COMP4DRONES

DELIVERABLE

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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
BIM	Building Information Modeling
GCS	Ground Control Station

Executive Summary

Following the publication of Deliverable D1.1, it focuses mainly on obtaining the details of typical constraints posed by the demonstrators and stakeholders for their systems including operations. Later in deliverable D1.2, the required information by the operators and stakeholders regarding the main technologies that are to be used, developed and improved for their demonstrations and tests can be overseen. Now in deliverable D1.3, a resourceful information of Verification and Validation has been updated by retaining the details from D1.2. Alongside, each demonstrator starting their analysis for the desired system a V&V methodology is adapted to obtain the conformity of the system and validate for its robustness. Hence, we can observe a from D1.2 a matured phase (detailing and describing the different steps related to component validation, functionality validation and system validation) can be seen in the D1.3 with details of V&V resources being updated.

D1.3 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 methods to improvements the tested technologies. The traceability matrices of all these requirements, functionalities, and components are also defined at the demonstrator level to ensure that all are focused on the objectives of achieving the necessary and indicated goals of the demonstrators.

The IV&V in D1.3 first describes the ***Strategy***, which presents the IVV activities that are to be performed sequentially and reminds the reader of its main objectives. Following ***Procedures and Means,*** describing the procedures descriptions, environment, planned inputs, and IVV steps to be followed for each of the IVV activities are identified in the previous IVV Strategy. Likewise, the necessary tools and methods to the complete the IVV activities. Finally, the ***Results,*** which represent any kind of deliverables or outputs (completed checklists, reports, results, validation, compliance or verification matrices …) from the completion of IVV activities for components/system functionalities.

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.

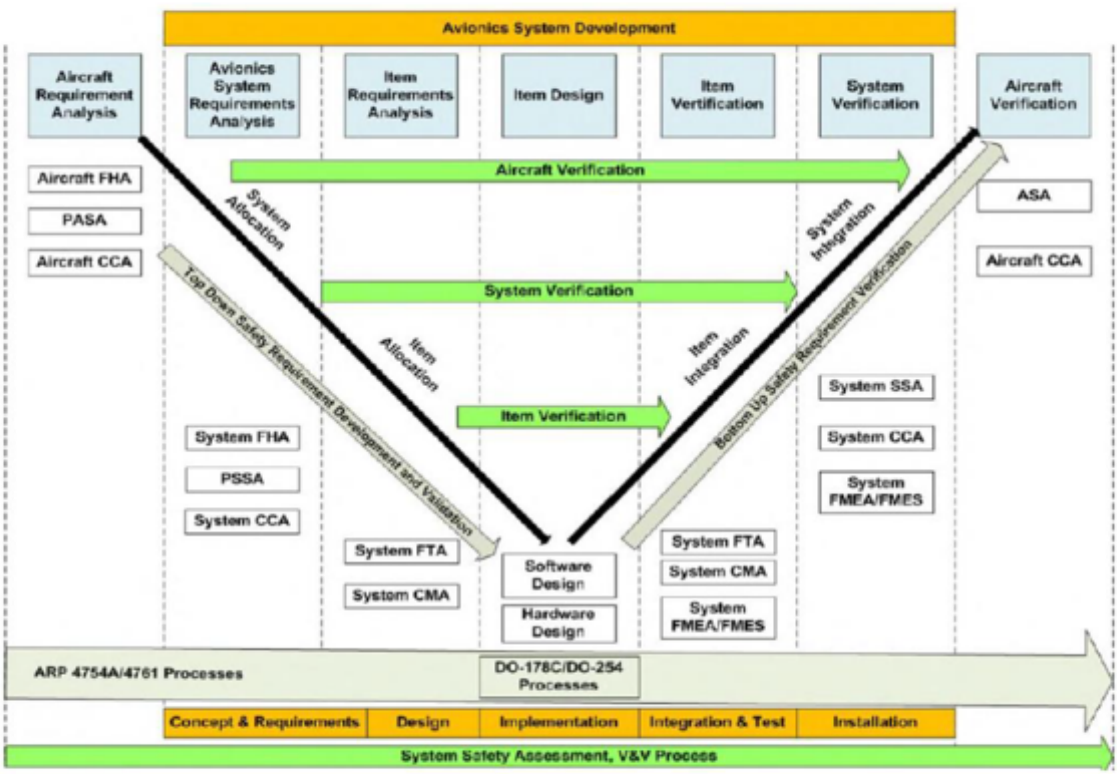


Figure 1 Avionics system development

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.

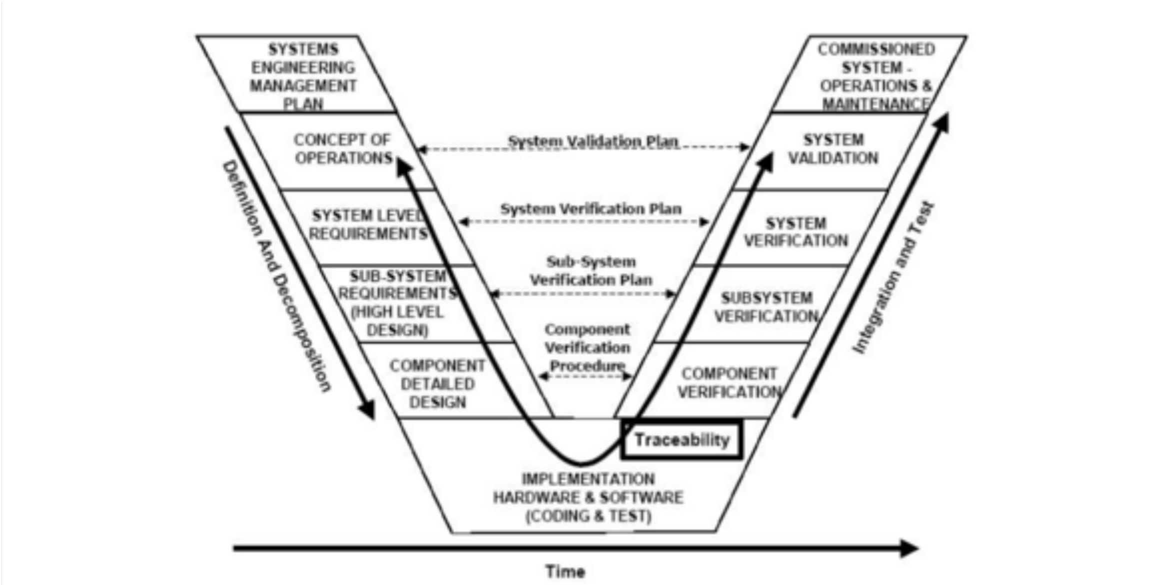


Figure 2 Engineering systems Design V model

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. IVV system plan

Earlier in D1.2 the above mentioned 8 steps were detailed in a precise manner with the workflow. Now, the **step 8** from D1.2 (Validation Plan) is being updated with modifications as IVV system plan according to the prior existing industry actors and experts.

IVV system plan in D1.3 creates necessary strategy on how to channel and have the robust system in-function for the operations (use cases). This strategy pushes the system to the next level by providing System Verification and Validation.

However, as detailed earlier the steps are again stated to precise the methodology flow to have a resilient and durable system.

The 8 steps are detailed below:

One of the prime essential pre-requisites of this process is to define the engineering constraints of the required system. This system design constraints should be of a real workable problem of the industrial sector that aims improvement. To obtain recent advancements on the technology of interested sector, all relevant industry players and their appropriate procedures should be considered for the development of the industry.

By defining the requirements as constraints, all conceptual design requirements should be addressed via ConOps. This defines the system description along with other operational procedures. The procedures defined on the ConOps always goes in-line with the end-user or client requirements. The proposed ConOps can be envisioned by a technical description, flow chart, operational procedures (from the start to the end of the mission), with next necessary steps for the development of product.

When the problem or constraints addressed by the end-user is clear and the system that is to be designed is ascertain, then the prime step of the process starts by noting the key requirements. This noted key requirements is critical for the whole entire design process. If the requirements are noted with precision, then a robust design can be expected, if not then a wrong, incomplete or non-functional system can be obtained. All participants (stakeholders) must be considered during the drafting of system requirements, due to various necessities of the constraints posed by them.

According to the end-user requirements defining main functionalities of the system aids developers to identify the type of the system that is foreseen to be developed. As the lower level of requirement specifications are covered in the previous D1.2, in this step V&V model covers the medium level update of the process. These functionalities cover both hardware and software functionalities, its modules including other technical details etc. Jointly together this intrinsically define the final system, with similar steps adapted during the requirements.

In above mentioned Figure 2, just before initiating the final verification step it includes traceability. This function not only allows us to trace all the essential requirements but even trace the necessities for the components defined as per each demonstrator (inc. identified functionalities).

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.

It is understood that not all the requirements can be traced with the functionalities, because certain constraint (needs) details for the system are as per the external stakeholders in the operation in addition to the system (e.g., a human operator). With the above system functional architecture can be defined that bridges the whole functionalities and define the overall system.

Finally, in Figure 2, the IVV system plan represents the horizontal lines of the V&V Model and are the link between Validation and Verification. There are different means 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. The performed tests particularly aim at verifying a specific functionality, by not integrating with others. However, some test's for the final system can be performed within a closed environment (i.e., in a laboratory) before conducting any operation outdoors.
- **Simulated environment:** Any component or tool before being tested for its authenticity, they must be validated by simulations to avoid the errors. At complex situations having prototypes of the system gives the significant outputs results that reduces the validation time in real environment. **Outdoor controlled environment:** In an outdoor controlled environment all the testing activities are conducted with the final systems tests to a more realistic scenario, but not the final one. These tests will verify the whole operation of the system before the real operation.
- **Outdoor controlled environment:** In, 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.

This is the step where all the functionality requirements set is carefully validated and verified. Those functionalities that are linked with the requirements must/shall have a level 1 compliance to perform the required demonstration or tests 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. Mostly these functionalities are tested in a lab environment or in a controlled environment by prototyping the final designed model to verify and validate its authenticity and later put into the real market for the actual practice with its conformity of operation.

This validation plan can be designed for each functionality, but the integration pattern, defined by the functional architecture of the system, has to be as verified & 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).

HORUS is the Traffic Control Center platform responsible for the organization of the traffic systems, their configuration, the automated management and coordination of the UTM and CMPD platforms to manage complex tasks more easily in the safe use of drones and their work flows allowing the reservation of the air space to carry out the operation with the drone in the area of influence of an incident detected by the integrated systems.

The HORUS system allows the user operator of the traffic control centre to request a drone service within the reserved area of airspace to ensure that it does not interfere with manned traffic or with other drones, monitoring the drone's telemetry, authorizing the drone's flight plan, follow-up of the flight plan during the mission and receive the video streaming sent by the drone in real time.

The main objective is to demonstrate that drones can help in the interpretation of a traffic incident in real time as well as the monitoring of traffic flows. For this reason, HORUS requests air space to request the drone service at the location of the incident or congestion, as a result of a request or notification that the operator/authority of the highway will receive.

Implement emergency services so that in the event of an incident, drones can be used to detect, prepare and keep emergency situations under control and surveillance, reducing the response time to the location and the danger of exposure for road agents. Likewise, the drones will be able to send high-quality images and data in real time of what happened, from different angles and with the ability to cover multiple road points, serving as a guide for the emergency services.

Regarding the UTM platforms used in this demo, both the CISP and USSP have as main objective to allow the safety access of UAS operations as new actors in the current airspace. These platforms provide appropriate, secured, updated and reliable information allowing the final user to report its own operations. The UTM system provides all these tools oriented to the final user (drone operator) as well as the authorities, which in fact, will manage the access to the airspace.

CISP is a cloud based platform totally apified to allow the interconnection with third party systems that has as main users the authorities. This platform was in charge of providing the following services (amongst others):

- Registration
- Geo-awareness
- Flight authorization (manual flow)
- Traffic Information (including conformance and tactical alerts)

Providing all this services, the CIS allows a complete situational awareness to the users of the airspace (authorities and other USSPs).

Moreover, the authorities are able to manage the airspace by creating/editing/deleting new geofences and providing the access to certain restricted zones for particular UAS operations authorized to enter in the restricted airspace. To do so the authorities can access the CISP platform directly or by connecting to it through an API. This API allows the reception of new geofences as well as their modification including the operators and drones authorized to fly.

USSP is a cloud based platform totally apified to allow the interconnection with third party systems. This platform provides services end to end to the UAS operators, the main services provided are:

- Registration
- Geo-awareness
- Flight Planning (including ground service)
- Flight authorization (automatic flow) and Strategic Deconfliction
- Traffic Information (including tracking service)
- Conformance Monitoring Service
- Tactical Conflict detection

The USSP through different APIs is able to receive from third party systems the planned operations in order to assess them and provide authorization (if possible). After the assessment the USSP sends through another API the result of the authorization to the third party system.

The USSP provides a complete situational awareness to allow the operator users to monitor their different operations. Finally the platform offers another API to connect a GCS to allow the intercommunication with the UAS pilot:

- The reception of the activation of the flight, the telemetry and emergency alerts (if any)
- The provision to the GCS of the geoawareness information, conformance or tactical alerts and the nearby traffic that may affect the operation

The starting drone to be used for UC-1 is Indra RPAS MANTIS. MANTIS is an advanced, low-cost solution for intelligence, surveillance, target acquisition and reconnaissance missions in short-range operations. It is compatible with STANAG 4586. However, this solution can only carry payloads with visible or infrared cameras with NTSC/PAL (SD) signal system.

For the execution of the use case it is necessary to increase the resolution and stabilization of the payloads, for which 2 new payloads will be developed (visible and infrared) that send digital video, preferably in HD. The solution will be conditioned by the MTOW system. Payloads will be developed using a three-axis gyrostabilized camera (hardware stabilization) supported by software stabilization.

The impact of this update on the MANTIS system involves modifications to both the avionics (autopilot, video encoder, target tracking and radio link) and the control station (GCS) for displaying video in the new digital formats. .

The system that will be in charge of centralizing the communications between the different actors of the use case for UC-1 will be CMPD. CMPD is a software resource (Web Portal) supported by hardware elements that allows a varied set of users to provide and catalogue the information collected in unmanned missions.

To adapt the CMPD with the different systems, web development is done using the Java Spring Boot tool. The exchange of messages with the aerial platform is through Stanag 4585, respect to the other systems; with HORUS via JMS messaging using activeMQ, with UTM the flight plan is exchanged through its REST API and to send the telemetry another messaging system (MQTT) is used.

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

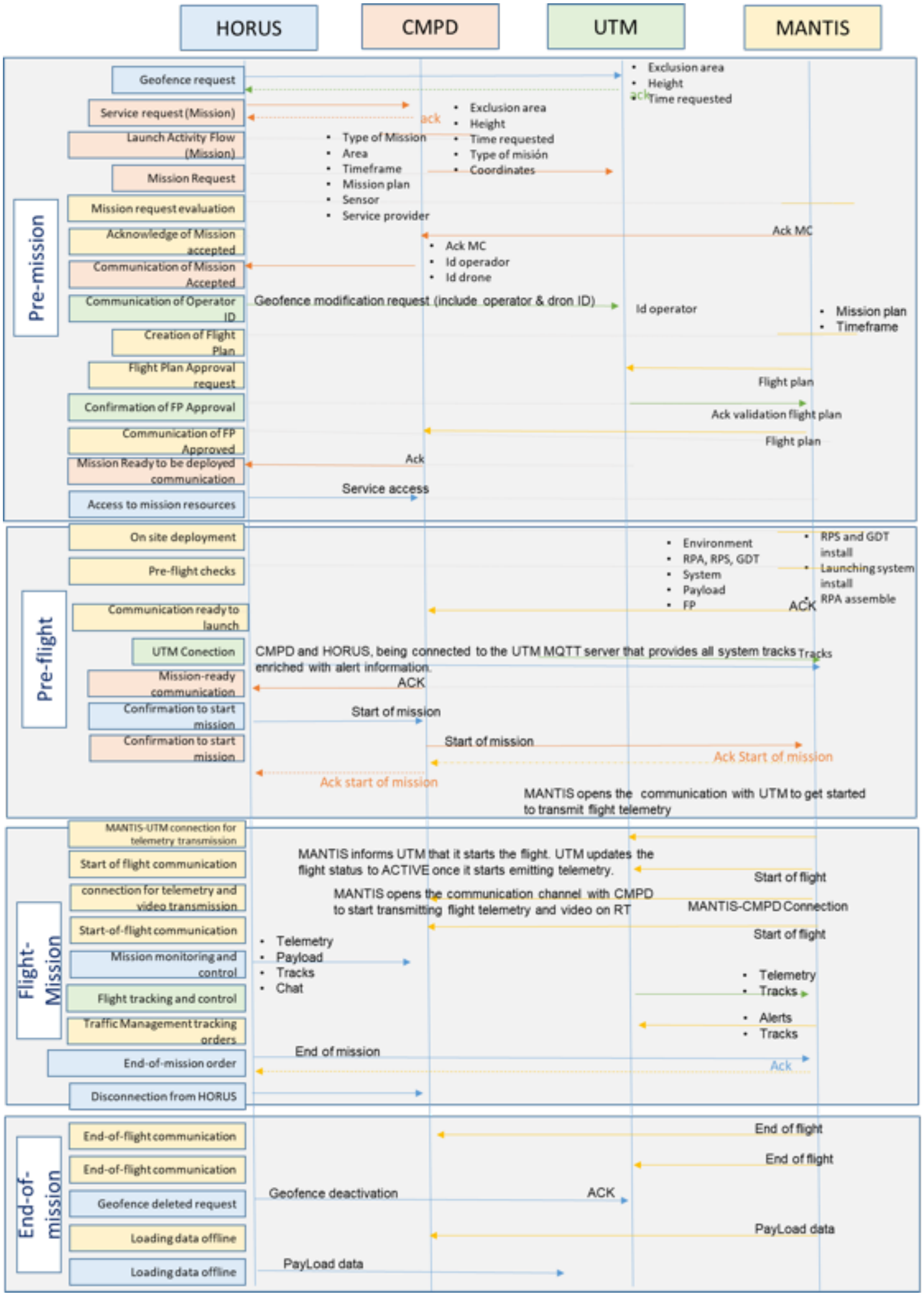


Figure 3 UC1 – D1 demonstrator's concept of operation scheme

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 Business KPIs

In D1.1 the main business KPIs for this demonstrator were introduced, the table below show an updated version detailing their definition and measurement:

ID	KPI	Definition and measurement of Indicator	Target Value
UC1-D1-KPI-1	Efficiency in the response time for monitoring traffic incidents	% Reduction of response time for monitoring of incidents. Current system from incident notification at the transport control center to first visual interpretation of the scene via local authorities arriving to the zone in patrol vehicle. End user defined the improvement on reduced of this time to be with this solution, at least of 5-10%	5-10%
UC1-D1-KPI-2	Optimization of costs in traffic management and incident monitoring activities	% Reduction of operational costs in traffic monitoring activities. Current mobilisation of resources in the monitoring activities of traffic incidents: patrol vehicles, helicopters. Each hour of flight of the Pegasus helicopter costs 1,500 euros. Solution of hour/cost will be compared against this.	5-10%

Table 1 UC1 D1 List of Business KPIs

2.3.2 Technical KPI`s and Metrics

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). 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.	Between 0-2 (currently it is between 2-4)

		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.	>=90%
		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	
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.	20%
		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.	
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 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	90%
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 2 UC1 D1 List of KPIs

2.3.3 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 3 UC1 D1 List of Main Requirements

2.3.4 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
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" 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
UC1-D1-DEM1-REG-5	Compliance with regulations	The UTM shall be compliant with European Union regulations	H	UTM

Table 4 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 5 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. 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.	Communications Intelligent data handling
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 5 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 720p, 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 its 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 its 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 6 UC1 D1 List of components

2.6 Traceability matrices

2.6.1 Requirements vs. functionalities

Before showing the links between the requirements and functionalities, the following clarifications are provided for the description of these requirements:

Requirement Type	Requirement ID	Short Description	Description
Functional Requirement	DEM1-FNC-6	Drone navigation	The drone must autonomously navigate with high position accuracy during landing. Landing accuracy is set at +-50 cms (longitudinal and lateral) from TDP (Touch Down Point). It can be validated by calculating the distance between the defined TDP and the TDP recorded in the flight log files.
Functional Requirement	DEM1-FNC-8	Drone GCS communication	The drone must communicate with the GCS and inform about its landing position. In the event of loss of communication between the aircraft and the GCS for more than 2 minutes, the aircraft will automatically go into landing mode. This mode executes the landing in the place indicated in the mission plan that the autopilot has loaded in memory, so the mission will be aborted. It can be validated by forcing the loss of signal and verifying that the drone lands in the predetermined place.

Table 7 Updated description of reviewed requirements

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 8 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 9 UC1 D1 Components and functionalities traceability matrix

2.7 IVV system 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

2.7.1.1 WP3-IND-1, WP3-IND2, WP3-IND-3: Payload (Single Visible HD), Payload (Infrared HD), Payload (Dual HD)

The *WP3-IND-1 and WP3-IND-2* be validated with a relevant environment in order to demonstrate that a TRL 6 is feasible.

2.7.1.1.1 Strategy

The activities to be carried out for the verification of components WP3-IND-1 (visible payment load) and WP3-IND-2 (infrared payment load) will be as follows:

1. Video visualization verification activity
2. Command execution verification activity
    a. Gyro- stabilization controller commands
    b. Optics commands

3. Auto tracking verification activity

All activities must be performed for each of the two components.

