, with improved situation awareness, will be guaranteed; Predictive power autonomy awareness approaches will be released. **(See feature 2 and feature 4 in D1.1.)**	Coordination – UAV and UGV Communication
UC5-D1-FUN – 03.1	Drone/rover cooperation: UAV-UGV identification, communication, and positioning.	Identification and communication are provided by a Low Power Wide Area Network medium range system, and by an Ultra-Wideband short-range system. The latter can also measure the distance between vehicles: based on this a guidance algorithm controls the *positioning phase* of the *autonomous approach, positioning, and landing*. Guided by the GPS the UAV approaches the UGV and then, if the UGV is not in the field of view of the dedicated video camera that controls the landing, the guidance algorithm drives the UAV to the correct position. **(See feature 2 and feature 4 in D1.1.)**	Coordination — UAV and UGV. Flight navigation. Positioning.

UC5-D1-FUN - 04	Automatic runtime Path planning	Design a path planner with suitable computation time such that it can be executed at runtime, enabling drones to safe autonomous decisions, i.e., without human intervention. Autonomous and cooperative flight aerial-terrestrial drones functionalities will enable reference generation for autonomous navigation. **(See F3.1 in D1.1.)**	Planning and navigation
UC5-D1-FUN - 05	Energy Management System	Design a hierarchical real-time control of unmanned aerial vehicles with rule-based strategy for mission time and energetic references generator based on optimal control theory. The objective of functionality is to design a control which ensures energy consumption close to optimality, and easily implementable thanks to its low computational cost. **(see F3.4 in D1.1)**	Energetic trajectory generation and control
UC5-D1-FUN - 06	Advanced SLAM algorithm and sensing capabilities	Advanced SLAM algorithms and sensing capabilities to allow drone positioning in the mission area even in presence of failures of the GPS. In particular, lack of GPS is compensated by magnetic field, odometry and distances from fixed points in the map. The core of the system is an Extended Kalman filter. **(see F5 in D1.1)**	Positioning

Table 85 UC5 D1 List of Functionalities

11.5 Components

Several components implement different scenarios of the demonstrator. These components have been described in detail in deliverables D3.1, D4.1 and D5.1. The scope of this section is to map the components with project indicators and to explain how they are going to be validated. Therefore, for the sake of conciseness we do not report their description here.

Please, note the WP3-related components here reported are named as in D3.1 but there is a mismatch between the deliverable D3.1 and the related component list IDs. In some cases, the component names from D3.1 do not correspond to the component names reported in the component list file. Furthermore, some couples of components have, in the component list file, only one ID and are here reported with an additional letter to identify them (i.e., COMP 01 – WP3.20.a, COMP 02 – WP3.20.b).

Please, note also that the component list has been revised. The component "Video and Data Analysis Algorithms" described in deliverable D3.1 (Sections 4.1.16 and 6.16) has been merged with component "AI Drone System Modules" (described in D3.1 Sections 4.1.13 and 6.13) in component COMP 03.

Table 86 maps the components to KPIs, project success criteria's, measurable outcomes, and objectives.

Partner	Work Package	Components	Component Number	KPI	Criteria	Measurable Outcome	Objective
MODIS	WP3	Highly Embedded Customizable Platform for SLAM technique	COMP01 (WP3-20.a)	Ease of HW/SW integration	SC1.1	MO1.1	O1
MODIS	WP3	Simultaneous Localization and Mapping Algorithms	COMP02 (WP3-20.b)	Ease of HW/SW integration	SC1.1	MO1.1	O1
UDANET - AI	WP3	AI Drone System Modules (merged with *Video and Data Analysis Algorithms* component - D3.1 Sect. 4.1.16 and 6.16)	COMP03 (WP3-36.a)	KPI - T4	SC4.1	MO4.1	O4
UDANET	WP3	Smart and Predictive Energy Management System	COMP04 (WP3-36.b)	Improving modelling and simulation accuracy	SC4.1	MO4.1	O4
UNIMORE UNISS	WP3	Onboard Programmable and Reconfigurable Compute Platform Design Methodology	COMP05 (WP3-22, WP3-28)	Easy to design, develop, and deploy applications	SC1.1 SC1.2	MO1.3	O1
UNIMORE	WP3	Onboard Programmable and Reconfigurable Compute Platform Design Methodology	COMP08	Easy to develop applications for heterogeneous platforms	SC1.2 SC4.1	MO1.3 MO4.1	O1 O4
UNISS	WP3	Onboard Programmable and Reconfigurable Compute Platform Design Methodology	COMP09	Improvements in performance and resource consumption	SC4.1	MO4.1	O4
UNIVAQ	WP3	Efficient Digital Implementation of Controller on FPGAs	COMP06 (WP3-24.a)	Improvements in performance and resource consumption	SC4.1	MO4.1	O4
UNIVAQ	WP3	Mixed-Criticality Design Space Exploration	COMP07 (WP3-24.b)	Easy to design and deploy	SC4.1	MO4.1	O4
				Improvements in performance and resource consumption	SC4.1	MO4.1	O4
AIK	WP4	Embedded AI obstacle detection and avoidance	COMP08 (WP4-44)		SC2.1	MO2.1	O2
MODIS	WP4	Resilient Positioning	COMP09 (WP4-11)	Improve positioning accuracy	SC2.1	MO2.1	O2

TEKNE	WP4	Transponder for drone-rover	COMP10 (WP4-18)	Drone-to-rover positioning for landing.	SC2.1	MO2.1	O2
TOPVIEW	WP4	High Accurate GNSS	COMP11 (WP4-40)	hardware with self-contained power and connectivity. Ease of HW integration	SC2.1	MO2.1	O2
UNISANNIO	WP4	Path Planning Algorithms	COMP12 (WP4-08)		SC2.1	MO2.1	O2
UNISS UNIMORE	WP4	Application-Specific Accelerator	COMP13 (WP4-09)	Easy to design and deploy	SC1.1, SC1.2	MO1.3	O1
				Easy to develop applications for heterogeneous platforms (FPGA SoCs)	SC1.2, SC4.1	MO1.3 MO4.1	O1 O4
				Improvements in performance and resource consumption	SC4.1	MO4.1	O4
UNIVAQ	WP4	Autonomy, cooperation, and awareness	COMP14 (WP4-33)		SC2.1	MO2.1	O2
MODIS	WP5	GPS Spoofing Detection Module	COMP15 (WP5-07-MODIS)	Data link availability	SC3.1	MO3.2	O3
ROT	WP5	Lightweight Cryptography	COMP16 (WP5-08-ROT)	Improve network performance	SC3.1	MO3.1	O3
TEKNE	WP5	LPWAN for Identification, Tracking, and Emergency Messages	COMP17 (WP5-05-TEK)	Data link availability	SC3.1	MO3.2, MO3.3	O3

Table 86 UC5 D1 List of components

11.6 Tools

Table 87 maps the tools to KPIs, project success criteria's, measurable outcomes and objectives. For details about tools description please refer to deliverable D6.1.

Partner	Work Package	Description	Tool ID	KPI	Criteria	Measurable Outcome	Objective
UNIMORE	WP6	Application development tools for the heterogeneous on-board computing platform	Tool WP6-13	The tool will indirectly address UC5-DEM10-KPI-004, even if the UC will not validate the tools directly, which are not visible to the final user.	SC4.1	MO4.3	O4
UNISANNIO	WP6	AirMPL-Simulator	Tool2 WP6-14	UC5-DEM10-KPI-005	SC4.1	MO4.2	O4
UNISS	WP6	MDC: Multi-Dataflow Composer	Tool3 WP6-15	The tool will address UC5-DEM10-KPI-004 even if the UC will not validate MDC directly, since the tool has not any “visibility” at user level.	SC4.1	MO4.1	O4
UNISS ABI	WP6	SAGE Verification Suite	Tool4 WP6-16	The UC will not validate the tools in the SAGE Suite directly, since it has not any “visibility” at user level.	SC4.1	MO4.2	O4
UNIVAQ	WP6	HEPSYCODE: HW/SW Co-Design of Heterogeneous Parallel Dedicated Systems	Tool5 WP6-17	DTC-07 DTC-08 DTC-09 DTC-10 DTC-11 DTC-12	SC4.1	MO4.1	O4

Table 87 UC5 D1 List of Tools

11.7 Traceability matrices

11.7.1. Requirements vs. functionalities

Table 88maps the requirements to the functionalities. Please, notice that at the end of the table there are some requirements, not described in this deliverable, that map some functions.