2.7.1.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Payload power supply	Laboratory	Power cord connection to payload and power supply	Video visualization
Connecting the output video from the payload to PC	Laboratory	Video cable with connection to the payload (Ethernet) and PC via RJ45	Video visualization
Video visualization from payload in VLC	Laboratory	Start commands of VLC program on PC IP and video streaming listening port	Video visualization
Connecting the payment load communications interface to PC	Laboratory	Data cable connection to payload and PC	Video visualization
Execution of gyro-stabilization controller commands	Laboratory	Starting commands of the turn-up controller program Execution commands of optical movement commands on the 3 axes (pitch, yaw and roll) and on/off auto tracking	Command execution
Execution of optic commands	Laboratory	Booting commands the optics configuration program Running of the following commands: On, off, zoom +, zoom -, autofocus on/off(visible), polarity on/off (IR)	Command execution
Auto tracking activation	Laboratory	Target to track Start target movement commands	Auto tracking verification

2.7.1.1.3 Means

Tools	Methods	Linked procedure(s)
Power supply	Testing	Video visualization Command execution Auto tracking verification
Testing cables	Testing	Video visualization Command execution Auto tracking verification
Software VLC	Visualization	Video visualization Auto tracking verification
Specific controller software	Testing	Command execution
Specific optic configuration software	Testing	Command execution

2.7.1.1.4 Results

Outputs	Linked procedure(s)
Video is received from the payload and visualized at the PC. Auto tracking of target in laboratory environment	Video visualization Command execution Auto tracking verification

2.7.1.2 WP3-IND-42: GCS - HMI

2.7.1.2.1 Strategy

The activities to be carried out for the verification of the WP3-IND-4 component (control of payload from the control station) will be as follows:

1. Verification activity on the connected camera type recognition control station
2. Command execution verification activity from the control station
3. Auto tracking execution verification activity from the control station

2.7.1.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Turn on GCS	Laboratory	Control station battery connection	Connected camera type recognition
Turn on the aircraft simulator	Laboratory	Simulator power supply at 220v	Connected camera type recognition
Connecting the GCS with the aircraft simulator	Laboratory	Cabling to interconnect systems	Connected camera type recognition
Start of the MANTIS Mission Program	Laboratory	Verification that the control station has the latest software version developed for the control of new payment charges and has enough charge in the battery or is connected to the electricity grid	Connected camera type recognition
Start of simulation program	Laboratory	Configuration parameters with the new payment loads	Connected camera type recognition
Selection in the simulator of the visible payment load	Laboratory	Connection between the GCS and the simulated aircraft	Connected camera type recognition
Visible payment load connection recognition	Laboratory	Status of new payment load received as "connected"	Connected camera type recognition
Executing commands in visible optics	Laboratory	Running the following commands from the GCS: video display, on/off pay load, zoom+, zoom -.	Running commands from the control station
Enabling auto tracking from the control station (visible payload)	Laboratory	Target to track Start target movement	Running autotracking from the control station

Selection in the infrared payment load simulator	Laboratory	Connection between the GCS and the simulated aircraft	Connected camera type recognition
Infrared payment load connection recognition	Laboratory	Status of new payment load received as "connected"	Connected camera type recognition
Executing commands in infrared optics	Laboratory	Running the following commands from the GCS: video display, on/off pay load, zoom+, zoom -, polarity	Running commands from the control station
Activation of auto tracking from the control station (infrared payment charging)	Laboratory	Target to track Start target movement	Running commands from the control station

2.7.1.2.3 Means

Tools	Methods	Linked procedure(s)
Aircraft simulator	Simulation	Connected camera type recognition Running commands from the control station Running autotracking from the control station

2.7.1.2.4 Results

Outputs	Linked procedure(s)
Video of visible and infrared cameras is received in the ground control station (GCS) Payloads respond correctly to control commands from GCS	Connected camera type recognition Running commands from the control station Running autotracking from the control station

2.7.1.3 WP4-25: Avionics - Encoder

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

2.7.1.4 WP4-26: Autopilot - Navigation

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

2.7.1.5 WP4-27, WP4-28: UTM Ground Service, UTM Airspace Structure

2.7.1.5.1 Strategy

The test for the UTM Airspace structure & Geofencing services will consist of 3 basic requests to the UTM System that are going to be performed by HORUS Platform. Those requests are:

1. New geofence request to UTM
2. Geofence modification request to UTM
3. Geofence deletion request to UTM

In this Demo, UTM Airspace Definition and Geofence Services will work both in the pre-flight and in-flight phases due to its inherited importance in providing critical information throughout the airspace structure.

HORUS Platform will send to the UTM System a request to create a new Geofence in the UTM System. Once created on the UTM platform, this Geofence will reserve a specific area to record the evidence of traffic accidents. Horus requests a contingent mission from CMPD and the flight plan required for that operation is generated.

Mantis receives the flight plan from the CMPD and once Mantis performs the flight, the HORUS Platform will send the Geofence removal request to UTM, so UTM will remove this emergency geofence.

2.7.1.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• HORUS requests geofence from UTM • UTM generates geofence • HORUS requests contingent service from CMPD • CMPD launches process and generates a flight plan with the required parameters and sends it to MANTIS • MANTIS ends mission and UTM clears geofence	*Laboratory - Simulator*	• Corresponding messages for change of state in the flow between the different systems • Flight plan •	• Validate software quality over a long period of time • Ability to perform all missions • Stability against "unexpected events" • Validate the necessary iteration between the systems to generate and operate the flight plan

2.7.1.5.3 Means

Tools	Methods	Linked procedure(s)
CMPD / C4D Simulator	Environment used to manage the exchange of messages between the different systems	CMPD / C4D Simulator
CMPD application		

2.7.1.5.4 Results.

Outputs	Linked procedure(s)
Flight plan successfully sent to Mantis	Simulated flight

2.7.1.6 WP4-29 & WP4-31: UTM Flight Plan Management UTM, Flight Plan Authorization

2.7.1.6.1 Strategy

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.

1. During Use Case 1, CMPD sends to the UTM Flight Planning services API the request to create a New Flight Plan.
2. 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.

2.7.1.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• HORUS requests geofence from UTM • UTM generates geofence • HORUS requests contingent service from CMPD • CMPD launches process and generates a flight plan with the required parameters and sends it to MANTIS • CMPD sending flight plan to UTM • UTM to CMPD valid flight plan • CMPD communicates approved flight plan to HORUS • HORUS gives order to start mission • CMPD notifies MANTIS to start mission • MANTIS ends mission and UTM clears geofence	Laboratory - Simulator	• Messages with the corresponding request status in the flow between the different systems • Flight plan	• Validate software quality over a long period of time • Ability to perform all missions • Stability against "unexpected events" • Validate the necessary iteration between the systems to generate and operate the flight plan

2.7.1.6.3 Means

Tools	Methods	Linked procedure(s)
CMPD / C4D Simulator	Environment used to manage the exchange of messages between the different systems	CMPD / C4D Simulator
CMPD application		

2.7.1.6.4 Results

Outputs	Linked procedure(s)
Flight plan exchange reflecting the corresponding expected state in the flow	Simulated flights

2.7.1.7 WP-30 & WP4-32: UTM Trajectory algorithms, UTM Telemetry and Tracking

2.7.1.7.1 Strategy

To verify proper service working, the UTM team will ensure in one hand that all API requests that should be performed from 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).

2.7.1.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• The different systems subscribe to the corresponding service • MANTIS starts of mission • UTM receives aircraft telemetry • CMPD observes mission from CMPD and also by iframe UTM • HORUS receives the video of the mission	*Laboratory - Simulator*	*API requests from HORUS and CMPD*	• Validate software quality over a long period of time • Ability to perform all missions • Stability against "unexpected events" • All systems receive information in real time

2.7.1.7.3 Means

Tools	Methods	Linked procedure(s)
CMPD client	Environment executable in the GCS of the UAV to obtain the telemetry and video in real time of the vehicle and distribute it to the rest of the consumers	CMPD client
CMPD application	Application used to view information in real time from vehicles	CMPD application
Mission center (CM)	Application used to monitor video and telemetry in real time. It also allows embedding the UTM iframe	Mission center (CM)
UTM interface	Used to visualize the information of the airspace in which the flight is executed	UTM interface
Interfaz Horus	Developed to view video in real time	Interface Horus

2.7.1.7.4 Results

Outputs	Linked procedure(s)
All systems represent the required vehicle information	Simulated flights

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

2.7.1.8.1 Strategy

The activities to be carried out for the verification of the WP5-IND-1 components (sending the video of the payment charges to the GCS, receiving the telemetry from the UAV in the GCS and sending Command and Control messages from the GCS to the UAV) will be as follows:

1. Activities carried out in the component WP5-IND-4
2. Activities carried out in the component WP5-IND-2
3. Activities related to telemetry and command of Command and Control of the aircraft

For the execution of these activities it is necessary to have previously and successfully executed the validations of the components WP3-IND-1, WP3-IND2, WP5-IND-4 and WP5-IND-2

2.7.1.8.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Implementation of activities carried out in the WP5-IND-4 component	Laboratory	Those indicated in the activities of component WP5-IND-4	Activity 1
Implementation of activities carried out in the WP5-IND-2 component	Laboratory	Those indicated in the activities of component WP5-IND-2	Activity 2
Telemetry receive verification in the GCS Confirmation that aircraft telemetry is displayed in the GCS application	Laboratory	The assembly of activities 1 and 2 is maintained GCS software for mission management is running	Activity 3
Check-in of command and control supplies from the GCS to the autopilot. Mission plan upload from the GCS to the aircraft. Confirmation of receipt of message from the aircraft indicating that the mission plan has been loaded correctly.	Laboratory	The assembly of activities 1 and 2 is maintained GCS software for mission management is running Mission plan sent to the aircraft	Activity 3

2.7.1.8.3 Means

Tools	Methods	Linked procedure(s)
Same tools as indicated in the activities of the WP5-IND-4 and WP5-IND-2 components	Same methods as those indicated in the activities of components WP5-IND-4 and WP5-IND-2	Activity 1 and 2

2.7.1.8.4 Results

Outputs	Linked procedure(s)
Video of the payment charges to the GCS is received the telemetry from the UAV in the GCS and the Command and Control messages from the GCS to the UAV	Activities 1, 2 and 3

2.7.1.9 WP5-IND-2: Communications - Autopilot

2.7.1.9.1 Strategy

The activities to be carried out for the verification of components WP3-IND-1 (visible payment load) and WP3-IND-2 (infrared payment load) will be as follows:

1. Command execution verification activity
    a. Gyro-destabilization controller commands
    b. Optics commands

All activities must be performed for each of the two components WP3-IND-1, WP3-IND2

2.7.1.9.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Power the fuselage through the aircraft battery	Laboratory	Verification of wp5-ind-3 component completed successfully	Command execution verification
*Configure autopilot in test mode	Laboratory	Video extender cable for video connected at one end to the paid charge and at the other to the PC via RJ45	Command execution verification
Connect video extender cable to paid charging	Laboratory		Command execution verification
Connect the payment load to the powered fuselage	Laboratory		Command execution verification
Viewing the video from the payment load, through the extender calbe, using VLC program	Laboratory	Booting command of VLC program on PC Configuring IP and video streaming listening port parameters	Command execution verification
Verification of execution of optics commands	Laboratory	Video stream in VLC to observe the execution of the on/off, zoom +, zoom -, autofocus (visible) and polarity (infrared) commands performed by the autopilot in "test" mode	Command execution verification
Running gyro-stabilization controller commands Autotracking is verified to work correctly	Laboratory	Video visualizing in VLC pointing to a target. The autopilot has activated in its "test" mode the autotracking	Command execution verification

The start of the autopilot in test mode implies that the autopilot automatically executes a check of all the peripherals with which it communicates. To do this, it sends all possible commands available against that peripheral.

2.7.1.9.3 Means

Tools	Methods	Linked procedure(s)
Cables for testing	Testing	Command execution verification
Software VLC	Visualization	Command execution verification

2.7.1.9.4 Results

Outputs	Linked procedure(s)
Video of visible and infrared cameras is received in the ground control station (GCS)	Command execution verification

2.7.1.10 WP5-IND-3: Communications Ports

2.7.1.10.1 Strategy

The activities to be carried out for the verification of the WP5-IND-3 component (enable physical connection through connectors, wiring and ports of the autopilot between it and the payment load) will be the following:

1. Cabling continuity check activity between the payment loads and the connectors of the interface connecting to the fuselage
2. Activity of verification of continuity of wiring between the autopilot of the avionics (installed in the fuselage) and the connectors of the connection interface with the payload
3. End-to-end cabling continuity verification activity (from payment loads to avionics autopilot)

All activities must be performed for each of the two components WP3-IND-1 and WP3-IND-2 (visible and infrared payment charges respectively)

2.7.1.10.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Power cabling continuity check from fuselage connection interface connector to optics	Laboratory	Tester configuration status in continuity check mode	Activity 1
Power cabling continuity check from fuselage connection interface connector to IMU	Laboratory		Activity 1
Power cabling continuity check from fuselage connection interface connector to turn card destabilization	Laboratory		Activity 1
Video cabling continuity check from fuselage connection interface connector to optics	Laboratory		Activity 1
Control data cabling continuity check from fuselage connection interface connector to optics	Laboratory		Activity 1
Control data cabling continuity check from fuselage connection interface connector to turnaround card	Laboratory		Activity 1
Power cabling continuity check from connection interface connector to payloads to avionics power supply	Laboratory		Activity 2
Video cabling continuity check from connection interface connector to payment loads to video input in avionics	Laboratory		Activity 2
Control data cabling continuity check from connection interface connector to payment loads to avionics autopilot	Laboratory		Activity 2
Connect payload to fuselage through the connectors provided on each connection interface	Laboratory		Activity 3
Power wiring continuity check from the pay load optics to the avionics power supply	Laboratory		Activity 3
Power wiring continuity check from the IMU to the avionics power supply	Laboratory		Activity 3
Power wiring continuity check from the turn-and-turn card to the avionics power supply	Laboratory		Activity 3
Continuity check of video wiring optics to video input in avionics	Laboratory		Activity 3

Continuity check of control data wiring from the optics to the autopilot of the avionics	Laboratory		Activity 3
Continuity check of control data wiring from the turn card to the avionics autopilot	Laboratory		Activity 3

2.7.1.10.3 Means

Tools	Methods	Linked procedure(s)
Tester (multimeter)	Testing	Activity 1, Activity 2 and Activity 3

2.7.1.10.4 Results

Outputs	Linked procedure(s)
Physical connection through connectors, wiring and ports of the autopilot between it and the payment load	Activity 1, Activity 2 and Activity 3

2.7.1.11 WP5-IND-4: Communications – GCS

2.7.1.11.1 Strategy

The activities to be carried out for the verification of the WP5-IND-4 component (communications between the GCS and the autopilot) will be as follows:

1. Video display verification activity in the GCS
2. Command submission verification activity, related to optics, between gcs and autopilot
3. Autotracking activation verification activity from the GCS

2.7.1.11.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Connection of the ground data terminal (GDT) to the control station. Automatic start of the GDT	Laboratory	Connection cable between GCS and GDT	Activities 1, 2 and 3
Running optics-related commands from the GCS	Laboratory	Run the following commands: On, off, zoom +, zoom -, autofocus on/off(visible), polarity on/off (IR)	Activity 2
Verification of receipt of commands in the autopilot and forwarding of orders to the optics of the payment load Reading commands sent by the autopilot towards the payment payload)	Laboratory	RS-232 port reader and cable connection between the PC and the data pins of the connectors that are located on the interface of the connecting fuselage with the paid load	Activity 2
Activation of autotracking from the GCS.	Laboratory	Autotracking commands on and off	Activity 3
Verification of receipt of autotracking command on the	Laboratory	RS-232 port reader and cable connection	Activity 3

autopilot and forwarding of orders to the turn cardstabilization of the payment load Reading commands sent by the autopilot towards the payment payload		between the PC and the data pins of the connectors that are located on the interface of the connecting fuselage with the paid load Fuselage movement commands on all 3 axes (pitch, yaw and roll) and autotracking on/off	
Connecting fuselage video input to PC	Laboratory	Video cable connection to l fuselage(ethernet) and PC via RJ45	Activity 1
Activation of video viewing from the GCS.	Laboratory	VLC Program Boot Local video streaming	Activity 1

2.7.1.11.3 Means

Tools	Methods	Linked procedure(s)
Cables para testing	Testing	Activity 1
Software VLC	Visualization	Activity 1
Serial Port Monitor	Testing	Activity 2,3

2.7.1.11.4 Results

Outputs	Linked procedure(s)
Reception and display of video sent by VLC through the aircraft	Activities 1, 2 and 3

2.7.1.12 WP5-IND-5 : Communications – GCS - CMPD

2.7.1.12.1 Strategy

In this test, the software that allows converting a MANTIS flight plan to the format expected by UTM is validated. It also implements all the business logic necessary to correctly execute the information exchange between the control station and the CMPD in the use case.

2.7.1.12.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• CMPD sending flight plan to UTM • UTM to CMPD valid flight plan • CMPD communicates approved flight plan to HORUS • HORUS gives order to start mission • CMPD notifies MANTIS to start mission • MANTIS runs the CMPD client itself GCS	simulator	Flight plan in UTM format	• verified that UTM can process the flight plan sent by the CMPD • validated that the CPMP client processes and parses the MANTIS telemetry and forwards it to the different consumers

2.7.1.12.3 Means

Tools	Methods	Linked procedure(s)
CMPD / C4D Simulator	Environment used to manage the exchange of messages between the different systems	CMPD / C4D Simulator
CMPD application	Application used by the GCS operator (Mantis) to exchange files containing the flight plan	CMPD application
UTM interface	Used to visualize the information of the airspace in which the flight is executed	UTM interface

2.7.1.12.4 Results

Outputs	Linked procedure(s)
Telemetry received by all systems with the correct formation	Simulated flights

2.7.1.13 WP5-IND-6 : Communications – UAV – GCS – CMPD - UTM

2.7.1.13.1 Strategy

This test covers all software developments that enable end-to-end communication between the UAV and the UTM.

The correct communication to UTM of the telemetry, the launch and landing time of the UAV is validated.

2.7.1.13.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• MANTIS starts the mission • Cmpd informs UTM of the start of the mission • MANTIS ends mission • CMPD informs UTM of end of mission	simulator	Mission status messages	The exchange of messages determining the mission status between CMPD and UTM is accepted

2.7.1.13.3 Means

Tools	Methods	Linked procedure(s)
CMPD / C4D Simulator	Environment used to manage the exchange of messages between the different systems	CMPD / C4D Simulator

2.7.1.13.4 Results

Outputs	Linked procedure(s)
Mission states reported correctly	Simulated flights

2.7.1.14 WP5-IND-7 : Communications – GCS - HORUS

2.7.1.14.1 Strategy

This test covers all the software developments that allow the communication of the MANTIS system with the HORUS system.

This component will be in charge of communicating with the HORUS system, through the CMPD system. These messages include requesting a new mission, accepting the mission, as well as orders to take off and land the aircraft.

2.7.1.14.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• CMPD accepts contingent mission to HORUS, sends data from operator ids and drone • CMPD communicates approved flight plan to HORUS • ACK start mission • ACK end of mission	Simulator	Mission status messages	The exchange of messages determining the mission status between CMPD and HORUS is validated

2.7.1.14.3 Means

Tools	Methods	Linked procedure(s)
CMPD / C4D Simulator	Environment used to manage the exchange of messages between the different systems	CMPD / C4D Simulator

2.7.1.14.4 Results

Outputs	Linked procedure(s)
Mission states reported correctly	Simulated flights

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	
	Campaign 6	Stage 3	M27-M32	

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

2.7.2.1 UC1-D1-FUN01 – Geofencing - UTM

2.7.2.1.1 Strategy

The test for the UTM Airspace structure & Geofencing services will consist of 3 basic requests to the UTM System that are going to be performed by HORUS Platform. Those requests are:

1. New geofence request to UTM (to isolate the area where Mantis is going to perform the operation).
2. Geofence modification request to UTM (to grant Mantis operator and drone permissions to fly inside the geofence).
3. Geofence deletion request to UTM (to delete the geofence once the operation has finished).

The 3 operations described above will consist in their correspondent requests to the UTM system API, whom will act as agreed. That operations are creating, modifying and deleting the Geofence.

2.7.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
(1) 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.	Laboratory	Geofence request	Interface connecting HORUS and UTM platforms. First individual integration tests.
(2) Geofencing of incident area with updates of drone identification parameters. Simulated test flights. Deactivation of geofence from HORUS	Outdoor controlled	Drone and operator ID parameters	Telemetry of the flights, data logs of the geofence.
(3) Complete geofence functionalities. Deployment of geofence scenarios. Test flights in realistic scenario.	Realistic	Geofence request Drone and operator ID parameters	Telemetry of the flights, data logs of the geofence.

2.7.2.1.3 Means

Tools	Methods	Linked procedure(s)
WebIssues	Node.js with Express framework and MQTT for asynchronous communications, and MongoDB as database.	(1), (2), (3)
iTestMan		

2.7.2.1.4 Results

Outputs	Linked procedure(s)
Geofence request by HORUS registered in UTM with all identification parameters.	(1), (2), (3)

2.7.2.2 UC1-D1-FUN02 – Flight plan Management

2.7.2.2.1 Strategy

HORUS Platform will send to the UTM System a request to create a new Geofence in the UTM System. Once created on the UTM platform, this Geofence will reserve a specific area to record the evidence of traffic accidents. Horus requests a contingent mission from CMPD and the flight plan required for that operation is generated.

Mantis receives the flight plan from the CMPD and once Mantis performs the flight, the HORUS Platform will send the Geofence removal request to UTM, so UTM will remove this emergency geofence.

2.7.2.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• HORUS requests geofence from UTM • UTM generates geofence • HORUS requests contingent service from CMPD • CMPD launches process and generates a flight plan with the required parameters and sends it to MANTIS • MANTIS ends mission and UTM clears geofence	simulator	• Corresponding messages for change of state in the flow between the different systems • Flight plan	• Validate software quality over a long period of time • Ability to perform all missions • Stability against "unexpected events" • Validate the necessary iteration between the systems to generate and operate the flight plan

2.7.2.2.3 Means

Tools	Methods	Linked procedure(s)
CMPD / C4D Simulator	Environment used to manage the exchange of messages between the different systems	CMPD / C4D Simulator
CMPD application	Application used by the GCS operator (Mantis) to exchange files containing the flight plan	CMPD application

2.7.2.2.4 Results

Outputs	Linked procedure(s)
Exchange of the flight plan in the field to carry out the mission	Real flights

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

2.7.2.3.1 Strategy

Field flights are carried out to verify that all systems communicate with each other, exchanging flight data and following the flow of the operation according to the use case.

2.7.2.3.2 Procedures.

Procedure description	Environment	Planned inputs	IVV Objective(s)
• HORUS requests geofence from UTM • UTM generates geofence • HORUS requests contingent service from CMPD • CMPD launches process (requests mission from MANTIS) • CMPD accepts contingent mission to HORUS, sends data from operator ids and drone • HORUS requests UTM authorization for Mantis operator and pilot to fly over geofence • CMPD sending flight plan to UTM • UTM to CMPD valid flight plan • CMPD communicates approved flight plan to HORUS • HORUS gives order to start mission • CMPD notifies MANTIS to start mission • MANTIS starts of mission • MANTIS begins mission and the aircraft takes off • UTM receives aircraft telemetry • CMPD observes mission from CMPD and by UTM´s iframe as well • HORUS observes mission	Real flights	Different states of the operation flow	Validate a real use case by checking the iteration between all systems and the execution of a real mission

2.7.2.3.3 Means.

Tools	Methods	Linked procedure(s)
CMPD client	Environment executable in the GCS of the UAV to obtain the telemetry and video in real time of the vehicle and distribute it to the rest of the consumers	CMPD client
CMPD application	Application used to view information in real time from vehicles	CMPD application
Mission center (CM)	Application used to coordinate video and telemetry in real time. It also allows embedding the UTM iframe	Mission center (CM)

UTM interface	Used to visualize the information of the airspace in which the flight is executed	UTM interface

2.7.2.3.4 Results

Outputs	Linked procedure(s)
Correct operation of the System in a real operation	Real flights

2.7.2.4 UC1-D1-FUN04 – Deconfliction – UTM

2.7.2.4.1 Strategy

Same as UC1-D1-FUN01and UC1-D1-FUN02. Deconfliction functionalities are based on geofencing and flight plan management, and represent an extension of the validation and verification of these.

2.7.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
(1) Implementation of conflict detections over the geofence area received by HORUS and flight plan created by Mantis.	Laboratory	Geofence information, Flight Plan	Implementation of functionality for the use case.
(2) Simulated tests of conflict detection and deconfliction workflow for the simulated mission.	Outdoor controlled	Geofence information, Flight Plan	First simulation test. Denials and alternatives for the conflictive missions.
(3) Complete deconfliction functionalities, with all the platforms integrated. Test deconfliction process in realistic scenario (scenario 2).	Realistic	Geofence information, Flight Plan	Real simulation tests. Execution of denials and alternatives for the conflictive missions.

2.7.2.4.3 Means

Tools	Methods	Linked procedure(s)
WebIssues	*Node.js with Express framework and MQTT for asynchronous communications, and MongoDB as database.*	*(1), (2), (3)*
iTestMan		

2.7.2.4.4 Results

Outputs	Linked procedure(s)
Updated Flight plan	*(1), (2), (3)*

2.7.2.5 UC1-D1-FUN05 – HD image acquisition

The activities to be carried out for the verification of the HD image acquisition functionality:

1. HD video display verification activity in the GCS.

2.7.2.5.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
(1) Initial tests of the image acquisition system. Correct gyro stabilization, commands.	Laboratory	Payload commands and signal	Visual validation of the images captured and analysis of quality, stabilization.
(2) Exterior image acquisition tests with components installed on Mantis (ground tests).	Outdoor controlled	Payload commands and signal	Visual validation of the images captured verification over GCS.
(3) Complete image acquisition functionalities, with all the components integrated. Exterior flight tests and visualization of HD images from Mantis.	Realistic	Payload commands and signal	Real image acquisition tests. HD video acquisition.

2.7.2.5.2 Means

Tools	Methods	Linked procedure(s)
N/A		

2.7.2.5.3 Results

Outputs	Linked procedure(s)
Checklists of results	(1), (2), (3)

2.7.2.6 UC1-D1-FUN06 – Image streaming

2.7.2.6.1 Strategy

In this test it is verified that HORUS can coordinate the operation in real time by viewing it in real time

2.7.2.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• MANTIS starts mission • CMPD communicates to HORUS the mission start ack • Horus displays the video in real time	simulator	Development provided to HORUS that allows access to video	HORUS can access the MANTIS video in real time

2.7.2.6.3 Means

Tools	Methods	Linked procedure(s)
CMPD / C4D Simulator	Environment used to manage the exchange of messages between the different systems	CMPD / C4D Simulator
CMPD application	Application used by the GCS operator (Mantis) to exchange files containing the flight plan	CMPD application

2.7.2.6.4 Results

Outputs	Linked procedure(s)
Horus views the UAV video	Real flights

2.7.2.7 UC1-D1-FUN07 – Autonomous navigation

2.7.2.7.1 Strategy

The activities to be carried out for the verification of the HD image acquisition functionality:

1. HD video display verification activity in the GCS
2. Activity of verification of the functionalities associated with tracking

2.7.2.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Initial analysis of the data received from the HD cameras in the autopilot.	Laboratory	Images from payload, tracking parameters	Analysis and visual validation of tracking capabilities.
First exterior tests of autopilot and tracking, setting a tracking objective (ground tests).	Outdoor controlled	Images from payload, tracking parameters	Analysis and visual validation of tracking capabilities.
Complete autonomous navigation functionalities. Visualization of autonomous tracking of Mantis the execution of the mission in a real scenario.	Realistic	Images from payload, tracking parameters	Real autonomous navigation tests. Analysis and visual validation of tracking capabilities.

2.7.2.7.3 Means

Tools	Methods	Linked procedure(s)
N/A		

2.7.2.7.4 Results

Outputs	Linked procedure(s)
Checklists of results	Activities 1 y 2

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 10 UC1 D1 system validation plan

2.7.3.1 Strategy

Two scenarios have been defined in D1.1 which will test all the components, integrations and information flows presented.

2.7.3.1.1 Scenario 1 will test the following functionalities

- UC1-D1-FUN01
- UC1-D1-FUN02
- UC1-D1-FUN03
- UC1-D1-FUN05
- UC1-D1-FUN06
- UC1-D1-FUN07

2.7.3.1.2 Scenario 2 will test the same functionalities as Scenario 1 with the addition of UC1-D1-FUN04. This scenario introduces the “complexity” of deconfliction activities in the geofenced area.

- UC1-D1-FUN01
- UC1-D1-FUN02
- UC1-D1-FUN03
- UC1-D1-FUN04
- UC1-D1-FUN05
- UC1-D1-FUN06
- UC1-D1-FUN07

2.7.3.2 Scenario 1

2.7.3.2.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
(1)HORUS generates a Geofence in UTM in the indicated area	*Realistic*	Geofence request	Creation of Geofence
(2) HORUS sends service request to CMPD	*Realistic*	Service request	Creation of drone operation
(3) CMPD launches priority FP new request to UTM	*Realistic*	FP request	Creation of Flight Plan
(4) FP approved by UTM	*Realistic*	FP authorization	Authorisation of Flight Plan
(5) Mantis carries out his operation	*Realistic*	Real time images from Mantis payload	Reception of HD images in real time
(6) In flight automatic tracking a vehicle	*Realistic*	Real time images from Mantis payload	Automatic tracking and autonomous navigation

(7) HORUS and CMPD receive the composite tracks generated by UTM	*Realistic*	Tracks and telemetry from UTM	Reception of telemetry data and tracks from UTM
(8) HORUS requests geofence erasure from UTM	*Realistic*	Geofence delete request	Free airspace

2.7.3.2.2 Means

Tools	Methods	Linked procedure(s)
Wireshark	Debug of IP sent	Mantis
WebIssues iTestMan	*Node.js with Express framework and MQTT for asynchronous communications, and MongoDB as database.*	UTM
Simulator developed ad hoc to simulate the messages exchanged by the MANTIS system between the CMPD system and the UTM platform	Simulator	Mantis-CMPD-UTM

2.7.3.2.3 Results

Outputs	Linked procedure(s)
Automatic tracking system of objects and persons	• UC1-D1-FUN05 • UC1-D1-FUN07
Detection, recognition and identification incident	• UC1-D1-FUN05 • UC1-D1-FUN06 • UC1-D1-FUN07
Integration with external systems by standards (UTM-HORUS-CMPD-Mantis)	• UC1-D1-FUN01 • UC1-D1-FUN02 • UC1-D1-FUN03 • UC1-D1-FUN06
Optimization of available bandwidth usage for HD video streaming	• UC1-D1-FUN06

2.7.3.3 Scenario 2

2.7.3.3.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
HORUS generates a Geofence in UTM in the indicated area	*Realistic*	Geofence request	Creation of Geofence
Part of the new Geofence collides with an area where a Recreational Flight is located. This is revoked and the pilot notified.	*Realistic*	Airspace structure status and geofence areas	Deconfliction of geofence area
HORUS sends service request to CMPD	*Realistic*	Service request	Creation of drone operation
CMPD launches priority FP new request to UTM	*Realistic*	FP request	Creation of Flight Plan

FP approved by UTM	*Realistic*	FP authorization	Authorisation of Flight Plan
Mantis carries out his operation	*Realistic*	Real time images from Mantis payload	Reception of HD images in real time
HORUS and CMPD receive the composite tracks generated by UTM	*Realistic*	Tracks and telemetry from UTM	Reception of telemetry data and tracks from UTM
UTM receives a new FP request from an operator who wants to fly over part of the area covered by the Mantis FP. Its initial FP is rejected and is proposed with deconflict options. The operator choses to shorten its FP so as not to interfere with the other operation.	*Realistic*	Tracks and telemetry from UTM	Deconfliction of Flight Plan
HORUS requests geofence erasure from UTM	*Realistic*	Geofence delete request	Free airspace

2.7.3.3.2 Means

Tools	Methods	Linked procedure(s)
Wireshark	Debug of IP sent	Mantis
WebIssues iTestMan	*Node.js with Express framework and MQTT for asynchronous communications, and MongoDB as database.*	UTM
Simulator developed ad hoc to simulate the messages exchanged by the MANTIS system between the CMPD system and the UTM platform	Simulator	Mantis-CMPD-UTM

2.7.3.3.3 Results

Outputs	Linked procedure(s)
Automatic tracking system of objects and persons	• UC1-D1-FUN05 • UC1-D1-FUN07
Detection, recognition and identification incident	• UC1-D1-FUN05 • UC1-D1-FUN06 • UC1-D1-FUN07
Integration with external systems by standards (UTM-HORUS-CMPD-Mantis)	• UC1-D1-FUN01 • UC1-D1-FUN02 • UC1-D1-FUN03 • UC1-D1-FUN04 • UC1-D1-FUN06
Optimization of available bandwidth usage for HD video streaming	• UC1-D1-FUN06

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.

Regarding the UTM platforms used in this demo, both the CISP and USSP have as main objective to allow the safety access of UAS operations as new actors in the current airspace. These platforms provide appropriate, secured, updated and reliable information allowing the final user to report its own operations. The UTM system provides all these tools oriented to the final user (drone operator) as well as the authorities, which in fact, will manage the access to the airspace.

CISP is a cloud based platform totally apified to allow the interconnection with third party systems that has as main users the authorities. This platform was in charge of providing the following services (amongst others):

- Registration
- Geo-awareness
- Flight authorization (manual flow)
- Traffic Information (including conformance and tactical alerts)

Providing all this services, the CIS allows a complete situational awareness to the users of the airspace (authorities and other USSPs).

Moreover, the authorities are able to manage the airspace by creating/editing/deleting new geofences and providing the access to certain restricted zones for particular UAS operations authorized to enter in the restricted airspace. To do so the authorities can access the CISP platform directly or by connecting to it through an API. This API allows the reception of new geofences as well as their modification including the operators and drones authorized to fly.

USSP is a cloud based platform totally apified to allow the interconnection with third party systems. This platform provides services end to end to the UAS operators, the main services provided are:

- Registration
- Geo-awareness
- Flight Planning (including ground service)
- Flight authorization (automatic flow) and Strategic Deconfliction
- Traffic Information (including tracking service)

- Conformance Monitoring Service
- Tactical Conflict detection

The USSP through different APIs is able to receive from third party systems the planned operations in order to assess them and provide authorization (if possible). After the assessment the USSP sends through another API the result of the authorization to the third party system.

The USSP provides a complete situational awareness to allow the operator users to monitor their different operations. Finally the platform offers another API to connect a GCS to allow the intercommunication with the UAS pilot:

- The reception of the activation of the flight, the telemetry and emergency alerts (if any)
- The provision to the GCS of the geoawareness information, conformance or tactical alerts and the nearby traffic that may affect the operation

The starting drone to be used for UC-1–Demo 2 will be a static multirole quadcopter captive UAV (ARGOS) based on low weight and wingspan, designed for a wide range of operations for civilian and military applications.

The drone is tethered by a captive kit consisting of a “Captive UAV Air Module” (that manages the operator's orders, system operation modes, controls the entire flight phase and reports information on the state of the system to the “Captive UAV Control Center”) and a micro-tether that provides continuous power supply to the UAV and a communications interface. It enables unlimited access to a global aerial vision, in real time and in a secure manner and provides a practically unlimited autonomy, being able to be operational for very long periods over different weather conditions, day or night, limited by the system maintainability.

The captive UAV integrates as a payload, a gimbal with RGB and thermal camera, with a wide angle of view, resolution and sufficient image quality to recognize any person, vehicle, infrastructure state, etc., at a reasonable distance. In addition, it has a 10X optical zoom to see any necessary detail.

However, this solution cannot be integrated on a mobile platform because there are not tracking algorithm developed for it.

For the execution of the use case, it is necessary to develop this tracking algorithm and design and manufacture the necessary fixing system of the “Captive kit” to the mobile vehicle. For the development of this “follow me” algorithm the technology implemented has been C++ and the development environment used is Visual Studio Code.

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:

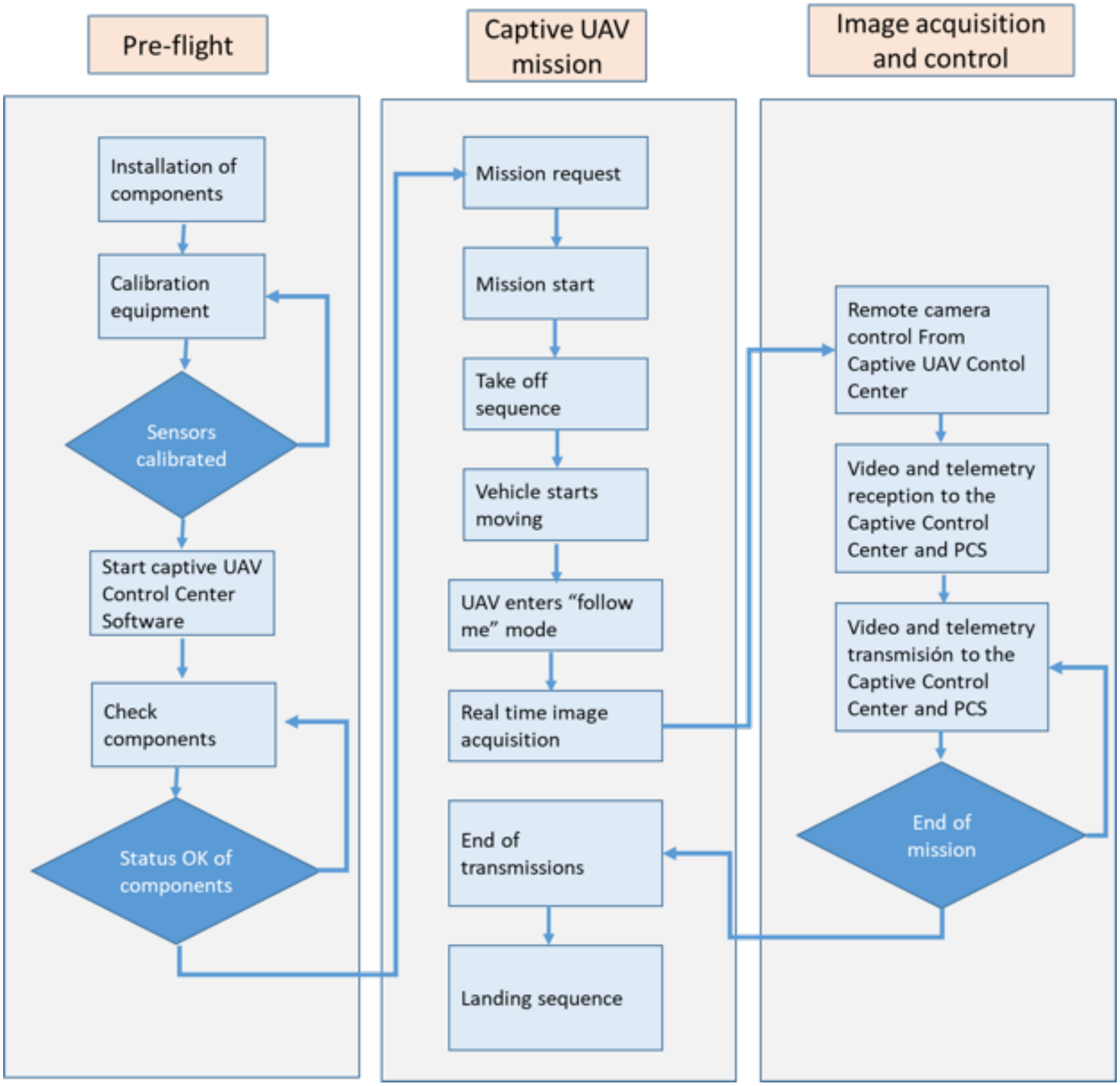


Figure 4 UC1 – D2 demonstrator's concept of operation scheme

- 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 Business KPIs

It is needed to clarify how the following KPIs will be measured. The baseline and objective measures of improvement, the calculation base (time and area) will be obtained by making the round in a traditional way with the surveillance vehicle once the deployment of the scenario is defined with the Port of Vigo.

ID	KPI	Definition and measurement of Indicator
UC1-D2-KPI-1	Shorter surveillance rounds	Time reduction to perform surveillance tasks.
		The indicator will be calculated compared to the volume of surface currently controlled at a specific time by the port surveillance equipment.
UC1-D2-KPI-2	Increase of controlled areas in the same space of time	Increase in controlled surface at the same time (camera 25 meters above the ground, which gives a wide range of vision).
		The indicator will be calculated compared to the volume of surface currently controlled at a specific time by the port surveillance equipment.
UC1-D2-KPI-3	Increase of visible areas and elimination of blind spots	Increase of area covered not currently visible with the existing surveillance system.
		The indicator will be calculated compared to the areas that are currently not covered.
UC1-D2-KPI-4	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.
		The indicator will be calculated compared to the movements currently detected.

3.3.2 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 11 UC1 D2 List of KPIs

3.3.3 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 centimetres'	*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 12 UC1 D2 List of Main Requirements

3.3.4 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
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 13 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 14 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 14 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 15 UC1 D1 List of components

3.6 Traceability matrices

3.6.1 Requirements vs. functionalities

Before showing the links between the requirements and functionalities, the following clarifications are provided for the description of this requirement:

Requirement Type	Requirement ID	Short Description	Description
Functional Requirement	DEM2 -10	Low visibility conditions	The system must be able to provide images in low visibility conditions. An operator with the naked eye will validate if the images sent in night conditions and in rainy conditions (if possible), have resolution enough to distinguish the image

Table 16 Table 6 Updated description of reviewed requirements

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 17 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 18 UC1 D1 Components and functionalities traceability matrix

3.7 IVV system 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

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

3.7.1.1.1 Strategy

The tracking algorithm will first be validated by simulation, checking that the UAV updates its position with respect to the coordinates to follow. Finally, the system will be validated in the field running vehicle tracking. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

The simulations take place after each development with the UAV connected, taking advantage of the HIL and SIL functionalities of the simulator to verify correct operation and debug errors for several hours before each field test.

In the field tests all the parameters of the autopilot that interfering with tracking mode are configured (gains, speeds, etc.) to achieve stable traceability with the vehicle's path, adjusting to its movements at all times.

3.7.1.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
QGroundControl Software in the loop(SIL) y Hardware in the loop(HIL)	Simulator	Different flight parameters (speed, height, ...) Different external conditions (wind, temperature...) Different routes	Validate software quality over long period of time. Capability to perform all the missions. Stability against "unexpected events.