Requirement	Short description	FUN01	FUN 01.1	FUN02	FUN 03	FUN03.1	FUN 04	FUN 05	FUN06
Main requirements									
UC5-DEM10-FNC-003	The system shall provide a path to perform the image acquisition campaign.					X			
UC5-DEM10-FNC-004	Advanced onboard computation	X							
UC5-DEM10-FNC-007	AI algorithms			X					
UC5-DEM10-INT-005	Address and process conditional instructions					X			
UC5-DEM10-INT-006	Interface GNSS receivers					X			
UC5-DEM10-SEC-002	This module shall guarantee the detection of unauthorized access to the network.				X				
Drone integration requirements									
UC5-DEM10-FNC-008	SLAM algorithms								X
UC5-DEM10-INT-001	Onboard camera			X					
UC5-DEM10-INT-002	Onboard unit to store images ROT			X					
UC5-DEM10-INT-003	Stream video and images for run-time and off-line processing.			X					
Design technology requirements									
UC5-DEM10-DTC-04	Offloading capabilities from the host processing system to the FPGA Overlay UNIMORE	X							

UC5-DEM10-DTC-05	Configuration of application-specific accelerators UNIMORE	X							
UC5-DEM10-DTC-06	Definition of on-board accelerators	X							
UC5-DTC-07	Design Space Exploration for mixed-criticality requirements		X						
UC5-DTC-08	SystemC models integration		X						
UC5-DTC-09	Hierarchical (hypervisor-based) scheduling Emulation		X						
UC5-DTC-10	Hypervisors characterization		X						
UC5-DTC-11	Time granularity independent simulation time		X						
UC5-DTC-12	Simulation time reduction		X						
UC5-DTC-41	Path planner simulation						X		
UC5-DEM10-DTC-42	Software criticality category support						X		
UC5-DEM10-DTC-43	Critical situations management						X		
UC5-DEM10-DTC-44	Solutions verification			X					
Others (see Annex 1)									
UC5-DEM10-FNC-001	The system shall provide a short-range communication link by which the unmanned vehicles (UAV and UGV) can communicate for identification, cooperation, and positioning.					X			
UC5-DEM10-FNC-002	The system should provide a long-range communication link by which the unmanned vehicles can be identified.					X			

UC5-DEM10-PRF-01	Energetic trajectory generation							X	

Table 88 UC5 D1 Requirements and functionalities traceability matrix

11.7.2. 1.1.1 Functionalities vs. Components

FUNCTIONALITY	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
F1					X								X				
F1.1							X										
F2			X														
F3						X										X	
F3.1										X	X						X
F4								X				X		X			
F5				X													
F6	X	X							X						X		

Table 89 UC5 D1 Components and functionalities traceability matrix

11.8 Validation plan

Considering the Validation and Verification methodology explained in the introduction of the document, all the requirements, components and tools have been identified and related to the main functionalities through the traceability matrices. This loop is closed with the verification and validation plan that acts at three different levels: components verification, functionalities verification and system validation.

11.8.1. Components Verification

COMP01 – WP3-20a - Highly Embedded Customizable Platform for SLAM technique

Test description	*The drone will sense the environment and the GPS signal in order to perform SLAM positioning and anti-spoofing.*
Planned inputs	*Environmental measurements as required by SLAM and GPS signal.*
Expected results	*Effective support to SLAM and anti-spoofing.*

COMP02 –WP3-20b - Simultaneous Localization and Mapping Algorithms

Previous test requirements	*Setup of the ICT infrastructure required for determining the distance of the drone from reference points in the map. This infrastructure consists of ultrasound Bluetooth sensors deployed in the reference test environment.*
	Due to covid19 limitation we might resort to purely simulated tests.
Test description	*The drone will sense the environment via magnetometers, accelerometers ad ultrasounds and by performing some computations will estimate its position within the mission map without resorting to GPS.*
Planned inputs	*Measurements of magnetic field, odometry and distances from fixed references.*
Expected results	*Drone position with the map.*

COMP03 – WP3-36a - AI modules for video analytics

Previous test requirements	Image collection campaign using the drone. Such images will be used to train the AI based algorithms (mainly CNN). A subset of such images will not be used for training but they will be preserved for some preliminary tests.
	In case of limitation to on-field activities due to covid19, the training set will be completed using simulated data (e.g., image datasets available online).

Test description	The AI modules for video analytics will receive images collected by onboard cameras. By means of the Neural Networks appropriately trained and deployed the video analytics functions will be executed. Some analysis will be done considering computational requirements of each NNs as well as detection precision and detection time.
Planned inputs	Images captured by the drone
Expected results	Plants detection Eventual disease recognition

COMP04 – WP3-36b - Smart and Predictive Energy Management System

Test description	*The test consists of evaluating the battery consumption with respect to the proposed mission based on battery discharge and comparing it with other trajectories in a laboratory/simulated environment.*
Planned inputs	*Initial and final position of the mission*
Expected results	*Compared to state-of-the-art solutions, the energy management system wants to tackle the optimal control problem by giving particular emphasis to the computational aspect. The objective is to find the energetic reference generator to track going from initial to final position that can be used by the controller.*

COMP05 –WP3-22; WP3-28 - Onboard Programmable and Reconfigurable Compute Platform Design Methodology

Previous test requirements	*Identification of the application to be implemented using the methodology.* *Implementation of the application following a dataflow approach.* *HDL version of the dataflow actors composing the application (using for example Vivado HLS).*
Test description	*This test will validate the automatic generation of a ready-to-use accelerator that can be controlled via OpenMP from the SW point of view.*
Planned inputs	*The planned inputs are the dataflow-like definition of the application to be accelerated (e.g. COMP13) and the HDL associated with each dataflow actor composing the application.*
Expected results	*The result will be a ready-to-use accelerator already embedded within the FPGA overlay that will be transparently managed from the SW via OpenMP clauses.*

COMP06 – WP3- 24a - Efficient Digital Implementation of Controller on FPGAs

Previous test requirements	*ISS (Input-to-State Stability) redesign methodology, the stabilization in the sampled-and-hold sense theory. The only knowledges required for the implementation of the control algorithm are their amplitude bounds.*
Test description	*This test will validate the implementation of efficient digital controller on FPGAs using pipelines approaches*
Planned inputs	*Different initial implementation of control algorithms of the UAVs trajectories (C/C++/VHDL/Verilog)*
Expected results	*Performance results w.r.t. timing constraints, sample rate and system implementation improvements*

COMP07 –WP3-24b - Mixed-Criticality Design Space Exploration

Previous test requirements	*Design Space Exploration (DSE) composed by 2 activities: "HW/SW Partitioning, Architecture Definition and Mapping" and "Timing HW/SW Co-simulation". The first one is responsible to define the HW architecture of the target system, and to perform HW/SW partitioning and mapping of processes and channels on available processors and physical links. Such data are then provided to HEPSIM2 (HEPSYCODE Simulator 2, i.e., an extension of the previous HEPSIM simulator developed in the context of other ECSEL projects, e.g., AQUAS; MEGAMART2) to check if timing constraints are satisfied by the proposed architecture/mapping item.*
Test description	*HEPSIM2 allows to perform the Timing HW/SW Co-simulation activity. It is responsible to check if the architecture/mapping item proposed by the HW/SW Partitioning, Architecture Definition and Mapping activity is able to satisfy the specified input constraints.*
Planned inputs	*SystemC models generated from the CSP model by means of Model2Text transformations. The generated code is then integrated with some SW components that allow to consider an (heterogeneous parallel) HW platform and the effects that the mapping on it would have on the system behaviour and its timing performances. HEPSIM2 allows to model complex testbenches by considering independent stimulus generators to represent the environment.*
Expected results	*Scalability analysis, timing performance metrics and results, power/energy consumptions, schedulability and feasibility analysis*

COMP08 – WP4-44 - Embedded AI obstacle detection and avoidance

Previous test requirements	Deep Neural Network trained in simulated 3D environment with data from simulated Lidar/Camera, GPS, and IMU. Vehicle equipped with proper sensors and a suitable on-board platform that uses DNN and raw data to navigate in the environment
Test description	*This component will take the sensors data in order to generate the right behaviour in terms of actions taken. These actions will be fed to the vehicle actuators after they've been converted in control signals.*
Planned inputs	• Lidar's distances from surrounding objects • Camera's depth images of the scenario (this is in mutual exclusion with the previous type of input) • GPS position • IMU data (accelerometer, gyroscope) + magnetometer
Expected results	*Vehicle is able to navigate in an unknown environment, without the knowledge of the map, reacting to the different obstacles.*