3.7.1.1.3 Means

Tools	Methods	Linked procedure(s)
Simulator SIL/HIL	Connected to the simulator: provides stimulus to the UAV sensors, receives output from UAV.	Qgroundcontrol
QGroundControl	Allows to edit the flight parameters of the autopilot.	QGroundControl

3.7.1.1.4 Results

Outputs	Linked procedure(s)
Validation of the convergence of the routes traced by the UAV and the vehicle.	Simulator

3.7.1.2 WP1-IND-1 Power Supply- Captive Kit

3.7.1.2.1 Strategy

The Captive Kit feeding system first will be validated monitoring its parameters through its control application and finally it will be validated in the field supplying power to all the components of the system while the missions are carried out. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

Application verifications are carried out connecting all the elements that power the system and analysing the consumption values through the application.

In the field, a validation of the system is carried out in its normal operation, stimulating the consumption of the UAV and ensuring the correct operation of the system in all operating modes.

3.7.1.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field missions	Outdoor controlled	Power all elements of the system. Carry out different trajectories varying the parameters that influence it (speed, height, change of turn, landing, take-off) Different weather conditions on several test days.	Validate constant system power without power outages or drops while the system is running.

3.7.1.2.3 Means

Tools	Methods	Linked procedure(s)
Application T-Monitor	All system components are powered: provides voltage to the system and monitors consumption according to its behaviour.	T-Monitor

3.7.1.2.4 Results

Outputs	Linked procedure(s)
Captive kit properly powered	Outdoor controlled

3.7.1.3 WP1-IND-2 Installation - Captive UAV System

3.7.1.3.1 Strategy

The installation will be validated checking that all the elements are well fixed according to the previous design. Finally, several flights will be carried out, checking the fastening of all the components. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

The design of the UAV establishes the location of each component analysing possible interferences, the layout of the wiring and the available space / size.

In the field, a validation is performed, checking that in the different flights, the vibrations do not affect the safety of the wiring / components and fastening of each element, Likewise, looking the relationship between the tightening torque applied to the joint and the traction-compression that is induced when applying it according to the forces resulting from the flight.

3.7.1.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field missions	Outdoor controlled	Carry out different flight paths subjecting the system to sudden movements. Different weather conditions on several test days.	Validate correct operation in flight without decompensation or vibrations and free from interference.

3.7.1.3.3 Means

Tools	Methods	Linked procedure(s)
Torque wrench	Used to determine the stress to which a screw is subjected.	Outdoor controlled

3.7.1.3.4 Results

Outputs	Linked procedure(s)
System properly anchored and installed	Outdoor controlled

3.7.1.4 WP1-IND-3 GNSS Receiver

3.7.1.4.1 Strategy

The GNSS will be validated by means of a specific simulator checking the evaluation, the performance analysis and the configuration of the GNSS receivers. Finally, in the field tests will be carried out to adjust the external parameters and validate the precision of the system. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

As a simulation and validation tool for the proposed solution, based on PID controllers to control the tracking mode, the algorithm in mathematical language, Matlab / Octave, is implemented as a previous step to the definitive implementation. This implementation allows to simulate the behaviour of the UAV and the vehicle based on their dynamic performance as speed or acceleration.

In the field, it is validated by checking that from the GPS coordinates of both the UAV and the vehicle, positioning information of the UAV with respect to the vehicle is obtained, according to the tracking mode coordinate system.

3.7.1.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Software UBLOX u-center	Simulator	Satellite summary Navigation summary Compass, speedometer, clock, altimeter	Validate the correct configuration of the GPS module
Matlab/Octave	Simulator	• Proportional component P • Integral component I • Derivative component D	Simulate the tracking algorithm

3.7.1.4.3 Means

Tools	Methods	Linked procedure(s)
u-center	U- blox GNSS receivers can be configured using u-center evaluation software	u-center
Matlab/Octave	Allows simulating the level of convergence of the UAV position with the randomly generated vehicle position	Matlab/Octave

3.7.1.4.4 Results

Outputs	Linked procedure(s)
Obtaining the corrected GPS plot	Outdoor controlled

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

3.7.1.5.1 Strategy

The control application will be validated checking the iteration with the vehicle, commanding the action orders to the team and receiving the telemetry and video accordingly. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

The pre-flight checks allow to check all the exchange parameters, the reception of all telemetry messages, the quality of the video and the response to the control orders received in the UAV.

In the field, a functional flight will be performed to check the stability of the video and the absence of interference induced by the flight.

3.7.1.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field missions	Outdoor controlled	Carry out different trajectories varying the parameters that influence it (speed, height, change of turn, landing, take-off) Different weather conditions on several trial days	Validate the exchange of information with the UAV

3.7.1.5.3 Means

Tools	Methods	Linked procedure(s)
Captive application control UAV	Interface that allows interaction with the UAV	Captive application control UAV

3.7.1.5.4 Results

Outputs	Linked procedure(s)
Captive application control UAV	Outdoor controlled

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.

3.7.2.1 UC1 – D2 - FUN01 – Captive UAV System

3.7.2.1.1 Strategy

The captive system will be validated by checking the integration of all the elements that compose it. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

Pre-flight checks allow you to verify communication between all the different components of the system.

In the field, a functional flight will be carried out in order to validate the correct operation of all the system components.

3.7.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field missions	Flight area	Carry out different trajectories varying the parameters that influence it (speed, height, change of turn, landing, take-off) Different weather conditions on several trial days	Validate the global operation of the system

3.7.2.1.3 Means

Tools	Methods	Linked procedure(s)
Captive UAV System	Field validation	Real flights

3.7.2.1.4 Results

Outputs	Linked procedure(s)
Captive UAV System	Real flights

3.7.2.2 UC1 – D2 - FUN02 – GNSS positioning

3.7.2.2.1 Strategy

For the UAV to operate properly in the different modes of operation, including the tracking mode, it is necessary for the control unit to have a correct georeferencing, both of the UAV and the vehicle. This georeferencing will provide the system with the positioning of the UAV with respect to the vehicle. This validation is carried out by subjecting the implemented functions to the following steps:

A reference GPS position is taken: the position of the vehicle.

Starting from that reference position, another GPS position is taken at a known distance and direction, the position of the UAV. For example, a position 10 meters north.

The GPS - ENU transformation is executed with those positions, checking that the result in ENU coordinates is (0 10 0).

The same tests are repeated with other positions at different distances and directions.

As a next step, once the functionality has been validated in mathematical language, the same functionality is implemented in the control application and real missions are performed to validate its operation.

3.7.2.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field missions	Flight area	Carry out different trajectories varying the parameters that influence it (speed, height, change of turn, landing, take-off). Different weather conditions on several trial days.	Verify the correct positioning of the UAV with respect to the vehicle

3.7.2.2.3 Means

Tools	Methods	Linked procedure(s)
Matlab/Octave	Allows to validate the tests developed in mathematical language	Matlab/Octave

3.7.2.2.4 Results

Outputs	Linked procedure(s)
Obtaining the corrected GPS plot	Real flights

3.7.2.3 UC1 – D2 - FUN03 – UAV surface vehicle navigation

3.7.2.3.1 Strategy

The control application will be validated by checking the handling of GPS coordinates; that is, the availability of functionalities that allow positioning the UAV in a given GPS coordinate. Finally, in the field will be validated that the UAV transitions in all flight modes according to the operational needs, adapting at all times to the route of the vehicle. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

In the current version of the OSDK, missions are the only functionality that allows the control of the UAV with the intervention of GPS coordinates In the previous tests, the behaviour of the UAV will be simulated through the simulator, switching between the different flight modes in a simulated trajectory.

A functional flight will be carried out in the field to check the transition between all operating modes.

3.7.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field missions	Flight area	Carry out different trajectories that contain different flight modes (landing, take-off, tracking)	Validate the transition between all flight modes

3.7.2.3.3 Means

Tools	Methods	Linked procedure(s)
DJI OSDK	It offers different options that allow the control of the UAV flight.	DJI OSDK
QGroundControl	Allows to configure the autopilot.	QGroundControl
Simulator HIL/SIL	QGroundControl offers the possibility of carrying out the missions in a simulated way	Simulator HIL/SIL

3.7.2.3.4 Results

Outputs	Linked procedure(s)
Validation of the convergence of the routes traced by the UAV and the vehicle	Real flights

3.7.2.4 UC1 –D2- FUN04 – Mission monitoring

3.7.2.4.1 Strategy

The monitoring interface will be validated by checking the execution of the application correctly connecting to the vehicle's server (SBC) and sending all messages without loss of information. The goal is to demonstrate the reliability of the system: it should run smoothly for several days of continuous operations.

Pre-flight checks allow to develop the communications interface between the different modules. The Control Center application acts entirely as a client of the captive UAV control application, which in relation to communication with the Control Center acts as its server. Up to 3 communication sockets are established between the UAV and the Control Center.

In the field, a functional flight is performed in order to check the exchange of the different messages generated by the Captive UAV Control Center application, which are system operation control messages.

3.7.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field missions	Flight area	Carry out different trajectories varying the parameters that influence it (speed, height, change of turn, landing, take-off) Different weather conditions on several trial days	Validate the exchange of messages between the vehicle and the Control system

3.7.2.4.3 Means

Tools	Methods	Linked procedure(s)
Captive application control UAV	Offers the ability to represent vehicle information in real time	Captive application control UAV

3.7.2.4.4 Results

Outputs	Linked procedure(s)
Captive application control UAV	Real flights

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.		

KPI	Definition and measurement of Indicator	Description and enhancements	Verification Method	*Campaign tests*
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 19 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

3.7.3.1 Strategy

Same info as 1.7.1, for system (The IVV strategy may include information about one or several scenarios)

3.7.3.2 Scenario 1: Improvement of efficiency in surveillance tasks: shorter surveillance rounds

3.7.3.2.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• From the "Captive UAV Control Center", take off is ordered at the desired operating altitude. • Start of "follow me" mode. • The UAV enters in "follow me "mode and flies at the indicated operating altitude, following the defined route of the vehicle as it moves. • Once the route is completed, the vehicle stops and the UAV descends on the resting platform.	Flight area	Defined route at different speeds.	Validate the reduction of time in Surveillance rounds.

3.7.3.2.2 Means

Tools	Methods	Linked procedure(s)
• Captive UAV system • Captive application control UAV	• Offers a surveillance point at the required altitude • Offers the ability to represent vehicle information in real time	• Captive UAV system • Captive application control UAV

3.7.3.2.3 Results

Outputs	Linked procedure(s)
Route optimized in time	Real flights

3.7.3.3 Scenario 2: Improvement of efficiency in surveillance tasks: increase of controlled areas in the same space of time

3.7.3.3.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• From the “Captive UAV Control Center”, take off is ordered at the desired operating altitude. • Start of “follow me” mode. • The UAV enters in “follow me“ mode and flies at the indicated operating altitude, following the defined route of the vehicle as it moves. • Once the route is completed, the vehicle stops and the UAV descends on the resting platform.	Flight area	Defined route covering a desired field of vision	Validate the increase of controlled areas in the same space of time

3.7.3.3.2 Means

Tools	Methods	Linked procedure(s)
• Captive UAV system • Captive application control UAV	• Offers a surveillance point at the required altitude • Offers the ability to represent vehicle information in real time	• Captive UAV system • Captive application control UAV

3.7.3.3.3 Results

Outputs	Linked procedure(s)
Larger controlled area in the same period of time	Real flights

3.7.3.4 Scenario 3: Improvement of efficiency in surveillance tasks: increase of visible areas and elimination of blind spots.

3.7.3.4.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• From the “Captive UAV Control Center”, take off is ordered at the desired operating altitude. • Start of “follow me” mode. • The UAV enters in “follow me“ mode and flies at the indicated operating altitude, following the defined route of the vehicle as it moves.	Flight area	Defined route increasing the visible areas (eliminating blind spots)	Validate the increase of visible areas.

• Once the route is completed, the vehicle stops and the UAV descends on the resting platform.			

3.7.3.4.2 Means

Tools	Methods	Linked procedure(s)
• Captive UAV system • Captive application control UAV	• Offers a surveillance point at the required altitude • Offers the ability to represent vehicle information in real time	• Captive UAV system • Captive application control UAV

3.7.3.4.3 Results

Outputs	Linked procedure(s)
More exhaustive surveillance of a defined area (eliminating blind spots)	Real flights

3.7.3.5 Scenario 4: Improvement of efficiency in surveillance tasks: greater ability to detect movements in low visibility conditions

3.7.3.5.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• From the "Captive UAV Control Center", take off is ordered at the desired operating altitude. • Start of "follow me" mode. • The UAV enters in "follow me" mode and flies at the indicated operating altitude, following the defined route of the vehicle as it moves. • Once the route is completed, the vehicle stops and the UAV descends on the resting platform.	Flight area	Defined route increasing the ability to detect movements in low visibility conditions.	Validate the system camera's ability to observe different viewing angles by detecting movement in low visibility conditions.

3.7.3.5.2 Means

Tools	Methods	Linked procedure(s)
• Captive UAV system • Captive application control UAV	• Offers a surveillance point at the required altitude • Offers the ability to represent vehicle information in real time	• Captive UAV system • Captive application control UAV

3.7.3.5.3 Results

Outputs	Linked procedure(s)
Ability to detect movements in low visibility conditions.	Real flights

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 enough, 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).

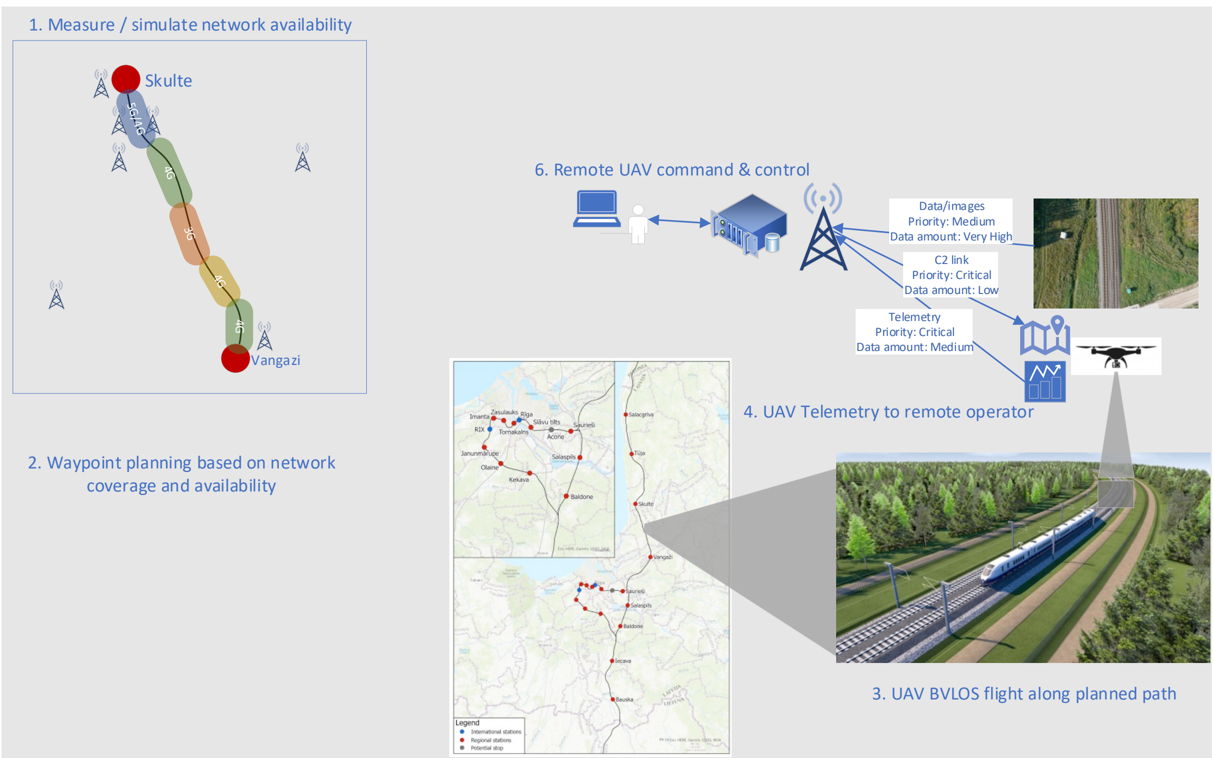
Only two of these areas are most vital to railway communications. The first point, critical environment communications, is very advantageous for maintenance and control applications, and it is also useful for critical operations. Using 5G, the railway can undertake and establish secure and reliable communications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

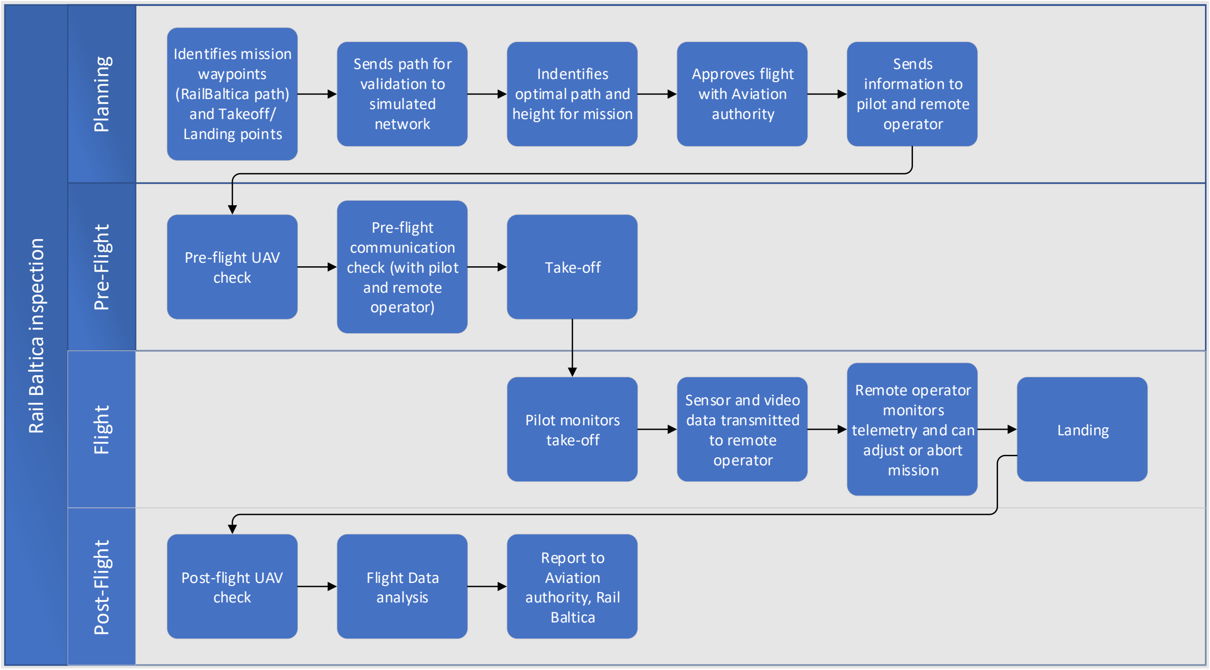


Test flights and network measurements allowed to make assumptions of network KPIs for safe and controlled drone flights. The next step is to validate network KPI values with data-based network measurements up to 120 m and simulate a 3D mobile network map to assess the feasibility of safe, controlled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

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.



Safe railway operation requires regular inspections due to possible track obstructions and environmental damage. Stations and possible launch and landing points are located up to 100km apart. UAV should be able to cover this distance to charge the batteries.

Our demonstrated flight will start at planned RailBaltica railway station near Riga airport. It will follow the railway and inspect over 40km distance. At the end it will land at planned RailBaltica logistics centre location.

1) we will plan the UAV flight waypoints in horizontal and vertical coordinates.
    a. To get the required resolution images the height above ground level is from 40 to 100 meters.
    b. We have minimum height requirement of 60 meters based on expected tree height and additional safety margin of 5 meters.
    c. Deviation in horizontal axis from actual railroad path based on camera field of view is height / 1.5. Possible deviation from path is 40m at 60m height and 66m at 100m height.
2) We will plan the waypoints at the optimal locations, i.e. 70-meter height and on top of the railway.
3) 4G and 5G cellular network coverage will be analysed before the flight, because Cellular network C2 link will be used during the BVLOS phase of the flight. The waypoint coordinates will be imported in the AirbornRF solution. This solution contains the LMT coverage mathematical model that is based on our infrastructure's information. The result is predicted cellular signal quality along the UAV flight path.
4) If we will not meet the KPI's for safe flight, then the path will be adjusted (increased height and / or horizontal coordinate) to meet the criteria.
5) After the final path is calculated, it will be coordinated with regulatory institutions and ANSP, as flights near Riga airport can take place only after approval and ANSP person present on site.
6) After regulatory clearance flight will take place with pilots located at launch and landing sites for safety purposes, in case manual override is required. Those pilots will prepare the UAV for the flight, the procedure that will be done automatically in the future using drone port solutions.
7) VTOL will be equipped with additional transmitters (cellular based and ADS-B based) to have backup channel for actual UAV location during the whole flight.
8) Remote pilot will launch the mission and drone will take off. After reaching required altitude, VTOL will engage forward propulsion and will start mission execution.

9) During mission the video feed will be transferred to remote site. During demonstration it will be available as video feed, but in the future it can be processed by Machine vision algorithms to automatically detect any deviations or object on the railway.
10) During mission execution (after take-off and before landing) it will be executed as Beyond Visual Line of Sight flight. Coordination between Remote Pilot and ANSP will take place if flight should be altered to ensure safety in airspace.
11) Upon reaching the target landing area, UAV will enter the VTOL landing sequence and land automatically. Backup pilot with possibility to manually override the automatic mission will be present in case manual adjustments are required for safety purposes.
12) As the final step, the flight logs will be analysed on actual network coverage during the flight and compared with mathematical model.

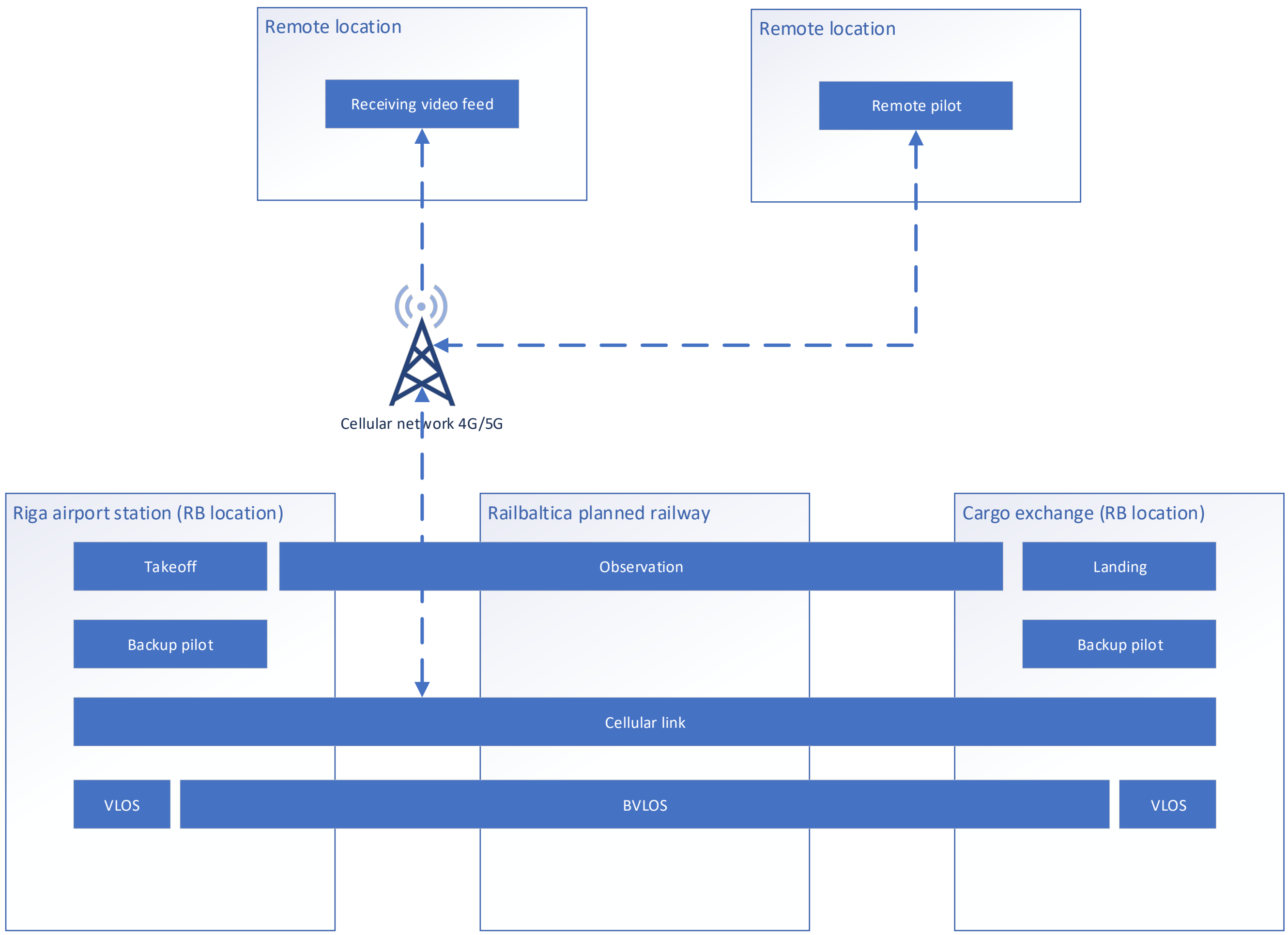


Figure 8 This diagram shows main phases and roles during the flight sequence.

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 Business KPIs

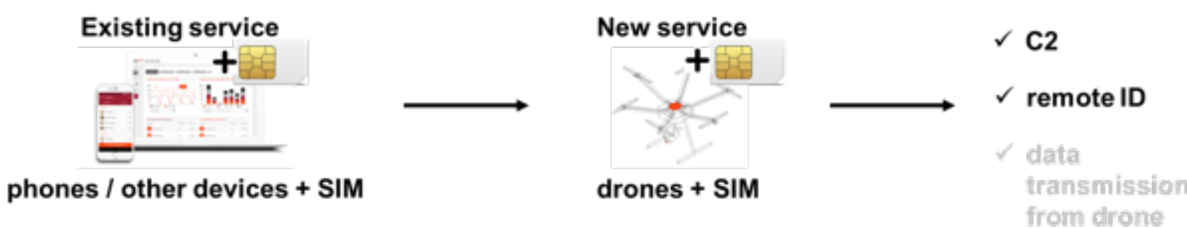
Business KPIs related to provide a reliable service without disturbing existing business.

KPI	Definition and measurement of Indicator	Description	Verification Method
Cellular connectivity complex KPI.	Identification of less disturbed bandwidth across existing cellular network.	Reconfiguration costs for drone flight above ground level are foreseen as current service thus require substantial connectivity antenna reconfiguration which affects existing network and client services.	Set up cost of new business case.
Cellular C2 link strength complex KPI.	Less disturbed bandwidth for next generation 5G connectivity.	As 5G network is in development stage it enables some opportunities for channelling connectivity in less densely used frequencies.	Set up cost of new business case.
Cellular C2 link strength complex KPI.	Reduced connectivity cost connecting abroad.	Roaming costs and its optimisation based on uplink/downlink mission requirements.	Set up cost of new business case.

Table 20 - UC1 D3: Business KPIs

The potential business opportunities of telecom operators in the field of drones are related to 2 blocks of issues - reliable communication, conducting drone flight entirely over the mobile network, and data transmission. Data transmission is not a new type of business - it is a question of the company's strategy, what, to whom and how to offer in the market.

Mobile network-enabled services from the perspective of customer:



The first two points: C2 and remote ID are directly related to business KPI. Demonstrator plans to provide 2 scenarios – 4G and 5G. Technologies validation and several test campaigns show that the 4G existing network already provides all technical KPIs for remote ID functionality. Cellular network integration with network coverage service solution can offer the route that meets the technical requirements, including in the case of roaming (business KPI-1 and KPI-3).

5G scenario will allow showing advantages of slicing functionality and validate or provide safe C2 with combined functionality - slicing combined with network coverage service solution to provide a trustable route for drone mission (business KPI-2).

4.3.2 Technical KPI`s and Metrics

KPI	Definition and measurement of Indicator	Description	Target metrics
C2 link power	Reference Signals Received Power (RSRP)	Mission reconfiguration before and during the flight	> -110 dB reference in simulated network
C2 link quality	Reference Signal Received Quality (RSRQ)		> -12 dB
C2 link interference	Signal-to-interference-plus-noise ratio (SINR)		> 5 dB
C2 link channel quality	Channel Quality indicator (CQI)		5
C2 link strength complex	Latency		< 50 ms
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/sec
Reliability of second C2 data link	Multi SIM switch		Down time less than 1 sec

Table 21 UC1 D3 List of KPIs

4.3.3 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 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	H	Service provider/ SW Developer	UC1-D3-KPI-01

		surveillance/ safety system.			
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	Authorization 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 22 UC1 D3 List of Main Requirements

4.3.4 Drone integration requirements

Requirement ID	Short Description	Description	Pr io rit	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.	H	Service provider/ SW Developer	UC1-D3-KPI-01 - UC1-D3-KPI-11

Table 23 UC1 D3 List Of drone integration Requirements

4.3.5 Regulatory requirements

As mentioned in D2.5, all EASA requirements, and means of compliance associated, have been detailed in SORA analysis of UC3 Demo 1 Metis Use Case.

Table 24 list requirements related with SORA analysis.

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 take-off/landing zone is controlled on the ground, with no uninvolved people on it.	H	Drone operator	-

Table 24 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/ optimization 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	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/ optimization Operation plan processing

Table 25 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 MachineType 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 26 UC1 D3 List of components

4.6 Tools

Main tool that allows 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 27 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 28 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 29 UC1 D3 Components and functionalities traceability matrix

4.8 IVV system plan

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

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

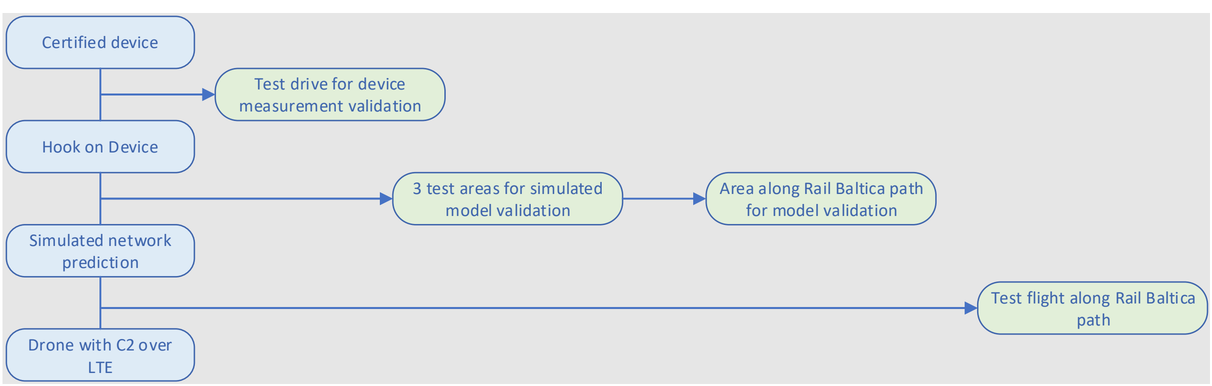
Test description	Network measurement in specified frequencies will be measured at different altitude levels using signal KPI (signal strength, quality, latency, UL/DL speed) measuring hook on device. Network parameter tests will be performed on multiple (at least 3) locations over the planned Rail Baltica path with different urban/rural locations. Those tests will be compared with the simulated 3D mobile network map predicting the network parameters. After determining if sufficient quality cellular network is present in the test locations based on the simulated 3D mobile network map the test flight will be performed along Rail Baltica path with distance of at least 50 km. During this flight C2 signal quality will be measured. In addition, video stream will be sent to the ground station and monitored to determine data link quality.
Planned inputs	Simulated 3D mobile network map over test flight area. Drone based network quality test device result comparison with certified device. Network quality measurements of flight path.
Expected results	Reliable communication cannel evaluation for UAV and C2 functionality in selected flight area

4.8.1.1.1 Strategy

To determine current network coverage and potential improvements for 4G cellular network actual flight will be performed in potential area of operations. Rail Baltica path is fixed, therefore it must be ensured that over whole path the C2 links works as expected. When using existing network setup only drone altitude can be adjusted to have better cellular signal reception. Horizontal position path can be only adjusted within specific sensor (e.g. camera) coverage width.

To find if existing network is sufficient, cellular signal will be measured along whole flight path. Before flight is executed, we must ensure that it is safe to be controlled over LTE C2 link, which will be done by simulating **3D mobile network map** (Component 3) the intended flight path. **Simulated 3D mobile network map** will be validated against actual measurements in several test areas and different altitude.

4.8.1.1.2 Procedures



Procedure description	Environment	Planned inputs	IVV Objective(s)
COMP01-P1 - Drone hook on network measuring device result comparison with certified device	Ground vehicle based path near planned test flight location	Certified device measurements Hook on device measurements	Evaluate accuracy of hook on device
COMP01-P2 Hook on device result comparison with Simulated 3D mobile network map	Rectangular test areas with flights in different altitude	Hook on device measurements Network quality predicted by **Simulated 3D mobile network map**	Evaluate accuracy of **Simulated 3D mobile network map** in test locations
COMP01-P3 Measurement flight along Rail Baltica path	Rail Baltica path specific locations	Hook on device measurements Network quality predicted by **Simulated 3D mobile network map**	Evaluate accuracy of **Simulated 3D mobile network map** in realistic locations
COMP01-P4 Test flight via LTE C2	Rail Baltica path min distance 15km	Network quality predicted by **Simulated 3D mobile network map**	Test real life scenario with C2 and data link

4.8.1.1.3 Means

Tools	Methods	Linked procedure(s)
Hook on network measuring device (certified device cannot be used due to payload weight limitations)	Evaluation against laboratory certified device	COMP01-P1
Simulated 3D mobile network map	Evaluation against real hook on device data within test area	COMP01-P2

4.8.1.1.4 Results

Outputs	Linked procedure(s)
Validated Simulated 3D mobile network map against hook on device results	COMP01-P2
Actual C2 and Data signal quality along Rail Baltica path	COMP01-P4

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

Test description	Identifying, enabling, and testing 5G 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

4.8.1.2.1 Strategy

Currently 5G networks is not widely available and it will be deployed over several next years. LMT will be building 5G test network in several locations and it will be available for testing various scenarios. Availability of test area will allow to test C2 link within 5G network in comparison to Comp01 4G LTE network. Via testing this network at different altitudes and network setups we will be able to provide recommendation on 5G network specification for UAV operations.

4.8.1.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
COMP02-P1 5G network measurements in test area from ground vehicle	Closed test area with dedicated 5G test antenna setup	5G network	Test 5G network requirements for UAV C2 and Data links
COMP02-P2 5G network measurements in test area from UAV in different altitude	Closed test area with dedicated 5G test antenna setup	5G network	Test 5G network requirements for UAV C2 and Data links

4.8.1.2.3 Means

Tools	Methods	Linked procedure(s)
5G network with test infrastructure	LMT will deploy test area with 5G network availability in closed territory. Test will be performed to determine best equipment, configuration for UAV C2 and Data links.	COMP02-P1, COMP02-P2

4.8.1.2.4 Results

Outputs	Linked procedure(s)
5G network specification for UAV C2 and Data link	COMP02-P1, COMP02-P2

4.8.1.3 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
Planned inputs	Tested and validated route simulation process
Expected results	Reliable route for UAV mission

4.8.1.3.1 Strategy

Accurate simulated 3D mobile network map is essential part to scale the BVLOS flights via cellular network, because it can ensure that the chosen routes are safe and meets specified criteria for C2 and data links.

In order to determine accuracy of simulated model, it will be compared with actual measurements both in test areas at different heights to test horizontal accuracy and along path to determine accuracy of areas between several cellular towers.

4.8.1.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulated 3D mobile network map validation	Test areas	Network infrastructure description, antenna locations, azimuths, etc. Actual measurements from HOD	-
Simulated 3D mobile network map in Rail Baltica path	Rail Baltica path	Network infrastructure description, antenna locations, azimuths, etc.	-

4.8.1.3.3 Means

Tools	Methods	Linked procedure(s)
Simulated 3D mobile network map prediction service	-	COMP01-P2

4.8.1.3.4 Results

Outputs	Linked procedure(s)
Validation report of model vs real situation network parameters	COMP01-P3, COMP01-P4

4.8.2 System Functionalities Verification

4.8.2.1 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 efficient communication channel for Drone C2

4.8.2.1.1 Strategy

C2 link should be maintained at reasonable quality in order to ensure safety of the drone and airspace around flight location. C2 link quality parameters will be measured in realistic scenario to determine KPI values in different locations. Those values will be compared to the KPI's described in 1.3.1. Technical KPI`s and Metrics.

4.8.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test C2 link in areas with different network quality	VLOS flight with backup control from radio transmitter	Location of areas where network quality is on boundary conditions based on simulation	Test boundary conditions for C2 link availability
LTE C2 link monitoring during flight	BVLOS flight along Rail Baltica path	-	-

4.8.2.1.3 Means

Tools	Methods	Linked procedure(s)
Drone with LTE enabled C2 link	-	COMP01-P2, COMP01-P3

4.8.2.1.4 Results

Outputs	Linked procedure(s)
Measurement of technical KPI's	COMP01-P4

4.8.2.2 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 center via the mobile network

4.8.2.2.1 Strategy

Camera data stream will be sent from the drone to the ground station. Quality of the streamed data will be measured to determine latency and network throughput. Continuous video data stream will be sent to the remote location during whole flight. This video stream will be stored during this demonstration. In realistic scenario, video stream can be passed to analysis algorithms for further processing.

4.8.2.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test data link quality	Drone flight in LTE network	-	-

4.8.2.2.3 Means

Tools	Methods	Linked procedure(s)
Drone equipped with high resolution camera payload	Payload data is sent through LTE link to remote location	COMP01-P4

4.8.2.2.4 Results

Outputs	Linked procedure(s)
Data link quality report	COMP01-P4

4.8.2.3 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

4.8.2.3.1 Strategy

Simulated 3D mobile network map will provide information about optimal flight path including height. This optimal path is calculated based on network data (cellular antenna location, azimuth, frequencies, etc).

4.8.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Prediction of network quality along selected test waypoints to compare with actual results	Test areas	Test area waypoints	-
Optimal height and waypoint locations for mission	Realistic	Actual Rail Baltic path	-

4.8.2.3.3 Means

Tools	Methods	Linked procedure(s)
3D mobile network map simulator	-	COMP01-P2, COMP01-P3

4.8.2.3.4 Results

Outputs	Linked procedure(s)
Suggested drone path - waypoint locations and optimal altitude	COMP01-P4

4.8.3 System validation (KPIs)

Finally, the system validation will be provided within the framework of Activity Blocks 4-6 with validation of 4G and 5G network KPIs:

KPI	Definition and measurement of Indicator	Verification Method	Activity Block
C2 link power	Reference Signals Received Power (RSRP)	Acquisition of network measurement data at different altitudes, their comparison with simulated network coverage 3D map data, acquisition of a safe and reliable route and flight in a real environment with uninterrupted communication in the mobile network. Network KPIs will be validated on each network - 4G and 5G separately.	4-6
C2 link quality	Reference Signal Received Quality (RSRQ)		
C2 link interference	Signal-to-interference-plus-noise ratio (SINR)		
C2 link channel quality	Channel Quality indicator (CQI)		
C2 link strength complex	Latency		
C2 link reliability	Downlink C2 data link		
4G/5G data transfer rate	Uplink end user specific data link		
Reliability of second C2 data link	Multi SIM switch		

Table 30 UC1 D3 system validation plan

A detailed description of Strategy, Procedures, and Results related to System and KPIs validation is provided in previous sections of this document related to UC1-Demo3.

Important remark: more detailed technical information about a scenario with 5G network involvement will be described in the next deliverable because of launch time reasons 5G Release 16.

5 UC3-Demo1 Logistics

5.1 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 9 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 10: 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.

5.2 Use Case Concept of Operation

UC3 demo 1 intends to demonstrate the sensor deployment part of the operation within a reduced and controlled area. It consists in automatically dropping ‘darts’ (external envelope encapsulating seismic sensors) 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 is scalable and 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.

5.2.1 Description of the system components

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

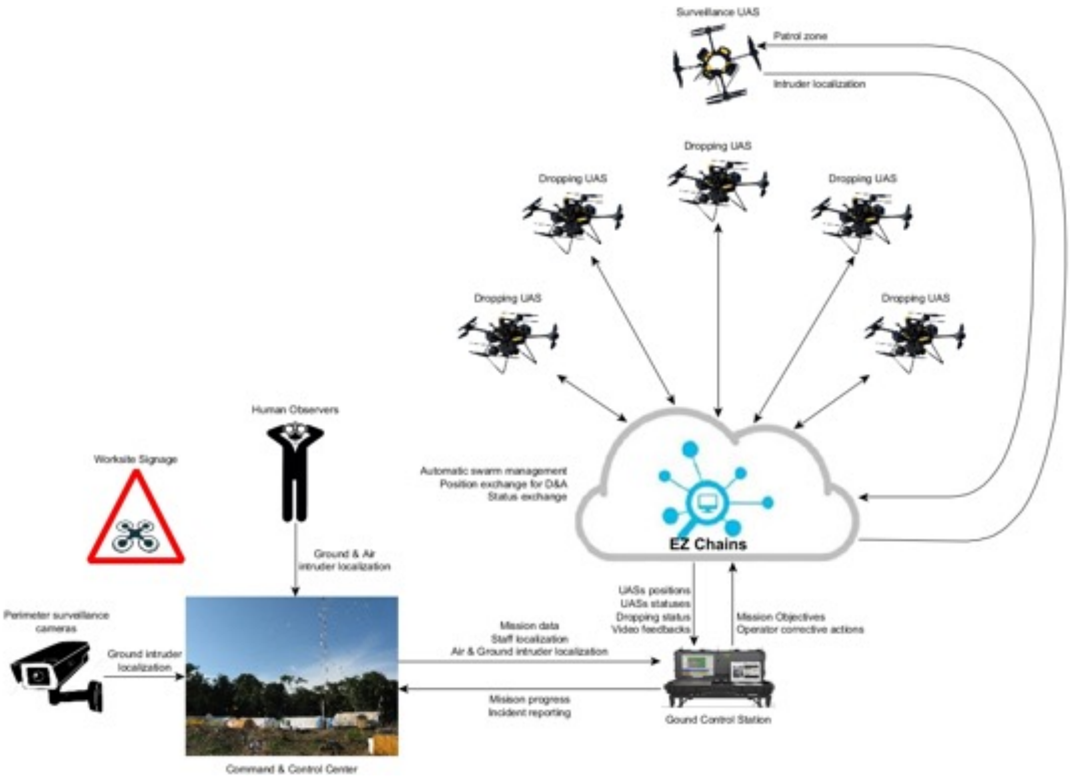


Figure 11: UC3 demo 1 system description

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

5.2.2 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, humans are 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 maneuver:
    - 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.