COMP09 – WP4-11 - Resilient Positioning

Previous test requirements	*Integration of SLAM and Anti spoofing.*
Test description	*The drone will be tested in presence of a spoofing attack (if covid19 limitations will allow) and GPS signal degradation and by performing some computation should ensure coherent positioning even in presence of such failures.*

Planned inputs	Spoofing alerts and GPS data.
Expected results	Coherent positioning

COMP10 – WP4-18 - Transponder for drone-rover (WP4-18-TEK)

Previous test requirements	Not applicable.
Test description	The goal is to verify the guidance algorithm that drives the UAV toward a target position. The target position is given relatively to the position of an "anchor", which is a fixed Ultra-Wideband (UWB) node (a transceiver and a controller). Another UWB node equips the UAV. The algorithm, which runs on the UAV on-board computer, is based on the autopilot navigation data and on the distance between the UAV and the anchor that the two nodes measure cooperatively, by using the UWB signalling. First version — The algorithm is implemented in Python, debugged with the CoppeliaSim simulator, and verified using the drone Crazyflie. Crazyflie is a small UAV for laboratory experimentation that can be equipped with the Loco Positioning UWB distance-measurement sensor; the company bitcraze https://www.bitcraze.io/ provides both the UAV and the sensor. Second version — The algorithm is ported and completed in C language, debugged with the JMAVSim simulator, and verified with an hexacopter. The verification includes the test of the hardware (on-board computer, UWB transceiver).
Planned inputs	The target position given relatively to the position of an UWB anchor.
Expected results	The UAV reaches the target position (with the constraints that it starts from a position inside the UWB transmission range with respect to the anchor)

COMP11 – WP4-40 - High Accurate GNSS receiver, improving and notifying drone position

Previous test requirements	Embedded hardware system with high accuracy receiver and LTE modem, it can be powered by itself or directly from the drone
Test description	This component is a compact solution that provides accurate information on the geographical position of the drone and notifies this position via 4G to the body in charge of air traffic control.
Planned inputs	GNSS signals and positioning notification by 4G LTE network
Expected results	The drone will have more accurate information of its position thanks to the RTK technology provided by the component

COMP12 – WP4-08 - Path Planning Algorithms

Previous test requirement	The drone's mission has to be clearly defined in advance and the map must be provided.
Test description	A mission is set-up, and a map is available. These inputs are provided to COMP12 and a feasible path is then achieved.
Planned inputs	Map, obstacles, timing requirements, mission goals and description, start position, intermediate positions.
Expected results	A path which satisfies all the constraints (temporal and spatial), possibly minimizing a user-defined cost function.

COMP13 – WP4-09 - Application-Specific Accelerator

This component is not under development yet, the roadmap for its definition is defined in details in Section 3.9. of D4.6. Preliminary discussions with Abinsula have been carried out to port on the on-board accelerators both UC-specific and communication tasks.*

COMP14 – WP4-33 - Autonomy, cooperation, and awareness

Previous test requirements	*Distributed control strategy for swarms of drones based on the leader-follower consensus approach which allow to take into account time-varying formations and switching topologies, while ensuring the collision avoidance of multi-UAVs and the rejection of environmental perturbations, and measurement uncertainties.*
Test description	*The software is based on a distributed control strategy for steering the agents of the swarm towards a collection point. In order to cope with the formation control, a procedure to arrange agents in a family of geometric formations is included in the software.*
Planned inputs	*The developed software simultaneously addresses a challenging time-varying distributed set-up of the UAVs, characterized by the following features: (i) each UAV has limited resources in terms of communication coverage, so that it can only receive information locally from a time-varying subset of the swarm; (ii) the UAVs are required to dynamically avoid obstacles by imposing on-line a time-varying formation pattern; (iii) both the topology of communication and the configuration of leader and followers are timevarying*
Expected results	*Autonomous and cooperative flight of UAVs, managing of critical situation with improved situation awareness (obstacle avoidance, constrained communication), compensate and reject environmental perturbations, and measurement uncertainties*

COMP15 – WP5-07-MODIS - GPS Spoofing Detection Module

Previous test requirements	*Data collection to train the spoofing detection classifier. Data consist of high-level GPS data and labels denoting whether the signal is under attack or not. Due to covid19 limitations we might not be able to collect realistic data and resort to simulation.*
Test description	*The drone will continuously acquire the GPS signal a classify it as spoofed or benign*
Planned inputs	*GPS signal.*
Expected results	*Alert when the signal is spoofed.*

COMP16 – WP5-08-ROT - Lightweight Cryptography

Previous test requirements	*All nodes must be associated with network topology and authenticated*
Test description	*A type of input message is processed and returned in output. This message, processed in reverse, must be identical to the input message to verify the success of the encryption processing.*

	An unauthorized (not authenticable) entity tries to authenticate itself to the network, but its attempt must be detected by the IDS.
Planned inputs	*A Plain Text to encrypt or a Cipher Text to decrypt.* *An entity attempting to intrude on the network.*
Expected results	*Data processing (encryption or decryption) successfully verified. Intrusion attempts detected*

COMP17 – WP5-05-TEK - LPWAN for Identification, Tracking, and Emergency Messages

Previous test requirements	*Not applicable*
Test description	*The COMP17 component is a Low Power Wide Area Network (LPWAN) that is used for vehicle identification and tracking, as well as for low throughput messages. The LPWAN technology of choice is LoRaWAN, i.e. the network layer together with the LoRa (Long Range) lower layers. In agricultural field of the Demo 1 (Use Case 5) LoRaWAN is common: part of the infrastructure can be reused (i.e. the gateways that connect the end nodes to the server, which can be a Cloud service or an owned computer).* *The application part of COMP17 is built upon "The Things Network": a LoRaWAN network server stack that provides end-nodes and network management (the UAV becomes a "thing in the network"). COMP17 includes an application server that interfaces the network server: it lets the services to be accessed from any Web browser, and can offer other services to higher level systems such as UTM (Unmanned Aircraft System Traffic Management).* *Step 1 — To verify the transceiver integration on the UAV and the basic transmission to/from the network server (a test network can be used).* *Step 2 — To verify the UAV tracking, the operating messages exchange, the network server services, the application server (a test network can be used).* *Step 3 — To verify the real network deployment, with the gateways and the wireless/wired connections these have to the server; extensive test with UAV and on-the-ground end nodes.*
Planned inputs	*The project prosecution will specify the test procedures.*
Expected results	*COMP17 ready to be integrated for functionalities verification.*

11.8.2. Functionalities Verification

At a higher level than the components, the main functionalities of the demonstrator must be validated in order to ensure that the final system will be able to meet the objectives. Compliance with the functionality, in turn, will ensure the validation of the requirements associated with each of them.

UC5-D1-FUN01 - On board processing platform

Environment	Goal	Output
Laboratory	Assessment of the on-board processing platforms derived with the methodology developed in WP3 (COMP5) over different testing scenarios, not necessarily UC specific.	Basic examples (explained in detail in Section 3.9 of D4.6) that proves that the FPGA-based overlay infrastructure with

		application specific HWPU is suitable to play the role of companion computer.
Outdoor controlled	Development of COMP13 for assessment of UC related needs.	The application-specific accelerator (COMP13) is going to be validated within the UC5 Demo1 in an outdoor controlled environment.