5.3 System Requirements, KPI´s and Metrics

5.3.1 Technical KPI`s and Metrics

5.3.1.1 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 31 - UC3 D1: Business KPIs

5.3.1.2 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 32 - UC3 D1: Technical KPIs

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

Requirement ID	Short Description	Description	Priority	Source	KPI
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-FNC-010	External positioning system	An UAV agent shall use a dedicated external positioning system giving it its position	M	Scalian	UC3-D1-KPI-1

		relative to the dronepad. This system must be attached to the dronepad			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-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-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	Capgemini Engineering	UC3-D1-KPI-4
UC3-FNC-027	Deconfliction warnings	The GCS shall display warning messages to a given airspace Flight Manager about the conflicts and unauthorized behaviors it has detected.	H	Capgemini Engineering	UC3-D1-KPI-4
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	Capgemini Engineering	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	Capgemini Engineering	UC3-D1-KPI-4
UC3-OPR-002	Worldwide operations	It shall be possible to transport the system via container	L	Total	UC3-D1-KPI-5
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-PRF-005	Precision landing conditions	The landing positioning system shall be able to provide the UAV with its position when the UAV is located on a 10m-radius disc at 20m altitude above the dronepad.	L	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3

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-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-USB-001	Monitoring workload allocation	The GCS shall allocate to a given Flight Manager a given airspace volume.	M	Capgemini Engineering	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	Capgemini Engineering	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	Capgemini Engineering	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	Capgemini Engineering	UC3-D1-KPI-4

Table 33 UC3 D1 List of Main Requirements

5.3.3 Drone integration requirements

Requirement ID	Description	Priority	Source	KPI
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-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	M	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3

	dronepad during the descent and adjust it.			
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	Capgemini Engineering	UC3-D1-KPI-4
UC3-FNC-026	The GCS shall detect unauthorized behaviour by any of the handled agents	H	Capgemini Engineering	UC3-D1-KPI-4
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
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-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-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-DSG-004	The system shall maintain a temperature inside its hull that allows its electronics to properly function.	H	Total	UC3-D1-KPI-5

Table 34 UC3 D1 List of Drone Integration Requirements

5.3.4 Regulatory requirements

Requirement ID	Short Description	Priority (H/M/L)	Source	Success Criteria, KPI´s or metrics
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	Capgemini Engineering	UC3-D1-KPI-4
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

Table 35 UC3 D1 List of Regulatory Requirements

5.4 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 allows 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-routing, emergency landing, payload blocking.	1.1.6 Command and control
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 manage 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 36 UC3 D1 List of Functionalities

5.5 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**

Capgemini Engineering 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 refueling 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 foci 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 attempts.

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
Capgemini Engineering	WP4	WP4-6	GCS	DEMO5, DEMO6	Improve Safety, mission autonomy	SC2.1	MO2.1	O2
Scalian	WP3	WP3-16_1	Generic Mission Controller	DEMO5	Improve system autonomy	SC1.2	MO1.1	O1
Scalian	WP3	WP3-16_2	Knowledge base	DEMO5	Improve system autonomy	SC1.2	MO1.1	O1
Scalian	WP4	WP4-2	Precision landing	DEMO5, DEMO6	Improve precision	SC2.2	MO2.1	O2
Scalian	WP4	WP4-5	Clearance	DEMO5	Improve safety	SC2.2	MO2.1	O2
Scalian	WP4	WP4-42	AI Stabilization	DEMO5	Improve reliability	SC2.2	MO2.1	O2
Scalian	WP5	WP5-03	Safe fleet communication	DEMO5	Improve safety and security	SC3.1	MO3.1	O3

Table 37 UC3 D1 List of <components

5.6 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 modeling 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 38 UC3 D1 List of Tools

5.7 Traceability matrices

5.7.1 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 39 UC3 D1 Requirements and functionalities traceability matrix

5.7.2 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 40 UC3 D1 Components and functionalities traceability matrix

5.8 IVV system plan

5.8.1 Components Verification

5.8.1.1 COMPONENT WP4-6 – GCS

5.8.1.1.1 Strategy

The IVV strategy for GCS components is bound by five pillars:

- **Component validation** – Checking that the built GCS is compliant with its purpose and functions.
- **Unit testing** – White box testing approach used by developers to evaluate the correctness of isolated code
- **Component and integration testing** – Black box testing approach to verify that the GCS sub-components interact well with one another and that every GCS inputs produce the expected outputs.
- **Performance testing** – Demonstrating that the speed, response time, stability, reliability, scalability and resource usage of the GCS software application under particular workload is compliant with the defined expectations.
- **Acceptance testing** – Beta-testing of the GCS done by a sample of users

5.8.1.1.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	MBSE model, GCS requirements	As part of the *Component validation* focus area, the validity of the GCS users requirements, system and sub-systems requirements are reviewed and evaluated.
Model validation	Capella	MBSE model	As part of the *Component validation* focus area, the GCS Capella model structure and artifacts are reviewed and evaluated.
Code verification	Code verification SW	GCS SW modules	As part of the *Unit testing* focus area, the GCS software modules are tested individually by the developers using code coverage techniques.
SIL testing	Simulator	GCS SW, test scenarios	As part of the *Component and integration testing* focus area, the GCS software is tested and evaluated using Software-in-the-Loop techniques. The GCS software behaviour and its interfaces are virtually validated through test scenarios.
HIL testing	Test bench	GCS component, test scenarios	As part of the *Component and integration testing* focus area, the GCS component is tested and evaluated using Hardware-in-the-Loop techniques. The GCS behaviour and its interfaces are virtually validated through test scenarios.
Performance testing	Simulator, test bench	GCS component, test scenarios	As part of the *Performance testing* focus area, the GCS component is submitted to specific test scenarios in order to identify and eliminate performance bottlenecks.

Final validation	Operational environment	GCS component, GCS requirements	As part of the *Acceptance testing* focus area, the GCS component is tested and evaluated in a realistic environment

5.8.1.1.3 Means

Tools/methods	Linked procedures
Engineering reviews	Requirements validation
Traceability analysis	Requirements validation
Capella integrated model validation functionality	Model validation
Code coverage analysis	Code verification
Simulation The GCS simulator shall allow the tester to plug the GCS software with simulated interfaced components, sending and receiving signals from the GCS in order to observe the component's behaviour in a safe and controlled environment.	Integration testing, component verification, performance testing, acceptance testing
Test bench The GCS test bench shall allow the tester to plug the GCS component with real or simulated interfaced components, sending and receiving signals from the GCS in order to observe the component's behaviour in a safe and controlled environment.	
Flight tests The GCS flight tests area shall allow the GCS component to operate in a realistic environment	Component verification, performance testing, acceptance testing

5.8.1.1.4 Results

Expected outputs	Linked procedures
Verification matrices • All GCS user requirements shall be linked to at least one GCS system requirements • All GCS system requirements shall be linked to at least one GCS sub-system requirements • All GCS requirements shall have a validation status set to "validated" and the associated validation mean shall be explicited • All GCS requirements shall have a verification status set to "verified" and the associated verification mean shall be explicited	Requirements validation
Model validation report ➔ All Capella validation steps shall be explicited ➔ All Capella validation steps shall be completed ➔ All GCS requirements shall be traced to Capella model artifacts	Model validation
Coverage reports • The code coverage status shall be equal to 100% and the associated code verification mean shall be explicited	Code verification
SIL test results	SIL testing

• The SIL test results shall provide background information on the tested configuration items, the test environment and the test scenarios. • The SIL test results shall provide a proof that the GCS component is compliant with its specification. Any deviation shall be documented and justified.	
HIL test results • The HIL test results shall provide background information on the tested configuration items, the test environment and the test scenarios. • The HIL test results shall provide a proof that the GCS component is compliant with its specification. Any deviation shall be documented and justified.	HIL testing
Performance test results • The performance test results shall provide background information on the tested configuration items, the test environment and the test scenarios. • The performance test results shall provide a proof that the GCS component is compliant with its specification. Any deviation shall be documented and justified.	Performance testing
Flight test results • The flight test results shall provide background information on the tested configuration items, the test environment and the test scenarios. • The flight test results shall provide a proof that the GCS component is compliant with its specification. Any deviation shall be documented and justified.	Component validation

5.8.1.2 COMPONENT WP3-16_1 – Generic Mission Controller

5.8.1.2.1 Strategy

The GMC will be first validated in simulation, starting with Software in the loop (SITL), then proceeding with Hardware in the loop (HITL). Finally the system will be run in a scaled-down real-life mission. The goal is to demonstrate the reliability of the component: it must perform without issues for several days of continuous operations.

The simulations will consist of several tens or hundreds of hours of missions with various operations areas, fleet configuration and external events.

The real-life mission will consist in 10 days of operations with a fleet of 5 dropping UAVs and 1 surveillance UAV. Those results will be extrapolated to determine the efficiency that can be expected from this system.

5.8.1.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Software-in-the-loop simulation	Simulator	Different scenarios Different field of operations Different fleet Different external events	Validate software quality over long period of time Capability to perform all the missions Stability against "unexpected events"
Hardware-in-the-loop simulation	Simulator with UAVs connected		
Real-life mission	Flight area, south of France	Definition of the mission area and the operations (position of the drop points) Metrics to measure the project KPIs	

5.8.1.2.3 Means

Tools	Methods	Linked procedure(s)
Simulator	Continuous simulation over several hours	SITL HITL
Test bench	Connected to the simulator: provides stimulus to the UAV sensors, receives output from UAV	

5.8.1.2.4 Results

Outputs	Linked procedure(s)
Flight statistics: total mission time, total flight time per UAV, duration of each flight, number of premature flights stop (due to low battery…).	SITL HITL Real flights
Operation statistics: number of UAVs used, operation setup time (setup of communication means…), mission setup time (UAV pre-flight check…), number of persons necessary for operations.	
Software quality: number of software errors and warnings	

5.8.1.3 COMPONENT WP3-16_2 – Knowledge base

This component will be demonstrated through the test of the Generic Mission Controller (COMPONENT WP3-16_1 COMPONENT WP4-6 – GCS).

5.8.1.4 COMPONENT WP4-2 – Precision landing

5.8.1.4.1 Strategy

This component aims at ensuring safe landings thanks to the level of precision it reaches, hence the demonstration will focus on the precision. The tests will consist in repeated take-off and landings in different conditions (wind, light rain, heavy sunlight…) in order to demonstrate the precision and its consistency and robustness.

5.8.1.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Take-off and landing test flights	Landing pad in different conditions Reference mark to measure precision	Variety of environmental conditions	Measure average precision (and standard deviation) over several take-off and landing, correlated to the flight conditions

5.8.1.4.3 Means

Tools	Methods	Linked procedure(s)
Instrumented landing pad	A reference will be sued to measure the position and orientation of the UAV once it has landed	Test flights

5.8.1.4.4 Results

Outputs	Linked procedure(s)
Measure of precision: general average precision, average precision clustered by environmental conditions, standard deviations	Test flights

5.8.1.5 COMPONENT WP4-5 – Clearance

5.8.1.5.1 Strategy

The clearance module is based on Machine Learning (Deep Learning) and will be tested with the customary method: a part of the training dataset will be used to validate the quality of the training. However, since the dataset is small the videos recorded during the real-life mission (see component WP3-16_1 above) will be used to complete the dataset and evaluate the component in a post-mission phase.

5.8.1.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test dataset	Computer	Video dataset of synchronized EO+IR stream, with nadir point of view	Measure: precision, recall, accuracy. Qualify software computation speed (FPS) and stability
Post mission evaluation			

5.8.1.5.3 Means

Tools	Methods	Linked procedure(s)
Computer	Datasets are split into two batch: one for training, one for evaluation	All tests

5.8.1.5.4 Results

Outputs	Linked procedure(s)
Qualification of clearance capability: precision, accuracy and recall Analysis of the feasibility of a fully autonomous system, without any human supervision/validation for drops.	All tests

5.8.1.6 COMPONENT WP4-42 – AI Stabilization

5.8.1.6.1 Strategy

The AI Stabilization component is a study on the feasibility of an approach, its intent is not to be used on a real-life mission in a first step. Therefore, the component will be demonstrated in simulation.

5.8.1.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulated test flights	Simulator	UAV dynamics Trajectory to follow, with different types of manoeuvres	Demonstrate feasibility and potential of using AI for stabilization Measure flight precision and dynamic with such control system

5.8.1.6.3 Means

Tools	Methods	Linked procedure(s)
Simulator	Different UAV dynamics and trajectory PID control loop in the same scenarios to compare quality	Simulated test flights

5.8.1.6.4 Results

Outputs	Linked procedure(s)
Analysis of AI-stabilization precision, comparison with PID approach and comparison with the state of the art of the field.	Simulated test flights

5.8.1.7 COMPONENT WP5-03 – Safe fleet communication

5.8.1.7.1 Strategy

The new communication system is being developed with two possibilities. Each is developed independently but could be combined. Consequently, each will be tested alone, then if the combination is possible/deemed interesting it will be tested.

5.8.1.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Field test for new hardware	Test on a field with enough distance and obstacles to be representative of usual mission areas	Expected throughput usage for correct fleet communications (fleet status message, video stream for surveillance)	Adequacy of the new communication for fleet communications
Simulated tests for new network architecture	Test using several computers to test the new network architecture (rely on VPN)		Adequacy of the new communication architecture for fleet communications
Integration test (optional)	Combination of the two tests above		Adequacy of the combination for fleet communications

5.8.1.7.3 Means

Tools	Methods	Linked procedure(s)
Cloud server	Deploy agents and architecture on a cloud server to test VPN over public networks	Simulated tests for new network architecture

5.8.1.7.4 Results

Outputs	Linked procedure(s)
Potentially: new network architecture, new communication means (hardware)	All tests

5.8.2 Functionalities Verification

5.8.2.1 UC3-D1-FUN-01 – Fleet operations

5.8.2.1.1 Strategy

The functionality that allows a fleet of UAVs to accomplish a mission requires several components. The mains are WP3-16_1 Generic Mission Controller and WP3-16_2 Fleet Knowledge Base, however it also requires all the UAV modules to perform the actions and the GCS to coordinate the mission. The test for this functionality consists in an integration test of all the components. Considering the level of risk, the test will be gradual from simulation, to controlled real-life experiment before a scaled-down mission.

5.8.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulated missions	Simulated missions, with 5 to 10 UAVs with different roles.	Different scenarios Different field of operations Different fleet Different external events	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.	Definition of the mission area and the operations (position of the drop points) Metrics to measure the project KPIs	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.	Definition of the mission area and the operations (position of the drop points) Metrics to measure the project KPIs	Same as above Measure of productivity and other aspects required to assess the business KPIs.

5.8.2.1.3 Means

Tools	Methods	Linked procedure(s)
Simulator (SITL and HITL)	See section above for component WP3-16_1 for more details.	Simulated missions

5.8.2.1.4 Results

Outputs	Linked procedure(s)
Measures for KPI metrics, allowing to compare performance for autonomous system against human operations.	All tests
Demonstration of reliability: no software crash, predictable and stable behaviour of the UAVs, autonomy of the system when facing unexpected issues – necessary to demonstrate that autonomous UAV operations are possible	All tests

5.8.2.2 UC3-D1-FUN-02 – Shared knowledge

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

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

5.8.2.3.1 Strategy

In addition to the tests described above in UC3-D1-FUN-01, specific tests will be created to demonstrate that the anti-collision watchdog triggers correctly when there is a collision-risk due to a flight deviation. For obvious safety reasons, this test will be limited to simulation.

5.8.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulated flights	During a simulated mission (similar to UC3-D1-FUN-01), a UAV trajectory will be modified by an external software).	Mission definition	Measure the response time for the detection in GCS and time for the operator to take appropriate measure.

5.8.2.3.3 Means

Tools	Methods	Linked procedure(s)
Simulator	Mission scenario performed in UC3-D1-FUN-01, allowing to really compare any modification in behaviour	Simulated flights

5.8.2.3.4 Results

Outputs	Linked procedure(s)
Measure on the response time and reliability of the watchdog Measure on the response time for the GCS operator	Simulated flights

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

5.8.2.4.1 Strategy

In addition to the tests described above in UC3-D1-FUN-01, specific tests will be created to demonstrate the system response to dynamic geofences. Events will trigger the creation of geofences, and then move then around the mission area.

5.8.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulated flights	During a simulated mission (similar to UC3-D1-FUN-01), a simulated intruder will be created and tracked with a moving dynamic geofence	Mission definition Number, and trajectories of intruders	Demonstration of system robustness and safety with regard to unexpected intruders
Outdoor controlled	During a real mission (similar to UC3-D1-FUN-01), a simulated or real intruder will move around the mission area while being tracked with a moving dynamic geofence		
Realistic			

5.8.2.4.3 Means

Tools	Methods	Linked procedure(s)
Simulator	Mission scenario performed in UC3-D1-FUN-01, allowing to really compare any modification in behaviour	All tests

5.8.2.4.4 Results

Outputs	Linked procedure(s)
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.	All tests

5.8.2.5 UC3-D1-FUN-05 – Safe precision landing

5.8.2.5.1 Strategy

The precision-landing functionality will be demonstrated and measured on an instrumented landing pad. In addition to the test carried out for the component WP4-2 Precision Landing, test will be conducted to detect intruder and verify that the landing phase is aborted.

5.8.2.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
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.	Landing pad position in the mission area	Measure precision (distance between target and final pose and orientation). 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.		Measure precision (distance between target and final pose and orientation).

5.8.2.5.3 Means

Tools	Methods	Linked procedure(s)
Landing pad with reference marks	Measure the distance between references on the UAV and the references on the landing pad (both in position and orientation)	All tests

5.8.2.5.4 Results

Outputs	Linked procedure(s)
Measure of the precision of the module	All tests

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

5.8.2.6.1 Strategy

In order to carry out fully-autonomous operations, the system requires safe decision for dropping: the clearance feature must be validated accordingly.

5.8.2.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Post-mission analysis	On the dropper UAV hardware, videos from the real missions will be played back to the camera. The UAV will have to answer in real-time if it can safely drop or not.	Videos from the real mission flights (see UC3-D1-FUN-01).	Demonstrate the level of reliability and precision in the clearance detection

5.8.2.6.3 Means

Tools	Methods	Linked procedure(s)
Simulator HITL	Simulate the mission and video feeds to the clearance module (on the real hardware).	Post-mission analysis

5.8.2.6.4 Results

Outputs	Linked procedure(s)
Measure of precision, recall and accuracy. Analysis on the feasibility to rely only on the clearance module to allow autonomous dropping operations	Post-mission analysis

5.8.2.7 UC3-D1-FUN-07 – Safe communications

5.8.2.7.1 Strategy

The fleet communication must be safe and secure, but also the work required to set it up on a mission area must be minimized. The tests on this functionality will compare the current architecture with the improved architecture proposed in Comp4Drones.

5.8.2.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulated mission	Demonstration of the different hypothesis and network architecture.	Expected throughput usage for correct fleet communications (fleet status message, video stream for surveillance)	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 …

5.8.2.7.3 Means

Tools	Methods	Linked procedure(s)
Cloud server	Deploy agents and architecture on a cloud server to test VPN over public networks	Simulated tests for new network architecture

5.8.2.7.4 Results

Outputs	Linked procedure(s)
Measure of usual network metrics (throughput, delay, lost messages …) Measure of operational aspects: time to setup, complexity of setup … Analysis of the feasibility and relevance/performance of the new architecture	All tests

5.8.2.8 UC3-D1-FUN-08 – GCS external communication

5.8.2.8.1 Strategy

The GCS operators communicate with ATM, UTM, remote pilots(on-going mission), and with other nearby airspace users . Therefore, these functionalities will be tested along with communication, navigation and surveillance between different GCS components and the other operators:

- First with the simulator by determining type of communication being used
- Transmitting allocated frequencies to maintain continuous communication network
- Using authorized S/W for pre-flight simulation, developing flight plan, network communication along with indication of other sensors. Typical ATM and UTM communication data with required actions
- U-Space services conformity for various levels of altitudes
- Authorized frequency usage for communication between Pilot and the GCS base
- Appropriate qualification and prior obtained training to operate the GCS
- Then simulated flights with different scenarios.

5.8.2.8.2 Procedures

Procedure description	Environment	Planned inputs	Objectives
Laboratory	Simulator	Different scenarios (Connect and test the GCS and its interfaces to the various communication means (link to external services for traffic management, intrusion, pilots, operators)	Unlimited communication with the GCS operators
Simulated flights	Outdoor controlled		
Realistic	Mission (Actual UC/Demo)	Planned mission including the test phase of a payload (test phase does not include the ground tests)	

5.8.2.8.3 Means

Tools/Methods	Linked procedures
Simulator	Testing a pre-planned mission for the defined UC / Demo's as per the ConOps using an authorized flight planning software in the GCS
Outdoor controlled	All the outdoor mission/s shall draw the above-mentioned similar steps of the Simulator.