UC5-D1-FUN01.1 - Processing platform: Advanced processing platform configuration

Environment	Goal	Output
Laboratory	Performance analysis of the heterogeneous processing platform with the tool developed in WP6 (COMP07) over different simulation scenarios.	Alternative configuration paths (tasks allocation, mapping, binding and schedulability plan) with different applications and HW/SW FPGA-based SoC platforms.
Outdoor controlled	Development of COMP07 for assessment of UC related needs.	The HEPSYCODE mixed-criticality-aware DSE component is going to be validated within UC5 in an outdoor controlled environment.
Realistic	---	---

UC5-D1-FUN02- On board video acquisition and processing

Environment	Goal	Output
Laboratory	Assessment of the AI based video processing modules using images collected by the drone or available online.	Correct detection of relevant information (i.e., plant recognition and/or disease detection)
Outdoor controlled	Assessment of the functionality by means of COMP03 tests, described in Section 11.8.1. UNISS (end user) will be involved in this process to verify if UC related needs are met	Correct detection of relevant information (i.e., plant detection and/or disease recognition)
Realistic	Assessment of the functionality by means of COMP03 tests, described in Section 11.8.1. UNISS (end user) will be involved in this process to verify if UC related needs are met	Correct detection of relevant information (i.e., plant detection and/or disease recognition)

UC5-D1-FUN03- Drone/rover cooperation: security and embedded discrete-time controller

Environment	Goal	Output
Laboratory	The final version of the proposed digital control strategy with new features concerning the robustification and the digital design of the controller. Efficient methodology for the implementation of the proposed digital control strategy on FPGAs (COMP06). Functionality assessment by test using simulation of input message to process (encryption or decryption) and Intrusion Detection System. (COMP16)	Compensate and reject environmental perturbations, and measurement uncertainties. Intrusion attempt detected correctly. Data correctly processed. (COMP16)
Outdoor controlled	Development of efficient digital controller on FPGAs (COMP06) through different implementation of control algorithms for assessment of UC related needs. Assessment of the component for UC needs. (COMP16)	Managing of critical situation with improved situation awareness (task interferences, scheduling issues, fault of failure conditions). Intrusion attempt detected correctly. Data correctly processed. (COMP16)

UC5-D1-FUN03.1- UAV-UGV identification, communication, and positioning

Environment	Goal	Output
Laboratory	The FUN3.1 functionality is intended for bringing the UAV in a position such that the UGV is in the field of view of the dedicated video camera on which the autonomous landing on the UGV is based. For completeness, an open-source landing system will be integrated. The goal is to verify this integration with the WP4 COMP10 component. In the first test the initial position of the UAV is such that the pad is in the field of view of the video camera. In the second test the guidance algorithm brings the UAV on the pad. Note: the “laboratory” is an industrial building with tens of meter of free space.	The UAV guided by a dedicated video camera lands on a pad
Realistic	On the UGV there must be installed (1) a UWB node, which is a subset of the WP4 component COMP10; (2) a LPWAN system, which is the WP5 component COMP17 but in a reduced configuration because the GPS position is the only needed data. Before the use case execution, this installation is verified by repeating with the UGV the most significant tests already executed in the “outdoor controlled” environment with the pad or the autovehicle.	The WP4 component COMP10 and the WP5 component COMP17 are correctly installed on the UGV.

UC5-D1-FUN04 - Automatic runtime Path planning

Environment	Goal	Output
Laboratory	Assessment of the computation time of the path planner across several virtual environments and corresponding missions.	Feasible path planning in reasonable time where all the spatio-temporal constraints are met and the user defined cost function is possibly minimized.
Outdoor controlled	Assessment of the computation time of the path planner across a small set of outdoor controlled scenarios and corresponding missions where the impact of the ICT infrastructure is also considered.	Feasible path planning in reasonable time where all the spatio-temporal constraints are met and the user defined cost function is possibly minimized. Minimum impact deviations are expected w.r.t. outcomes in the Laboratory environment.
Realistic	Assessment of the computation time of the path planner within the realistic UC5 scenario and corresponding missions where the impact of the ICT infrastructure and the unexpected change of the environment are also considered.	Feasible path planning in reasonable time where all the spatio-temporal constraints are met and the user defined cost function is possibly minimized. Some deviations are expected w.r.t. outcomes in the Outdoor controlled environment.

UC5-D1-FUN05 - Energy Management System

Environment	**Goal**	**Output**
Laboratory	Given the initial and final position of a mission the test wants to evaluate the battery consumption compared with other trajectories in a simulated environment. A rule-based strategy will be used obtained from the analysis of the optimal control choices so that the reference generator will have profiles of the status variables (position, speed, orientation) close to the optimal ones from an energy point of view. The computational cost of the reference generator is evaluated in closed-loop unlike the optimal control problem, which, due to the mathematical model present in the problem, is intractable from a computation point of view, is open-loop and therefore cannot be done online. at less than a high cost for electronic devices.	Energy trajectories that can be followed to carry out a mission to have lower battery consumption and that can be easily integrated into a closed-loop controller
Outdoor controlled	Not Applicable because the final TRL is planned to be around 3 - 4	-
Realistic	Not Applicable because the final TRL is planned to be around 3 - 4	-

UC5 – D1- FUN06 - Advanced SLAM algorithm and sensing capabilities

Environment	Goal	Output
Laboratory	Assessment of computation time and root means square positioning accuracy via simulated scenarios.	Small estimation time for the positioning and accuracy within a narrow GPS reference range.
Outdoor controlled	Assessment of computation time and root means square positioning accuracy via small outdoor tests where the sensing infrastructure is also considered. Comparison with simulated results.	Small estimation time for the positioning and accuracy within a narrow GPS reference range. Small deviations are expected w.r.t. outcomes in the Laboratory environment.
Realistic	Assessment of computation time and root means square positioning accuracy via tests in the UC5 scenarios.	Small estimation time for the positioning and accuracy within a narrow GPS reference range. Some deviations are expected w.r.t. outcomes in the outdoor controlled environment.

11.8.3. System Validation

The main objective of the Validation plan is to check if the specification meets the customers' needs. This use-case aims at giving evidence that certain manual operations can be perfectly carried out in an autonomous manner by a coordinated system composed of UAV and UGV equipped with cameras and advanced technologies. This can be used for reducing the impact on the environment of certain operations (i.e., precisely sizing the amount of water and pesticides to be used and acting on spot where needed, promptly activating treatments at the first symptoms on individual crops/plants) while saving human effort.

The validation of the systems will be carried out in a field test in Sardinia. Following the same structure presented in 11.2 Use Case Concept of Operation*11.2* validation plan is composed of 3 different missions that will incrementally validate the proposed approach.

In the **Scenario 5.1.1** the main goal will focus on be to correctly acquire images by drones. Images are then validated off-line by the agriculture expert.

In the **Scenario 5.1.2** the further goal will be to analyse the acquired data to determine if and where local treatments are needed. In this case, it will be validated the system for the correct positioning of the UAV, as well as the improved analyses capabilities of the on-board embedded processing platform.

In the last **Scenario 5.1.3** the safe cooperation and communication between UAV and UGV will be validated. In this case the interface and the data exchange between the 2 vehicles will be proven. A dashboard will be added in order to collect all the information coming from the 2 vehicles and making them available in real time to an operator. The agricultural expert will evaluate if:

- the acquired images data have the correct quality and definition,
- the position of the 2 vehicles is sufficiently precise to perform precise agricultural interventions,
- the requested action is correctly defined.

The stakeholder (agricultural expert) will directly participate to the validation in all the 3 scenarios and the results of the tests done will be evaluated according to the Business KPIs.

12 UC5-Demo2: Agriculture: Vineyard Demonstrator

12.1 Current state of the technology

In agriculture, the condition of the plants and the arable land is of great importance in order to achieve the greatest possible yield for the farmer. In addition to a prompt reaction to shortages, diseases and pests, it is also important to minimize the impact on the environment. In the field of smart and precision farming, great attention is paid to the condition of the soil and the single vine, to effectively manage plants, soil, fertilization and irrigation and respond to shortages, diseases or pests in a timely, targeted and local manner, For this purpose, land-bound sensors are distributed in selected positions in the vineyard, which measure temperature, humidity or nutrient content, and images of the vineyard are collected using multispectral and daylight cameras mounted on a drone.

By analysing the different colour and spectral bands of the collected images, pests, diseases and weeds can be identified, and nutrient deficiencies can be determined, as well as important information for evaluating soil productivity and analysing plant health can be provided. In addition, the position data from the drone can be used to optimize the land-based sensor distributor, taking into account areas with similar behaviour in terms of vegetation growth and hydric-stress. By combining static data from the sensors on the ground and image and position data gathered by the drone, using data fusion and Artificial Intelligence a holistic model of the condition of the soil and the single vines can be created.

Trustworthy and reliable communication of the drone with the sensor nodes in the vineyards and the base station guarantees that only valid data is retrieved, and only authorized partners participate in the communication. The advantage is that defective sensors are detected, the sensor data cannot be manipulated or retrieved by any foreign drones. This is achieved through the use of Secure Elements (hardware security components) comprising hardware, firmware and software and support mutual authentication to the sensor nodes and base station. Likewise, crypto libraries, a collection of cryptographic basic elements and protocols, are evaluated, whose properties are tailored to needs of drone communication, taking into account resource consumption and latency.