5.8.2.8.4 Results

Expected outputs	Linked procedures
Simulator	The simulation of the pre-planned mission allows the remote pilot/ an operator to get to know the obstacles in real time and overcome it in advance
Outdoor controlled	During this session the whole mission is conducted in live, to train and collect the minor difficulties faced by the remote pilot to fly the whole mission in a successful manner

5.8.2.9 UC3-D1-FUN-09 – GCS monitoring extent

5.8.2.9.1 Strategy

This functionality will test command and control of the operator/RP (Remote pilot), the GCS operators can send orders to the operator (automated or piloted), including but not limited to, entry access validation, mission pause, re-routing, emergency landing, payload blocking.

5.8.2.9.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Laboratory	Simulator	Test flight scenarios with different procedures to the RP/Operators	Command and Control
Simulated flights	Outdoor controlled		

5.8.2.9.3 Means

Tools/ Methods	Linked procedure(s)
GCS Joy-stick	Mission control software and GCS hardware
GCS control joy-stick	Procedure linked to the right orientation of the UAS at a given airspace in respects to its position data

5.8.2.9.4 Results

Outputs	Linked procedure(s)
• Every command and control data transmitted from the GCS reaches the UAS in a safe manner. • All the data transmitted via the GCS follows an appropriate procedure	• Simulated flights • Direct mission

5.8.2.10 UC3-D1- FUN-10 – GCS main display

5.8.2.10.1 Strategy

The operator/RP send the pre-programmed instructions via GCS software to have the DAA; this functionality allows DAA (detect and avoid) collision to perform the desired use case in a safe approach.

The tests will be portrayed on a simulated flight with respects to different scenarios.

5.8.2.10.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Laboratory	Simulator	Different scenarios	Detect a probable collision and avoid it as soon possible
Simulated flights	Outdoor controlled		

5.8.2.10.3 Means

Tools	Methods	Linked procedure(s)
GCS interface	Provides the necessary information according to the mission by coding the desired output For example: IRF: Interface Radio Frequency	The associated software can highlight the three letter coding when the cursor moves over the displaying interface.
GCS mission control S/W	The S/W uses various means to provide the right useful data to control the UAS to stay on the right path; In addition, the installed autopilot and GPS sensors takes care of positioning the UAS on its location.	These means do retain the drone in its flight path; In addition always the drone remains in a path when the Geo-fencing & Geo-caging options are in place.

5.8.2.10.4 Results

Outputs	Linked procedure(s)
Report indicating the level of approval of the GCS display (average, dispersion, blocking points...)	**Refer all mission related S/W & H/W for more information**

5.8.2.11 UC3-D1-FUN-11 – Worksharing management

5.8.2.11.1 Strategy

In addition to the UC3-D1-FUN-09, Worksharing management is to ensure an observer and mission execution by GCS operator in case of unavailability of another personnel, to test this functionality will need in the simulator and simulated flight.

5.8.2.11.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Laboratory	Simulator	Simulate operation with large number of operator/RP's and several GCS operators, modify the number of required operators and GCS operators; Meanwhile, test each GCS manager workload by triggering various events	
Simulated flights	Outdoor controlled		

5.8.2.11.3 Means

Tools	Methods	Linked procedure(s)
Simulator	Provide appropriate training to use the system in an efficient manner	Simulator and simulated flights

5.8.2.11.4 Results

Outputs	Linked procedure(s)
Worksharing management provides additional means to cover the handovers given by the one personnel to the other when required	Refer the user manual for the appropriate handover procedures

5.8.2.12 UC3-D1-FUN-12 – GCS alarm display

In addition, of the UC3-D1- FUN-10 if conflict is detected, this functionality will trigger alarms on the GCS, therefor the tests will adapt the procedures similar to that of UC3-D1- FUN-10.

5.8.2.13 UC3-D1-FUN-13 – Heterogeneous management

The UC3-D1- FUN-10, The GCS provides the overall view of all the connected operators and monitor their actions, which allows the GCS to perform controlling and managing actions easily. In addition, this type of management allows the control the action of the payloads (through a compatible protocol)

5.8.2.14 UC3-D1-FUN-14 – Display – clarity

5.8.2.14.1 Strategy

The UC3-D1-FUN-14, the Swarm of operators are tracked using a single GCS operator at a time and the swarm are identified as such. In GCS, like for the heterogeneous management, here all the operators are identified and tracked using their unique tracking id that enables the GCS to take easy management actions to fulfil the mission criteria when required. This function helps in the creation of SWARM formation of the UAS in a consistent manner.

5.8.2.14.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Laboratory	Simulator	Simulate operation with large number of operator/RP's and several UAS to create the swarm formation Meanwhile, test each operator by testing their sensors for their unique id	
Simulated flights	Outdoor controlled		

5.8.2.14.3 Means

Tools	Methods	Linked procedure(s)
Simulator	Provide appropriate steps to track and trace the connected operators with the type of the remote controllers and UAS being operated	Simulator and simulated flights

5.8.3 System Validation

5.8.3.1 Strategy

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 geo-fences and drop batches of darts acting as acquisition-sensors.

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

5.8.3.2 Scenario 1

5.8.3.2.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
1. Customer needs	Requirement validation	Sensors encapsulated in darts Darts dropped from height by UAVS	Autonomous fleet management Safety clearance (flying and dropping) Payload weight Regulations / Permit to fly
2. Customer input opinion	Global localization of sensors for GPS/GNSS	GNSS/GPS module	
3. Functional system architecture	GPS/GNNS Card	Refer Manufacturer's manual	
4. Key functional traits	GPS/GNNS localization	Check for the potential receiver antenna signal	
5. System architecture	Refer Manufacturer's manual	Refer Manufacturer's manual	
6. System assessment results	Compliant with little deviation due to the satellite errors		

5.8.3.2.2 Means

Tools/ Methods	Linked procedure(s)
Simulation	*Refer ConOps*
Test bench	*Refer Test bench user manual*
Flights test	*Refer ConOps and GCS user manual*

5.8.3.2.3 Results

Outputs	Linked procedure(s)
The expected output is as per the Manufacturer's instructions and	

6 UC3-Demo2 Logistics: Logistics in urban areas

6.1 Current state of the technology

Update this section if needed.

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 businesses 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 12: 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.

6.2 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.

6.2.1 Description of the system components

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

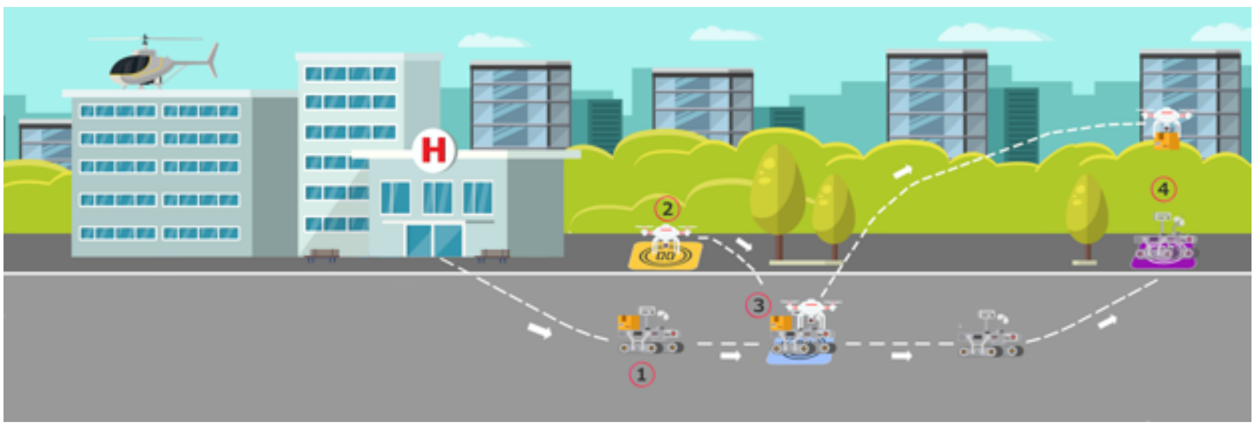


Figure 13: UC3 demo 2 1st part system description

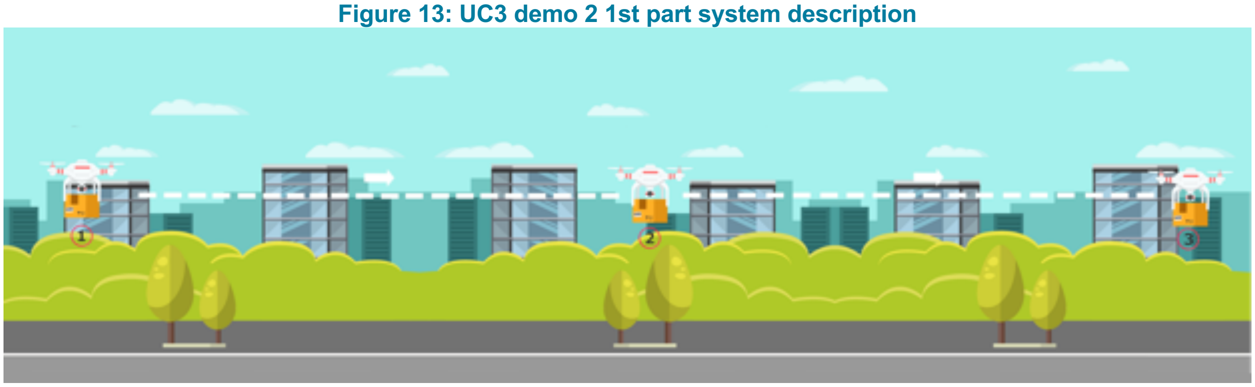


Figure 14: UC3 demo 2 2nd part system description

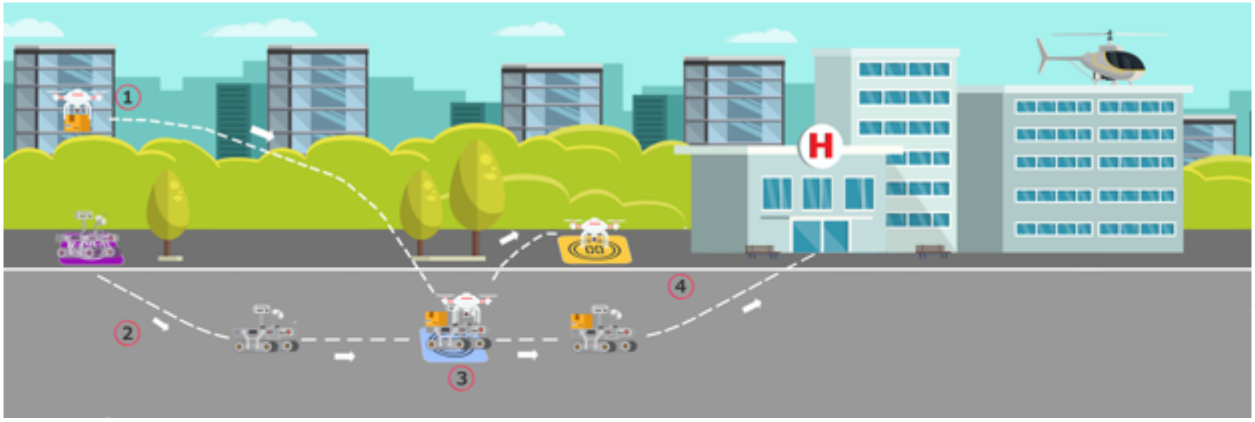


Figure 15: UC3 demo 2 3rd part system description

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

6.2.2 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.

6.3 System Requirements, KPI´s and Metrics

6.3.1 Technical KPI`s and Metrics

6.3.1.1 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}
	• A common mission defined and interpreted by both drone and rover	The mission can identify the part for the rover and the part for the drone	No interpretation by the drone for the rover mission part and the opposite ($<10^{-6}$)
	• A communication established between the drone and the rover	The drone and the rover can exchange positioning information	No loss of data ($<10^{-6}$) in the respected range of the technology
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
	• A standard mission, a standard drone and a standard droid, that can be	The C4D drone/droid can be used with minimal adaptation, in other scenario	Time used to adapt the mission to a new scenario, modification to do on drone and rover are under 50 hours

	used in different scenario (with same mass but different population density or different topography)		
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
	• Ability to flight in specific mode with technological bricks over private zone with high reliability		The global risk assessment of the drone is under 10^{-6} Same for the droid
	• Capacity of holding the parcel with high safety		The drone and the droid will keep the parcel with 10^{-7} safety accuracy

Table 41 UC3 D2 List of Business KPIs

6.3.1.2 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 42 UC3 D2 List of Business KPIs

6.3.2 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	H	TwinswHeel +	UC3-D2-KPI-2

		drone shall land with high accuracy		Scalian+Sherpa	
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. Redundancy of sensors/ sources to get a precise relative position between drone and rover	H	TwinswHeel + Scalian+Sherpa	UC3-D2-KPI-1
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 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)	H	CEA(drone) TwinsWheel (rover)	UC3-D2-KPI-1
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 43 UC1 D1 List of Main Requirements

6.3.3 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,	H	Atechsys

	considering requirements	Battery: 400g, sensors, SBC:150g) - 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 restrict 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	M	??

		a relative localization that give more accuracy for the final landing phase		
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 44 UC3 D2 List of Regulatory Requirements

6.3.4 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	Capgemini Engineering	UC3-D2-KPI-3
High-P&C-GCS-010	The GCS regulation compliance (EU)	The GCS shall be compliant with European Union regulations	H	Capgemini Engineering	UC3-D2-KPI-3

Table 45 UC3 D2 List of Regulatory Requirements

6.4 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 e ncuentra 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 (without obstacles)	The rover shall navigate in its environment, considering a virtual route and its mission	6.2.2 Flight Nav (.3)

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 46 UC3 D2 List of Functionalities

6.5 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 on 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 refueling 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: Capgemini Engineering 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**

Capgemini Engineering 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 anticollision 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 drone 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
CAPGEMINI ENGINEERING	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 communication	Demo	Improve communication capabilities	SC3.1	MO3.3	O3

Table 47 UC3 D2 List of components

6.6 Tools

Enable implementation of the requirements.

Partner	Work Package	Components	Demo	WP6 requirement	Criteria	Measurable Outcome	Objective
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 48 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

6.7 Traceability matrices

6.7.1 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 49 UC3 D2 Requirements and functionalities traceability matrix

6.7.2 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 50 UC3 D2 Components and functionalities traceability matrix

6.8 IVV system plan

6.8.1 Components Verification

6.8.1.1 COMPONENT WP3-16_1 Flight Mission Controller

6.8.1.1.1 Strategy

The component aims to achieve following objectives:

- C03-16.OBJ1: Ensure proper planning of a mission based on environmental parameters (weather forecast, typical mission, landing, …)

To implement the component in a proper manner, have been defined following IVV:

- C03-16.IVV1: The software has been tested by simulation on the development platform
- C03-16.IVV2: The software has been tested by simulation on the operational platform
- C03-16.IVV3: The software has been tested in actual conditions operating 2 rovers and an UAV

6.8.1.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Validation of the mission planning	Development environment	New missions and usage for UAV	C03-16.IVV1
Validation of the software transfer	Operational environment	New missions and usage for UAV	C03-16.IVV2
Validation of the mission tracking in flight condition	Operational Environment	New missions and usage for UAV + 2 rovers + 1 UAV	C03-16.IVV3

6.8.1.1.3 Means

Tools	Methods	Linked procedure(s)
Software : SITL	Simulation	CXX.IVV1; CXX.IVV2
Rover	Testing	CXX.IVV3
UAV	Testing	CXX.IVV3

6.8.1.1.4 Results

Outputs	Linked procedure(s)
A software allowing the mission planning, capable of treating any kind of operational mission (any combination of defined actions) or use of the drone	

6.8.1.2 COMPONENT WP3-16_2 Knowledge Base

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

6.8.1.3 COMPONENT WP3-16_3 Generic Mission Controller

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

6.8.1.4 COMPONENT WP3-32 Traffic by TSE

6.8.1.4.1 Strategy

C03-32.OBJ1: Verify the integrity, the scope, the latency, the loss of packet, and the loss of communication of the communication system. Also compare the efficiency of this communication system compared to radio command link (C2).

C03-32.IVV1: Test of the communication link between laboratories systems. Records and display data for comparison.

C03-32.IVV2: Test of the communication link between ground systems. Roll-out of the transmission/reception ground systems. Records and display data for comparison.

C03-32.IVV3: Test of the communication link between aerial and ground systems. Roll-out of the transmission/reception ground systems. Records and display data for comparison.

6.8.1.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Implementation of a test bench for the radio-communication and TSE systems to test these in laboratory.	Laboratory	Command radio - TSE	C03-32.IVV1
Roll-out of the communication systems in outdoor and compare the results	Outdoor environment	Command radio - TSE	C03-32.IVV2
Implementation of a mission with a UAV operated by both technologies	Flight test zone	Command radio - TSE	C03-32.IVV3

6.8.1.4.3 Means

Tools	Methods	Linked procedure(s)
Spectral analyzer Oscilloscope UAV Radio	Simulate the TSE and radio link, and visualize the signal. Check with various parameters. Verify the respond of the drone to the command control. Check of the good reaction to the command/control sent.	

6.8.1.4.4 Results

Outputs	Linked procedure(s)
A redundant command link allowing to control the UAV thanks to TSE and radio frequency	

6.8.1.5 COMPONENT WP3-35 Determinism and qualification for autopilot

6.8.1.5.1 Strategy

CO3-35.OBJ1: Verify the good behaviour of the full autopilot

C03-35.IVV1: Unit tests of the functionalities in simulation (SITL)

C03-35.IVV2: Functionalities tests of the autopilot on ground after integration in the UAV

C03-35.IVV3: C03-35.IVV2 but in flight

6.8.1.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Connection to the autopilot with a computer, verify the behaviour in SITL	Laboratory	Autopilot	C03-35.IVV1
Autopilot integration in UAV, link verification between ground station and autopilot	Outdoor	Autopilot, UAV, Ground station	C03-35.IVV2
UAV behaviour verification in flight, validation in flight	Flight zone	Autopilot, UAV, Ground station	C03-35.IVV3

6.8.1.5.3 Means

Tools	Methods	Linked procedure(s)
Platform software SITL UAV Autopilot	Simulate a UAV operated by the autopilot software. Check the behaviour, failsafe alarms, functions, flight parameters. Manual and automatic flight implementation testing and validating the full parameters/functions of the autopilot	

6.8.1.5.4 Results

Outputs	Linked procedure(s)
A reliable autopilot allowing UAVs to do manual and automatic flights.	

6.8.1.6 COMPONENT WP3-38 Simulation for drone

6.8.1.6.1 Strategy

The component aims to achieve following objectives:

- C03-38.OBJ1: Ensure a trusted and precise landing drone technology in any mission kind
- C03-38.IVV1: The UAV firmware has been tested by simulation in laboratory
- C03-38.IVV2: The UAV firmware has been tested on an operational case
- C03-38.IVV3: The UAV firmware has been tested on an operational case under a variety of conditions

6.8.1.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Landing validation in simulation	Laboratory	List of possible conditions	C03-38.IVV1
Landing validation under real conditions	Flight test	List of possible conditions + UAV	C03-38.IVV2
Landing validation with variable conditions	Flight test	List of possible conditions + UAV	C03-38.IVV3

6.8.1.6.3 Means

Tools	Methods	Linked procedure(s)
Software SITL UAV	Simulation Testing	C03-38.IVV1 C03-38.IVV2; C03-38.IVV3

6.8.1.6.4 Results

Outputs	Linked procedure(s)
An embedded software in the UAV allowing a precision landing. This solution has to show reproducibility in almost any kind of conditions and limiting the conditions uncovered	

6.8.1.7 COMPONENT WP4-2 Precision Landing

6.8.1.7.1 Strategy

C04-2.OBJ1: Verify the good behaviour of the precision landing

C04-2.IVV1: Unit test of functionalities in simulation (SITL)

C04-2.IVV2: Functionalities tests for landing technology in various conditions

C04-2.IVV3: Functionalities tests for landing technology with various autopilot platforms

6.8.1.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Connection between ATP system to its software, visualization of the target through HMI, verify detection precision with various length	Laboratory	Precision landing system	C04-2.IVV1
Integrate ATP system in UAV, achieve various mission with ATP in various flight conditions	Flight zone	System ATP, UAV, landing platform, weather data	C04-2.IVV2
Mission done with ATP in various flight conditions and with various autopilot platform types	Flight zone	System ATP, UAV, landing platform, weather data	C04-2.IVV3

6.8.1.7.3 Means

Tools	Methods	Linked procedure(s)
IHM with ATP system System ATP UAV Various autopilots	Show of the flight detection of the landing target thanks to ATP system and HMI Autonomous flights made in various flight conditions and with various autopilot	

6.8.1.7.4 Results

Outputs	Linked procedure(s)
A reliable landing system allowing a land with less than 10cm precision to the target	

6.8.1.8 COMPONENT WP4-5 Clearance

6.8.1.8.1 Strategy

The component aims to achieve following objectives:

- C04-5.OBJ1: Ensure an accurate and safe landing acknowledge depending on the present disturbance around the landing zone

To implement the component in a proper manner, have been defined following IVV:

- C04-5.IVV1: The clearance system has been tested in case of fake landing zone
- C04-5.IVV2: The clearance system has been tested in case of parcel transfer operations
- C04-5.IVV3: The clearance system has been tested in case of intruder around the landing zone

6.8.1.8.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Validation of the landing submission with a simulated landing zone and a wrong one	Flight test	Training video dataset in an environment close to the target operation landing site.	C04-5.IVV1
Validation of the landing submission with a simulated landing zone with a parcel transfer	Flight test	Training video dataset in an environment close to the target operation landing site.	C04-5.IVV2
Validation of the landing submission with an intrusion in the landing zone	Flight test	Training video dataset in an environment close to the target operation landing site.	C04-5.IVV3

6.8.1.8.3 Means

Tools	Methods	Linked procedure(s)
UAV	Testing in flight condition	C04-5.IVV1; C04-5.IVV2; C04-5.IVV3

6.8.1.8.4 Results

Outputs	Linked procedure(s)
A validation landing system allowing the safety of the landing procedure	

6.8.1.9 COMPONENT WP4-6 – GCS

6.8.1.9.1 Strategy

C04-6.OBJ1: Verify that the GCS take in account all the functions allowing the UC3 demo 2 to be done.