The available battery capacity and the energy consumption of the system are limiting factors for the mission duration the drone and the lifetime of the sensor nodes in the vineyard. This is influenced by the weight of the payload, the energy consumption of computers or cameras, or for example, weather conditions such as strong winds, as more energy is required for the motors to keep the drone in the correct pose. By using a policy based Self- Adaptability Framework, it is possible to respond to these conditions. This allows to react to a reduction in the battery capacity or an increase in the CPU load and, for example, to reduce the data rate to be processed or to buffer the data until more CPU time is available.

12.2 Use Case Concept of Operation

This use case demonstrator has been designed to assist the winemaker in his work, to minimize the workload and the travel time to remote and poorly connected to the infrastructure vineyards. The state of health of the vines and the soil is important for a profitable harvest. Therefore, modern sensor technology and data analysis will be used to provide the winegrower with the necessary information. The measurements of sensors on the ground and images from daylight and multispectral cameras on a drone will be used, so the winegrower can monitor the condition of the soil and the single vine, to effectively manage plants, soil, fertilization and irrigation and respond to shortages, diseases or pests in a timely, targeted and local manner, to reduce the impact on the environment, the cost, and at the same time the yield increases. The drone will additionally be used as gateway, to send the collected sensor data to a base station.

An UAV equipped with a visual and/or multispectral camera will be used to collect land-bound sensor data, images and georeferencing data by flying autonomous over the vineyards following a predefined flightpath. These data can be put together by means of the position to form an overall picture of the vineyard. Since these missions are carried out at regular intervals for each vineyard, it is possible to create a time history of the condition of the plants and the soil and to monitor the effects of the treatments.

The mission consists of two parts: the flight over the vineyard, these are agricultural areas on which there will be no people, for the data acquisition and a postprocessing step for the evaluation of the collected data (see Figure 30).

After loading the predefined waypoint list and a stable GNSS link is available, the UAV can start the mission and take off. It will follow autonomously the defined waypoints and collect multispectral and/or daylight camera images along with the GNSS positions. During the flight, the drone will connect to a set of land-bound sensors and transmit their data to the base station. As soon as all the waypoints have been processed, the drone will land.

After the flight mission, the post-processing step will be carried out by downloading the collected image and position data. These are then combined with the data from the soil sensors by using LAYERS®[1] AI Agro platform to create a model and provide the necessary information about the condition of the vines and the vineyard.

[1] Layers is a platform that combines agronomical knowledge, Earth Observation Remote Sensing (drones, satellites, etc.) and Artificial Intelligence to obtain a proactive field monitoring system. It’s constituted by a web-tool (https://layers.hemav.com) that contains a map viewer and a field analytics dashboard, and iOS and Android field sampling application.

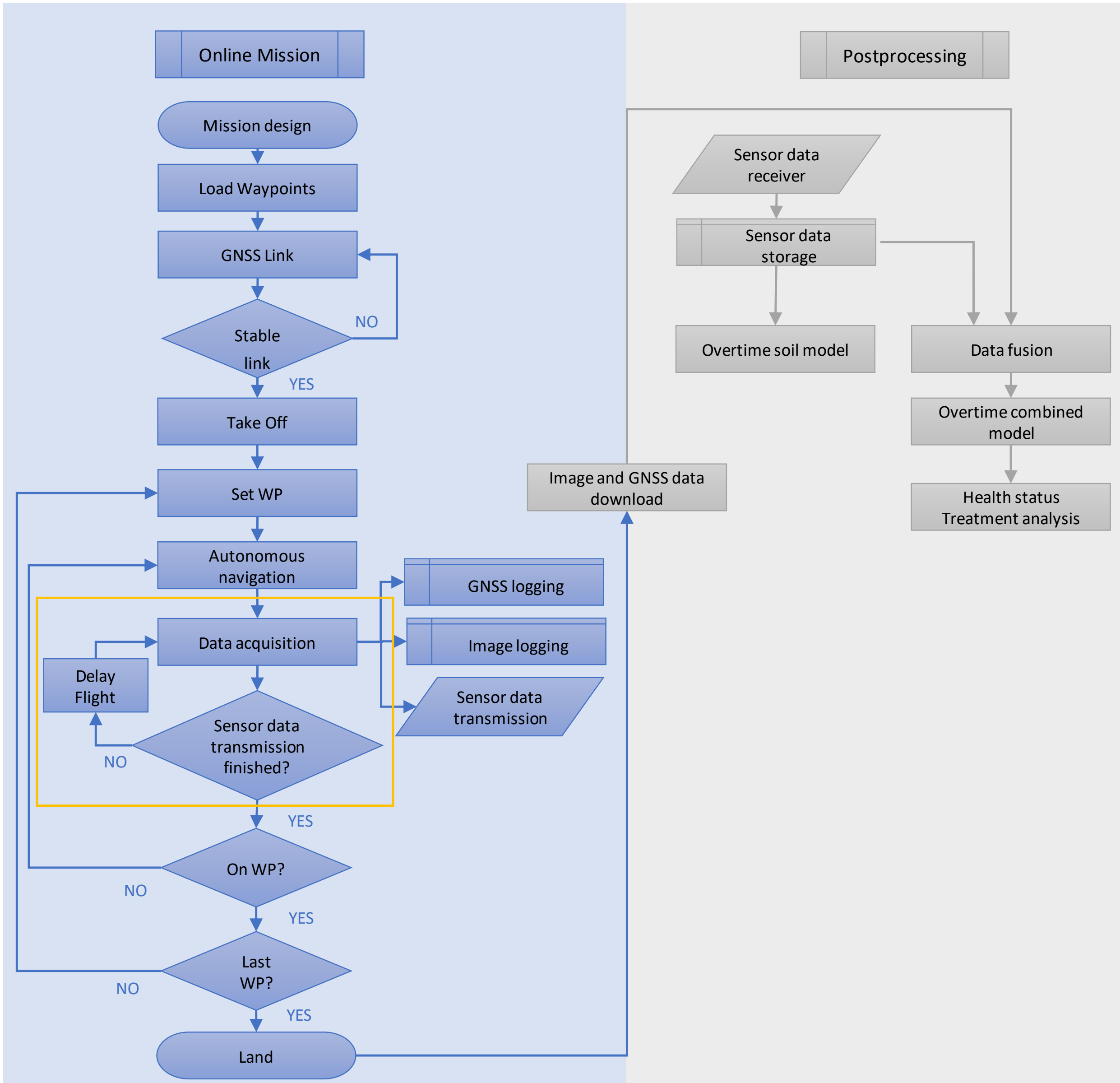


Figure 30 Use case 5 demonstrator 2 concept of operation

12.3 System Requirements, KPI´s and Metrics

In the following section there is the list of the technical Key Performance Indicators defined in "D1.1 Specification of Industrial Use Cases" (Table 90) and their link to the main requirements defined for the use case5 demonstrator2.

12.3.1. Technical KPI`s and Metrics

In D1.1 the main business KPIs for this demonstrator were introduced. Complementary to those KPIs already identified, the table below presents the entire KPIs of this demo, with their definition, measurement indicator and target value:

nº	KPI	Definition and measurement of indicator	Target value
		Business KPIs	
UC5-D2-KPI-01	Time saving in data collection and evaluation of growth, health and overall plant status. Based on data analysis performed by the overall drone-based application.	No need to go to the vineyard, to get the senor readings and check representative satisfactory conditions, such as health, growth and overall status of the plant manually. Full coverage of vineyard in less time than walkthrough.	Time savings per observation phase and condition of at least 50% is expected to be observed in the execution of a demonstrator.
UC5-D2-KPI-02	Resources saving (time, fertilizer, water, etc.) – work on demand and optimized to the specific areas incl. early warnings for detection of unsatisfactory conditions such as diseases and water stress.	Remote data analysis enables the necessary work steps (spraying, fertilizing, irrigation) to be specifically prepared and directed to the specific areas. Representative unsatisfactory situations and the corresponding, required monitoring information will be defined, documented, and evaluated in a demonstrator.	A resource saving for the given situations of at least 20% is expected.
		Technical KPIs	
UC5-D2-KPI-03	Trusted communication and data collection from land-bound sensors to the drone, and from the drone to the base station.	Establishing a chain of trust by securely onboarding the drone, land-bound sensors, and base station in the Eclipse Arrowhead local cloud. All communication partners need to be authenticated and authorized to ensure that monitoring data is not manipulated, intentionally or unintentionally.	Time saving by performing the Eclipse Arrowhead secure onboarding procedure, rather than manually generating certificates.
UC5-D2-KPI-04	Reduce the number of land-bound sensors.	By fusing (multispectral) image data with data from landbound sensors and using a self-adaptability approach to trade off energy with performance in	We assume to confirm a reduction of at least 25% of the number of landbound

		changing conditions (which should allow for e.g. stronger antennas), the number of sensors on the ground can be reduced comparing to a sensor grid/ systematic sensor sets.	sensors after analysing the demonstrator.
UC5-D2-KPI-05	Trusted communication establishment for data collection from land-bound sensors to drone supported by hardware security IC.	Both communication partners need to authenticate during TLS connection establishment (TLS handshake) to harden identity-tampering and manipulation – intentionally or unintentionally. Therefore, required key material needs to be protected with a "Common Criteria" certified hardware security IC (also referred to as Secure Element).	"CC EAL6+" certification (of the hardware security IC)

Table 90 UC5 D2 List of KPIs

12.3.2. Main requirements (functional, interface, performance, security, usability…)

D1.1 introduced the main functional requirements of the demonstrator. In this section, the remaining technical requirements for the demonstrator are shown, linked to specific KPIs of the demonstrator

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC5-DEM9-FUN07	The hardware component shall provide measures to establish integrity and authenticity.	This hardware component (Secure Element, SE) provides security-measures to support the main application microcontroller of the drone with functionality such as cryptographically secured drone identification and drone and/or control unit authentication, and measures to provide the integrity of key credentials.	H	Component Provider	UC5-D2-KPI-05

UC5-DEM9-FUN08	An API for hardware component shall be provided.	The corresponding firmware- and software-components provide APIs for potential use in the modular drone architecture framework, primarily supporting security-relevant tasks in the security management, such as TLS support functions for establishing trusted communication	H	Component Provider	UC5-D2-KPI-05
UC5 - DEM9-INT-07	The Self-Adaptability Framework shall provide a set of interaction interfaces	The Self-Adaptability Framework shall provide a set of interfaces to allow the interaction between generic control mechanism and system adapters.	H	Component Provider	UC5-D2-KPI-04
UC5 - DEM9-INT-08	The Self-Adaptability Framework shall provide system adapters	The Self-Adaptability Framework shall provide system adapters to allow the interaction of generic control mechanisms with the target system.	H	Component Provider	UC5-D2-KPI-04
UC5 - DEM9-PRF-01	The SE shall offer meaningful performance to establish secure communic	The SE shall accelerate cryptographic operations to establish secure communication channels (e.g. to support TLS	H	Component Provider	UC5-D2-KPI-05

	ation channels (like TLS).	handshake operation)			
UC5 - DEM9-PRF-02	The Self-Adaptability Framework should be lightweight	The Self-Adaptability Framework should be e.g. a small Java library with fundamental autonomic management functions and very little impact on the target system's runtime.	M	Component Provider	UC5-D2-KPI-04
UC5 - DEM9-PRF-04	Telemetry transmission	Flight parameters should be transmitted to ground station (Battery life, flight parameters, etc.).	M	Drone operator	U-space Telemetry
UC5 - DEM9-SEC-07	Low latency forward-secret 0-RTT KE	The key exchange mechanism used within TLS may provide low latency (zero round-trip or 0-RTT) and at the same time full forward secrecy	L	Component Provider	UC5-D2-KPI-03
UC5 - DEM9-SEC-08	Post-quantum security	The cryptographic primitives to provide trusted communication may be resistant against future powerful quantum computers.	L	Component Provider	UC5-D2-KPI-03
UC5 - DEM9-OPR-02	Easy disassembly	Sensors should be easy to disassemble by the end user before harvest. They will not withstand the forces of the harvest machine.	M	Stakeholder	UC5-D2-KPI-04

UC5 - DEM9-OPR-06	Weather Conditions Camera	Camera Data (Multispectral) should be taken with low wind speed and dry leaves.	M	Stakeholder	KET Payload Technologies: Optical Sensors
UC5 - DEM9-OPR-07	Digital Elevation Model (DEM)	Digital Elevation Model of terrain should enable more precise flight planning and positioning of stationary sensors.	M	Drone operator	UC5-D2-KPI-04

Table 91 UC5 D2 List of Main Requirements

12.3.3. Drone integration requirements

Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI´s
UC5 - DEM9-DSG-02	Drone – Sensor interface	Interface between Drone and Airsensor should be accessible.	M	System Integrator	UC5-D2-KPI-03
UC5 - DEM9-PRF-03	Failsafe Operation	The drone should safely carry the Airsensor and camera equipment when a subcomponent (Motor, controller,…) fails.	M	System Integrator	UC5-D2-KPI-03 KET Payload Technologies: Optical Sensors

Table 92 UC5 D2 List of Drone integration Requirements

12.3.4. Regulatory requirements

The requirements below are related with the SORA analysis performed (Reference to the methodology in D2.5.) and the boundary conditions introduced in D1.1, as well as to the regulatory framework that dictates the deployment of the scenarios of the demonstrator.

Requirement ID	Short Description	Description	Priority (H/M/L)	Source
UC5 - DEM9-OPR-05	Pilot	For Austrocontrol a pilot shall operate the drone to be able to oversteer autonomous operation in case of need.	H	Drone operator
UC5 - DEM9-P&C-01	Drone Operator	Drones in Austria shall only be operated with pilots mentioned in the aircraft notification.	H	Drone operator

UC5 - DEM9-OPR-03	Flight Boundaries	Flight boundaries shall be within the airspace authorities' law (flight height, distance to home point, etc.).	H	Drone operator

Table 93 UC5 D2 List of Regulatory Requirements

12.4 Functionalities identification

Figure 31 describes an overview of the system functions that will be implemented in the UC5 Demonstator2. The focus here is, on the one hand, on trusted communication between the sensors on the ground, the drone and a base station, improving the communication security by a hardware secure element and a cryptography library tailored to the needs of drones, and, on the other hand, on dynamic energy management using dependability metric based self-adaptability. The implemented system functionalities are listed in Table 94.

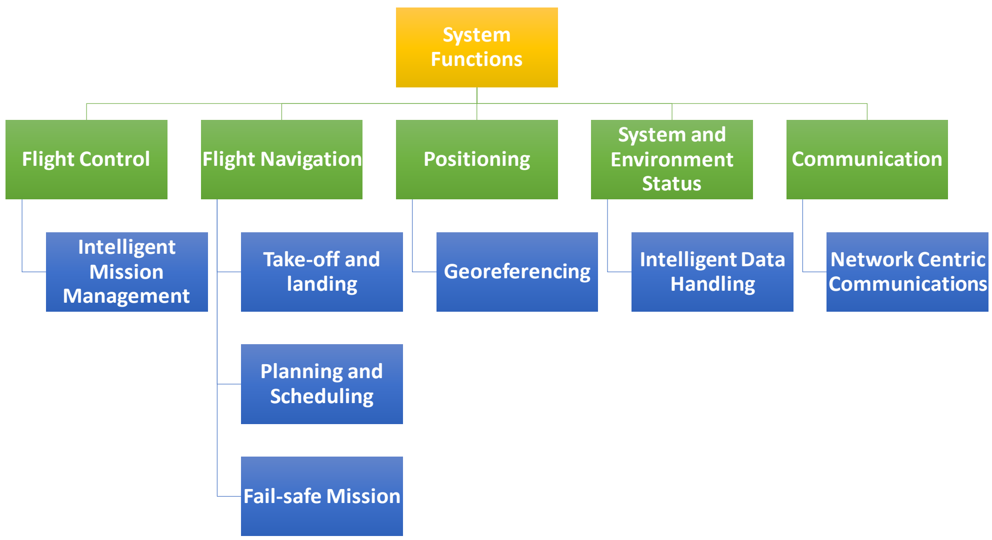


Figure 31 Drone System Functions

Figure 32 provides an overview of the payload technologies that are used in this application. These include a visual and a multispectral camera that are mounted on the drone, as well as sensors that are distributed in the vineyards that monitor the condition of the soil and the weather and transmit these measured values to the drone.

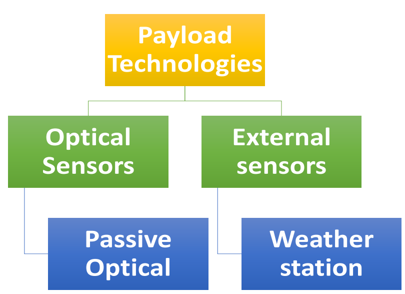


Figure 32 Payload Technologies

ID	Functionality	Description	System function
FUN – 01	Drone platform	UAV following the Austrian regulations, to carry visual and/or multispectral camera, an Air-sensor (communication with land-bound sensors), able to fly autonomous following a predefined flightpath.	Flight control Flight navigation Positioning
FUN – 02	High resolution visual and multispectral camera	High resolution visual and multispectral cameras for evaluating soil productivity and analysing plant health.	Intelligent data handling
FUN - 03	Land-bound sensor	Sensor nodes that are distributed in the vineyards and record various parameters (e.g. humidity, temperature) and send them to the drone.	Intelligent data handling
FUN - 04	Data fusing and analysis	Postprocessing step to fuse and analyse the collected multispectral and daylight camera images, position data with the sensor readings of the sensors in the vineyard to create a holistic model of the condition of the plants and the soil.	Intelligent data handling
FUN - 05	Trustworthy and reliable data collection	To guarantee that all communication partners are in a valid state, defective sensors are detected, and the data are not manipulated.	Network Centric Communications
FUN06	HW-Support for Secured Communication Establishment	Hardware security components, comprising hardware, firmware and software, for trusted communication in drones, to establish secure TLS channel and support mutual authentication (via TLS) to the communication partners.	Network Centric Communications
FUN07	Autonomic Computing based on MAPE-K Feedback Loop	A policy based Self-Adaptability Framework, to react to declining battery capacity or increasing CPU usage and to reduce the data rate to be processed or buffering image data until more CPU time is available again.	Intelligent data handling

Table 94 UC5 D1 List of Functionalities

12.5 Components

In order to be able to carry out the tasks in the field of smart and precision agriculture, the following components are developed in the technical work packages for this demonstrator. Table 95 provides the relationship between the components and the project objectives and success criteria.

- **COMP01 (WP5-16-AIT) - Cryptographic Primitives and Protocols**

This component represents a collection of cryptographic primitives and protocols whose characteristics are tailored to the use within drone environments (resource consumption, latency). In particular, the cryptographic protocols while providing means to satisfy low latency requirements will at the same time provide strong security guarantees (like full forward secrecy). Another important focus will be to provide long-term security and in particular resilience to quantum computers, i.e., post-quantum security.

It represents a collection of basic cryptographic building blocks and protocols (e.g., forward secret key-exchange or anonymous authentication) and typically replaces or augments other existing cryptographic primitives (e.g., basic mechanisms in the transport layer security (TLS) protocol). It is intended to be used together with a Secure Element (SE) to provide stronger security features (i.e., realize secret key operations within the SE). It also provides primitives to establish secure communication (confidential and authenticated). Moreover, the component will provide features to protect the privacy of communication partners by means of anonymity.

With respect to validation and test, the overall correct behaviour of the component verified and tested on a microcontroller that is communicating with the SE and some test-service.

- **COMP02 (WP5-17-FB) - Generic Autonomic Management Framework**

The Generic Autonomic Management Framework (GAMF) is a Java-based framework used to develop autonomic elements for any target system without having to (re)implement the generic control mechanisms. GAMF provides generic control mechanisms based on the autonomic control loop (MAPE-K) and a set of interfaces to allow the interaction between control mechanism and system specific management components, the system adapters. System adapters include event generators and effectors, which allow interaction of the control mechanism with the target system, as well as metric extractors and policy evaluators, which provide the means for computing a specific response determined by policies to an observed situation modelled by metrics. The information about how a specific system adapter is triggered is held in the system adapters registry.

From a Service Oriented Architecture perspective, Generic Autonomic Management is designed as a component-based REST service and will be integrated in the Eclipse Arrowhead Framework.

For this specific use case, autonomic elements can be used for various adaptations e.g. to adapt the sensor reading interval, to check if the certificates in the drone are still valid, etc.

- **COMP03 (WP5-14-IFAT) - Hardware Security Component**

To achieve certain security related communication parameters, such as confidentiality, integrity, and availability, it is recommended to establish a protected communication channel. The communication protocol shall be extended with the Transport Layer Security (TLS). Typical attack scenarios, which are based on tampering, can be hardened by supporting the corresponding communication protocol layer of the host controller, with a hardware security component (also called Hardware Security Module (HSM)).

The HSM shall offer meaningful performance in regard of security, to protect credentials such as drone- and server identities and to establish the protected communication channels. The hardware security component is composing hardware, firmware and APIs for trusted communication in drones, for securing the crucial TLS handshake and supporting mutual authentication (via TLS) to the communication.

With respect to test and validation, the overall correct behaviour of the component verified, when the TLS-library + generic-API on the general-purpose microcontroller is communicating with the HSM component and finally able to establish a TLS connection to some test-server.

Partner	Work Package	Components	Demo	Component ID	KPI	Criteria	Measurable Outcome	Objective
AIT	WP5	Cryptographic Primitives and Protocols	DEM09	COMP01 WP5-16-AIT	Improve network performance	SC3.1	MO3.1	O3
FB	WP5	Autonomic Management Framework	DEM09	COMP02 WP5-17-FB	Improve network security	SC3.1	MO3.3	O3
IFAT	WP5	Hardware Security Component	DEM09	COMP03 WP5-14-IFAT	Improve network security	SC3.1	MO3.3	O3

Table 95 UC5 D2 List of components

12.6 Tools

To support the development process of drone components and systems, three tools from the field of system development (see Figure 33) are provided within this UC demonstrator, to reduce the design, validation and verification effort for the development of new drone components and systems (Table 95).

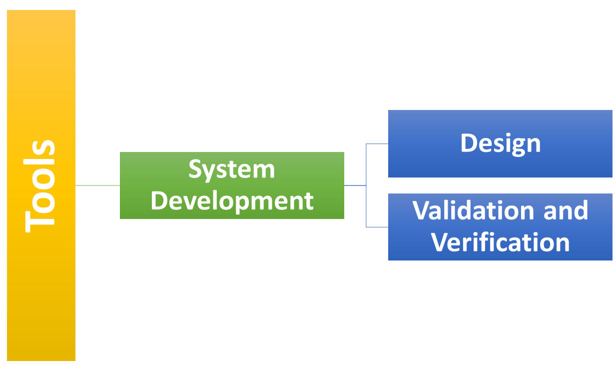


Figure 33 Tools for drone systems

- **TOOL01 WP6-01 - Workflow Engine**

A workflow engine will be established which allows the modelling of a development workflow for the drone domain, to enable standards compliant engineering and to support the certification for drone system.

- **TOOL02 WP6-02 - Security Analysis Tool**

A drone domain specific database for the security analysis tool ThreatGet will be developed to enable tailored security analysis and it will be worked on compositional threat analysis.

- TOOL03 WP6-03 - MoMuT Protocol Testing

The existing model-based test case generation tool MoMuT will be used to develop and explore new features for security protocol testing, to assure specific security aspects for drone communication.

Partner	Work Package	Components	Demo	KPI	Criteria	Measurable Outcome	Objective
AIT	WP6	Extended workflow engine for usage by drone manufacturers	TOOL01 WP6-01	DTC-31	SC4.2	MO4.3	O4
AIT	WP6	AIT Security Analysis for Drones	TOOL02 WP6-02	DTC-56 DTC-57 DTC-58	SC4.1	MO4.2	O4
AIT	WP6	MoMuT Protocol Testing	TOOL03 WP6-03	DTC-32	SC4.1	MO4.2	O4

Table 96 UC5 D2 List of Tools

12.7 Traceability matrices

12.7.1. Requirements vs. functionalities

The following Table 97) describes the relationship between the functionalities and the main requirements of the use case demonstrator.

Requirement	Short description	FUN01	FUN02	FUN03	FUN04	FUN05	FUN06	FUN07
UC5-DEM9-FNC-07	The hardware component shall provide measures to establish integrity and authenticity.					X	X	
UC5-DEM9-FNC08	An API for hardware component shall be provided.					X	X	
DEM9-INT-07	The Self-Adaptability Framework shall provide a set of interaction interfaces							X
DEM9-INT-08	The Self-Adaptability Framework shall provide system adapters							X
DEM9-PRF-01	The SE shall offer meaningful performance to establish secure communication channels (like TLS).							X
DEM9-PRF-02	The Self-Adaptability Framework should be lightweight							X
DEM9-PRF-03	Failsafe Operation	X						
DEM9-PRF-04	Telemetry transmission	X						
DEM9-SEC-07	Low latency forward-secret 0-RTT KE					X		
DEM9-SEC-08	Post-quantum security					X		
DEM9-OPR-02	Easy disassembly			X				
DEM9-OPR-05	Pilot							
DEM9-OPR-06	Weather Conditions Camera		X					
DEM9-OPR-07	Digital Elevation Model (DEM)		X		X			

DEM9-DSG-02	Drone – Sensor interface		X					

Table 97 UC1 D1 Requirements and functionalities traceability matrix

12.7.2. Functionalities vs. Components

This section describes which functionalities are implemented by certain components (see Table 98). FUN02 and FUN04 concern the data collection and analysis, no components are developed for this in the technical work packages, and these are implemented directly in the use case.

Therefore, the UAV is equipped with a high resolution visual and multispectral camera (FUN2) to acquire images of the plants and the soil. The data fusing and analysis (FUN4) will be carried out in the post processing step, where the collected image and position data will be merged with the data from the sensors on the ground using LAYERS® AI Agro platform to create a holistic model vineyard and provide information about the condition of the vines and the soil.

FUNCTIONALITY	Short description	COMP 01	COMP 02	COMP 03
UC5 –D2-FUN01	Drone platform			X
UC5-D2- FUN02	High resolution visual and multispectral camera			
UC5-D2- FUN03	Land-bound sensor	X		X
UC5-D2- FUN04	Data fusing and analysis			
UC5-D2- FUN05	Trustworthy and reliable data collection	X		X
UC5-D2- FUN06	HW-Support for Secured Communication Establishment			X
UC5-D2- FUN07	Autonomic Computing based on MAPE-K Feedback Loop		X	

Table 98 UC1 D1 Components and functionalities traceability matrix

12.8 Validation plan

12.8.1. Components Verification

The components developed in the technical work packages form the basis of the demonstrator. The following list provides a description of the tests for the individual components

- **COMP01 - WP5-16-AIT - Cryptographic Primitives and Protocols**

Test description	*Testing the correctness of the protocols provided by the library and validating the correctness of the interplay of the implementation running on the microcontroller, the Secure Element and a test backend service. Evaluation of the overhead and the performance via benchmarks.*
Planned inputs	*The authentication and key-exchange primitives do not require any specific input. We will use simulated application data whenever required.*
Expected results	*Demonstrating applicability of the cryptographic library (and the increased security and privacy guarantees) on hardware components as deployed within the use-case.*

- **COMP02 - WP5-17-FB - Autonomic Management Framework**

Test description	*Automated test cases for framework components (monitor, analyse, plan, and execute)* *Testing the applicability of the framework in the use case (e.g. using the framework to change the sensor reading interval)*
Planned inputs	*Sensor data (e.g. environmental data from land-bound sensors or data from the drone)*
Expected results	*Improved trade-off between e.g. resource usage and security using autonomic elements*

- **COMP03 - WP5-14-IFAT - Hardware Security Component**

Test description	*Testing contact based communication at APDU layer to validate the correct behaviour and the correct output of hardware security component.*
Planned inputs	*Application ID for selecting required application on hardware security component; dummy data as input for generating and verifying of an ECDSA signature*
Expected results	*Successfully select application (e.g. 0x9000 -> typical APDU success value); generation of a valid signature; successful verification of ECDSA signatures*

12.8.2. System Functionalities Verification

On the next level of complexity, the individual main functionalities of the demonstrator must be validated, as their interaction forms the specific application. This ensures that the requirements linked to the functionalities are also achieved.

UC5-D2-FUN01 - Drone platform

Environment	Goal	Output
Laboratory	Integration of the Airsensor for communication (with the land-bound sensors and the base station) and the multispectral and visual camera on the drone. Communication with drone and Airsensor for flight parameter indication.	Confirmation of correct installation by the drone integrator/operator/ Sensor Stakeholder Parameter Readings from drone to Airsensor
Outdoor controlled	NA - the test flights are already being carried out on the vineyards (real scenario).	
Realistic	The drone will autonomously follow predefined waypoints and collect multispectral and/or daylight camera images along with the GNSS positions and land-bound sensor readings for postprocessing step. WP of Landbound sensors may require flight delay the flightplan of data acquisition and sensor transmission are separated.	Telemetry of the flight Set of multispectral and daylight images Land-bound sensor readings GNSS position

UC5-D2-FUN02- High resolution visual and multispectral camera

Environment	Goal	Output
Laboratory	Proper installation of the multispectral and/or daylight camera on the UAV airframe.	Confirmation of correct installation by the drone integrator/operator.
Outdoor controlled	NA - the test flights are already being carried out on the vineyards (real scenario).	
Realistic	The cameras work as expected under real conditions and deliver the images in the quality and data rate required by the stakeholder.	Set of multispectral and daylight images

UC5-D2-FUN03- Land-bound sensor

Environment	Goal	Output
Laboratory	Test sensor nodes on a desk demo record various parameters (e.g. humidity, temperature) and send them to a server on request.	Land-bound sensor readings
Outdoor controlled	NA - the test flights are already being carried out on the vineyards (real scenario).	
Realistic	Sensor nodes in the vineyards record various parameters (e.g. humidity, temperature) and send them to the drone on request.	Land-bound sensor readings

UC5-D2-FUN04 - Data fusing and analysis

Environment	Goal	Output
Laboratory	NA - the test flights are already being carried out on the vineyards (real scenario).	
Outdoor controlled		
Realistic	Postprocessing step create a holistic model of the condition of the plants and the soil s of a vineyard to identify treatments which must be carried out by the winegrower.	Model of the vineyard

UC5-D2-FUN05 - Trustworthy and reliable data collection

Environment	Goal	Output
Laboratory	Test communication partners (sensor nodes, base station and Air-Sensor) on a desk demo. All partners need to authenticate to send/receive data, identification of defective sensors.	Sensor readings transmitted to the base station.
Outdoor controlled	NA - the test flights are already being carried out on the vineyards (real scenario).	
Realistic	Collect measurements from the sensors nodes distributed in the vineyard on request and transmit to base station using the drone as a gateway. All communication partners need to authenticate to	Land-bound sensor readings transmitted to the base station.

	ensure that they are authorized, and only valid data are transmitted.	

UC5-D2-FUN06 - HW-Support for Secured Communication Establishment

Environment	Goal	Output
Laboratory	Verification and test of HSM-supported TLS connection establishment between two single board computers (e.g. Raspberry Pi).	Successful connection establishment (="trusted communication" part verified)
Outdoor controlled	NA - the test flights are already being carried out on the vineyards (real scenario).	
Realistic	Drone is equipped with a Raspberry Pi and communicates via an HSM-supported TLS channel with a base station in order to forward the collected data – verification in combination with FUN03.	Successfully sending data to base station via protected TLS channel.

UC5-D2-FUN07 - Autonomic Computing based on MAPE-K Feedback Loop

Environment	Goal	Output
Laboratory	• Test the functionality of MAPE-K components and their interaction • Test the integration with the Eclipse Arrowhead Framework	• GAMF up and running • GAMF as a system in the Eclipse Arrowhead Framework
Outdoor controlled	NA - the test flights are already being carried out on the vineyards (real scenario).	
Realistic	• Integration of GAMF in sensor nodes and/or drone.	• Improved trade-off between resource usage and security

12.8.3. System Validation

The final step in the validation plan is the evaluation of the entire system in a field test. For this purpose, a mission is carried out to collect images and measurements from the sensors on the ground distributed in a vineyard to check the integration of the multispectral and visual camera and the Air-sensor on the airframe, as well as the data exchange on the defined interfaces, the implemented functionalities and the underlying components. In addition to the data acquisition campaign, the results of the post-processing step of the collected sensor and image data, the resulting holistic model of the condition of the soil and the plants in the vineyard is evaluated. This ensures that the images are recorded in the expected quality and data rate, the communication between the sensors on the ground, the drone and the base station works, and the measured values are correctly transmitted.

The results of the field test are evaluated in accordance with the business and technical KPIs defined in the "D1.1 Specification of Industrial Use Cases" in order to ensure that the demonstrator meets the requirements of the stakeholders.

13 Conclusion

This deliverable describes the demonstrators included in the Comp4drones project, provides information on the technologies to be used and the main technical requirements and functionalities of each demonstrator to meet different business KPIs and project objectives. All this information is related to each other and to other deliverables and finally, the described validation plan will allow the monitoring of the results and the reporting of the achievement of the objectives.

During these months of the project, technical components and tools are being developed so this deliverable is considered a preliminary version. Due to problems, new requirements or changes in the validation plan that may arise during the development of the technical tasks, in six months all the information included in the document will be re-verified and new information will be included if necessary for the correct development and understanding of demonstrators.