C04-6.IVV1: Verify the functions in SITL.

C04-6.IVV2: Verify the functions in operational environment.

6.8.1.9.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Full test mission of the demo, simulated	Laboratory	Steps for the demo	C04-6.IVV1
Same than above but in flight	Flight test zone	Steps for the demo	C04-6.IVV2

6.8.1.9.3 Means

Tools	Methods	Linked procedure(s)
SITL **UAV** **Ground Station**	Visualization of the steps on the HMI in simulation Verify the steps of the demo in operational environment with UAV and Ground Station.	

6.8.1.9.4 Results

Outputs	Linked procedure(s)
A ground station allowing the mission planning, gathering all the steps of the UC3 demo 2 (instructions and parameters).	

6.8.1.10 COMPONENT WP4-12 Safe monitoring components

6.8.1.10.1 Strategy

The component aims to achieve following objectives:

- C4-12.OBJ1: Ensure behaviour sensor to follow the rover to the limits.

To implement the component in a proper manner, have been defined following IVV:

- C4-12.IVV1: The monitoring components has been tested on a nominal use case
- C4-12.IVV2: The monitoring components has been tested on the worst case

6.8.1.10.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Sensors validation in nominal use	Exterior test	Rover Monitoring components	C4-12.IVV1
Tracking sensor validation in the limit conditions	Exterior test	Rover Monitoring components	C4-12.IVV2

6.8.1.10.3 Means

Tools	Methods	Linked procedure(s)
Monitoring software	Testing	C4-12.IVV1; C4-12.IVV2

6.8.1.10.4 Results

Outputs	Linked procedure(s)
Embedded components are still working in the worst-case scenario	

6.8.1.11 COMPONENT WP4-18 Transponder for drone rover

6.8.1.11.1 Strategy

C4-18.OBJ1: Check the good communication between all the platforms in operational environment.

C4-18.IVV1: Checks functionalities in SITL

C4-18.IVV2: Checks functionalities in operational environment

6.8.1.11.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Mission made of the full demo, with rover and UAV. Simulate it with rover and drone	Laboratory	Demo steps	C4-18.IVV1
Demo made with UAV in flight	Flight test zone	Demo steps	C4-18.IVV2

6.8.1.11.3 Means

Tools	Methods	Linked procedure(s)
SITL **UAVs/Rover/Ground station**	Verify the communication between all the platform thanks to various HMI Communication validation during situational exercise, in flight environment with UAV, Rover and Ground Station	C4-18.IVV1 C4-18.IVV2

6.8.1.11.4 Results

Outputs	Linked procedure(s)
Compatible, reliable and robust communication system in simulation and in operational environment	C4-18.IVV1, C4-18.IVV2

6.8.1.12 COMPONENT WP4-41 Design tools

6.8.1.12.1 Strategy

The component aims to achieve following objectives:

- C4-41.OBJ1: Ensure that thanks to the tools optimization, it’s possible to reduce the integration time needed.

To implement the component in a proper manner, have been defined following IVV:

- C4-41.IVV1: The time needed between to integration procedure is better for the technics developed in C4D project

6.8.1.12.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Take a brick to install with our methodology and compare it to the fast integration described in C4D project	Laboratory	methodologies	C4-41.OBJ1

6.8.1.12.3 Means

Tools	Methods	Linked procedure(s)
UAV Technological brick methodology	Apply the method proposed by C4D partners to implement new tech onto UAV after the standard integration	C4-41.IVV1

6.8.1.12.4 Results

Outputs	Linked procedure(s)
Increase of the integration time needed given in %	C4-41.IVV1

6.8.1.13 COMPONENT WP5-01 Intrusion detection system

6.8.1.13.1 Strategy

The component aims to achieve following objectives:

- C5-01.OBJ1: Monitor the landing platform to secure the landing phase.

To implement the component in a proper manner, have been defined following IVV:

- C5-01.IVV1: The intrusion detection system follows the drone during the landing phase

- C5-01.IVV2: The intrusion detection system follows and secures the drone during the landing phase during an intrusion.

6.8.1.13.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Check the landing procedure during the landing	Laboratory	UAV, landing zone, detection issue technology	C5-01.IVV1
Interaction between the issues detected in the landing procedure on the ground and the correction commands	Aerial test zone	UAV, landing zone, detection issue technology	C5-01.IVV2

6.8.1.13.3 Means

Tools	Methods	Linked procedure(s)
UAV, landing zone, detection issue technology	Test and validate the capacity of the fighting system to stop its landing mission and restart it when the threat is off	C5-01.OBJ1

6.8.1.13.4 Results

Outputs	Linked procedure(s)
A calculus of reliability of the system that has to be above 99.9%	C5-01.IVV2

6.8.1.14 COMPONENT WP5-18 Improved communication

6.8.1.14.1 Strategy

The component aims to achieve following objectives:

- C5-18.OBJ1: Monitor the communications between all the vectors and the ground.
- C5-18.OBJ2: Avoid any loss of data

To implement the component in a proper manner, have been defined following IVV:

- C5-18.IVV1: All data sent between 2 vectors are correctly received and treated
- C5-18.IVV2: All data sent between a vector and the GCS are correctly received and treated.

6.8.1.14.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Unit test with different message sent between the vectors and GCS. Monitor the good reception	Laboratory	Monitoring device for communications Vectors and GCS	C5-18.OBJ1
Monitor a standard mission and check that no data is lost	Flight test zone	Monitoring device for communications Vectors and GCS	C5-18.OBJ2

6.8.1.14.3 Means

Tools	Methods	Linked procedure(s)
Monitoring device for communications UAV and rover, GCS	Get all data transmitted and received and compare these to get a success transmission reliability ratio	C5-18.IVV1-2

6.8.1.14.4 Results

Outputs	Linked procedure(s)
A proof, depending on the remoteness, of the reliability of the communications	

6.8.2 Functionalities Verification

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

6.8.2.1.1 Strategy

The function aims to achieve following objectives:

- FUN-SYS-009.OBJ1: Transfer the parcel from a vector to the other in a controlled environment
- FUN-SYS-009.OBJ2: Transfer the parcel from a vector to the other in a mission environment

To implement the function in a proper manner, have been defined following IVV:

- FUN-SYS-009.IVV1: The parcel can be transfer without any disturbance
- FUN-SYS-009.IVV2: The check for the parcel placement validates the transfer

6.8.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test in laboratory, the UAV put onto the rover in different position (in the range of the precision landing capabilities), the parcel transfer	laboratory	Precision landing capabilities and brick Rover uav parcel	FUN-SYS-009.OBJ1
Same but in outdoor	outdoor	Precision landing capabilities and brick Rover uav, parcel	FUN-SYS-009.OBJ2

6.8.2.1.3 Means

Tools	Methods	Linked procedure(s)
Precision landing capabilities and brick Rover uav, parcel	Multiple try and estimation of the potential failure	FUN-SYS-009.IVV1 FUN-SYS-009.IVV2

6.8.2.1.4 Results

Outputs	Linked procedure(s)
The parcel can be transfer in any kind of landed configuration. Otherwise, the operator is informed that the parcel can’t be transported, and the mission is stopped	

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

Same as component C4-02

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

6.8.2.3.1 Strategy

The function aims to achieve following objectives:

- FUN-ROV-001.OBJ1: Ensure that all the functionalities needed for the mission can be planned
- FUN-SYS-009.OBJ2: Ensure that all the functionalities needed for the mission can be interpreted by the rover

To implement the function in a proper manner, have been defined following IVV:

- FUN-SYS-009.IVV1: The GCS can plan all the mission
- FUN-SYS-009.IVV2: The rover can accomplish all the mission

6.8.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Implement a full operational mission in the GCS (all functionalities)	Laboratory	Functionalities to implement in the mission GCS	FUN-ROV-001.OBJ1
Test the mission to verify the rover is able to do all the actions planned	Laboratory	Functionalities to implement in the mission GCS, rover	FUN-ROV-001.OBJ2

6.8.2.3.3 Means

Tools	Methods	Linked procedure(s)
Functionalities to implement in the mission GCS, rover	Multiple try of rover mission	

6.8.2.3.4 Results

Outputs	Linked procedure(s)
All functions are interpreted by the rover and the rover follow the mission planned	

6.8.2.4 UC3-D2-FUN-Rover-002

6.8.2.4.1 Strategy

The function aims to achieve following objectives:

- FUN-ROV-002.OBJ1: Validate the configuration of the rover and the drone being able to do the mission

To implement the function in a proper manner, have been defined following IVV:

- FUN-ROV-002.IVV1: The drone and the rover are able to do the full mission
- FUN-ROV-002.IVV2: The limits of weather for these both vectors are estimated and observed

6.8.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Tests in controlled environment the autonomy of the system of system, equipped with all the technological bricks and doing all the functions wanted	Flight test zone	Rover UAV, all technological bricks and all functionalities	FUN-ROV-002.OBJ1
Same tests but with various weather	Flight test zone	Rover UAV, all technological bricks and all functionalities	FUN-ROV-002.OBJ1

6.8.2.4.3 Means

Tools	Methods	Linked procedure(s)
Rover UAV, all technological bricks and all functionalities	Compare the results from all tests to validate the good autonomy of the system of systems	

6.8.2.4.4 Results

Outputs	Linked procedure(s)
The system of systems is able to do the operational mission	

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

6.8.2.5.1 Strategy

The function aims to achieve following objectives:

- FUN-ROV-009.OBJ1: Detect the environment of the rover
- FUN-ROV-009.OBJ2: Rover reacts depending on what has been detected

To implement the function in a proper manner, have been defined following IVV:

- FUN-ROV-009.IVV1: the rover is able to orientate and detect obstacle
- FUN-ROV-009.IVV2: the rover can evaluate the importance of the obstacle and change its behaviour depending on it.

6.8.2.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Detect different object and test the reaction of the rover in lab	Laboratory	Rover	FUN-ROV-009.OBJ1, FUN-ROV-009.OBJ2
Detect different object and test the reaction of the rover outdoor with various weather	outdoor	Rover	FUN-ROV-009.OBJ1, FUN-ROV-009.OBJ2

6.8.2.5.3 Means

Tools	Methods	Linked procedure(s)
Rover	Compare the real behaviour of the rover depending on the detected object, to the planned behaviour	

6.8.2.5.4 Results

Outputs	Linked procedure(s)
The rover reacts in all cases to what has been detected	

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

Same that GCS component.

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

6.8.2.7.1 Strategy

The function aims to achieve following objectives:

- FUN-ROV-027.OBJ1: Orientation of the rover de=pending of the detected forms and planned path

To implement the function in a proper manner, have been defined following IVV:

- FUN-ROV-027.IVV1: The rover is fully autonomous, based to the planned path

6.8.2.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test the precision of the rover when it's going to the landing pad	outdoor	Rover, landing pad	FUN-ROV-027.OBJ1

6.8.2.7.3 Means

Tools	Methods	Linked procedure(s)
Rover	Same method than FUN-ROV-009	

6.8.2.7.4 Results

Outputs	Linked procedure(s)
The rover is considered as fully autonomous (less than 1/10^7 detection error)	

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

6.8.2.8.1 Strategy

The function aims to achieve following objectives:

- FUN-SYS-009.OBJ1: Validate the good synchronization between UAV and Rover
- FUN-SYS-009.OBJ2: Validate that there is no loss of data on the mission distance

To implement the function in a proper manner, have been defined following IVV:

- FUN-SYS-009.IVV1: There is no loss of data under 100m
- FUN-SYS-009.IVV2: There is no loss of data under 1km

6.8.2.8.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test and validate with different distance the link between rover and UAV in lab	laboratory	UAV, rover, GCS	FUN-SYS-009.OBJ1, FUN-SYS-009.OBJ2
Test and validate with different distance the link between rover and UAV outside, with different topologies	outdoor	UAV, rover, GCS	FUN-SYS-009.OBJ1, FUN-SYS-009.OBJ2

6.8.2.8.3 Means

Tools	Methods	Linked procedure(s)
UAV, rover, GCS	Use the GCS and logs to check the connection between rover and UAV, depending on the distance and topology	

6.8.2.8.4 Results

Outputs	Linked procedure(s)
Produce a document, summing all the results, to limit the operational range of the UAV-rover combination	

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

6.8.2.9.1 Strategy

The function aims to achieve following objectives:

- FUN-COM-009.OBJ1: No loss data validation and low latency for control data
- FUN-COM-009.OBJ2: Redundancy efficiency estimation

To implement the function in a proper manner, have been defined following IVV:

- FUN-COM-009.IVV1: No loss of data
- FUN-COM-009.IVV2: latency under 50ms

The procedure, means and results are the same than the component describe above.

6.8.3 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 synchronization 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 51 UC3 D2 system validation plan

6.8.3.1 Scenario 1

6.8.3.1.1 Procedures

The function aims to achieve following objectives:

- FUN-SYS-009.OBJ1: Full mission in controlled environment
- FUN-SYS-009.OBJ2: Full mission in operational environment

To implement the function in a proper manner, have been defined following IVV:

- FUN-SYS-009.IVV1: The repeatability proves the reliability of the system for the operation

Procedure description	Environment	Planned inputs	IVV Objective(s)
Combine all the tools allocated to this demo and test multiple times the solutions in controlled environment to ensure reliability	Flight test center	All the component and function above UAV, Rover, GCS	FUN-SYS-009.OBJ1
Combine all the tools allocated to this demo and test multiple times the solutions in operational environment to ensure reliability	Operational environment	All the component and function above UAV, Rover, GCS	FUN-SYS-009.OBJ2

6.8.3.1.2 Means

Tools	Methods	Linked procedure(s)
All the component and function above UAV, Rover, GCS	Test and compare multiple flights	

6.8.3.1.3 Results

Outputs	Linked procedure(s)
The system of system is allowed to do the operational mission	

7 UC4-Demo1 Surveillance and Inspection: Mapping of Construction sites with hyperspectral technology carried by autonomous drones

7.1 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 16 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.

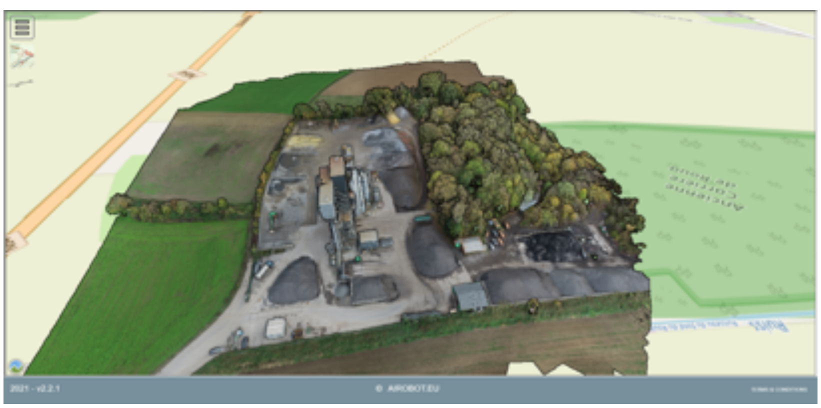


Figure 17 UC4 – D1 Construction site mapping

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.

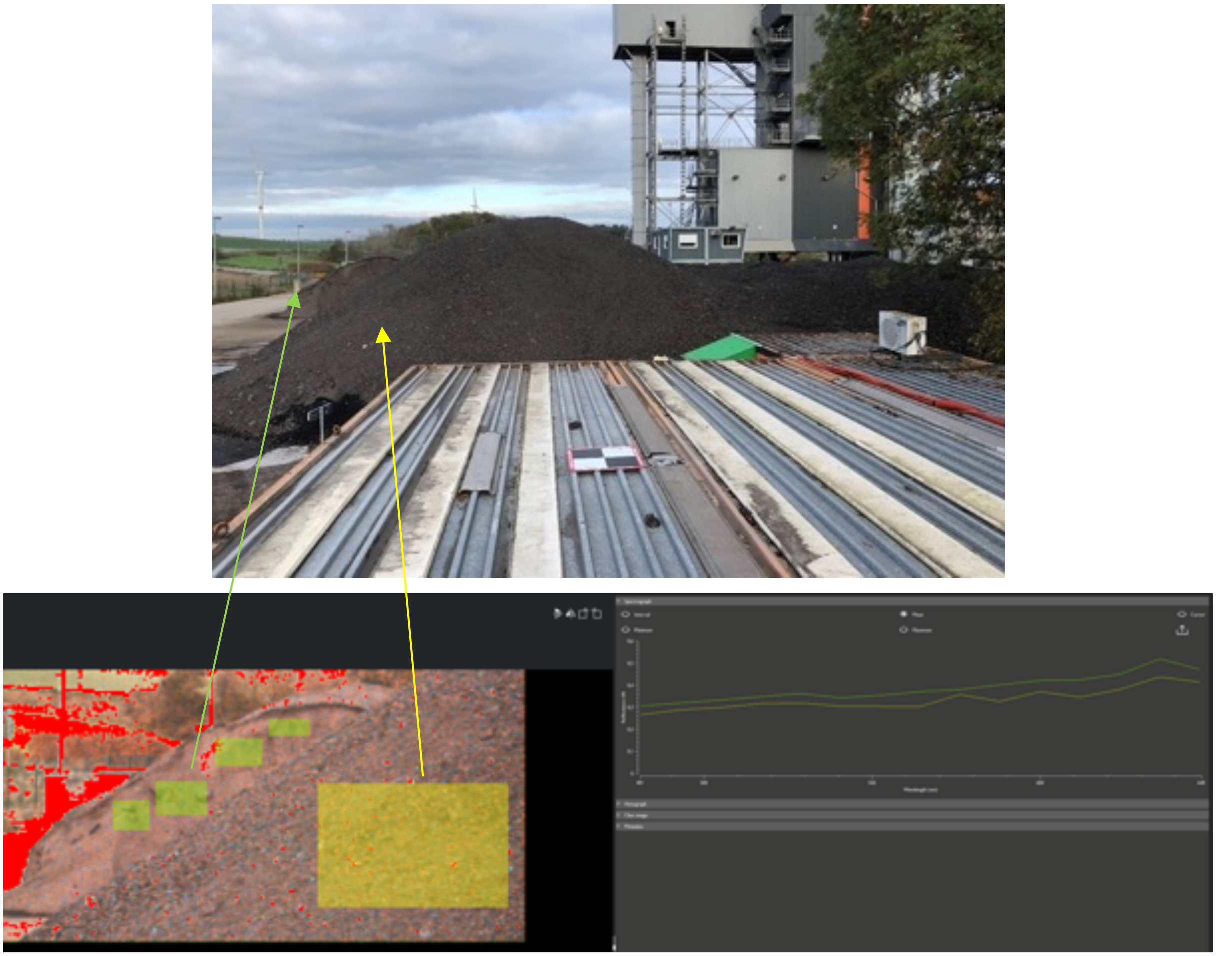


Figure 18 UC4 – D1 demonstrator's preliminary test images

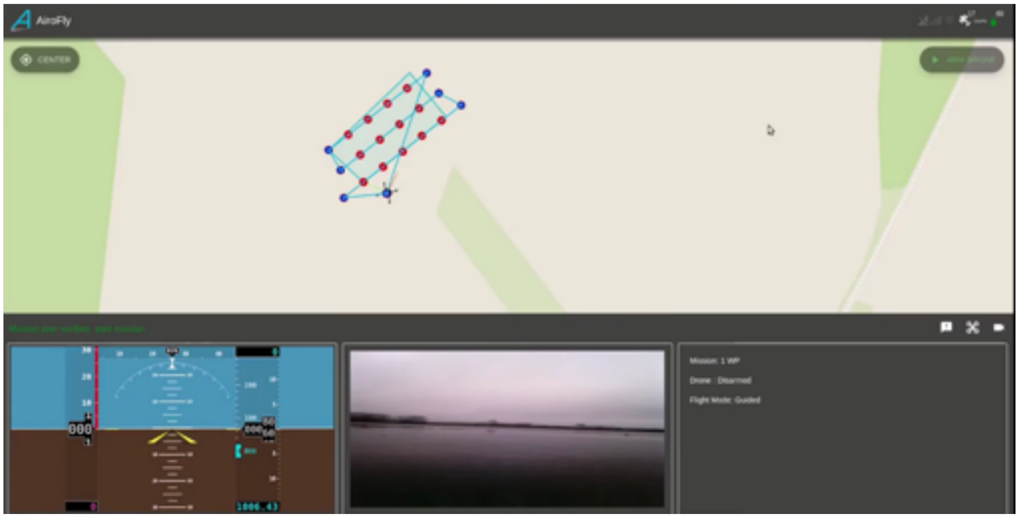
To correctly interpret hyperspectral data, it is important that the spectral content of the incoming light is known. Today, reference tiles are used to calibrate the processing. A limiting factor for use in the field is that when the light conditions change, e.g. clouds, etc. a new image of the reference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

7.2 Use Case Concept of Operation

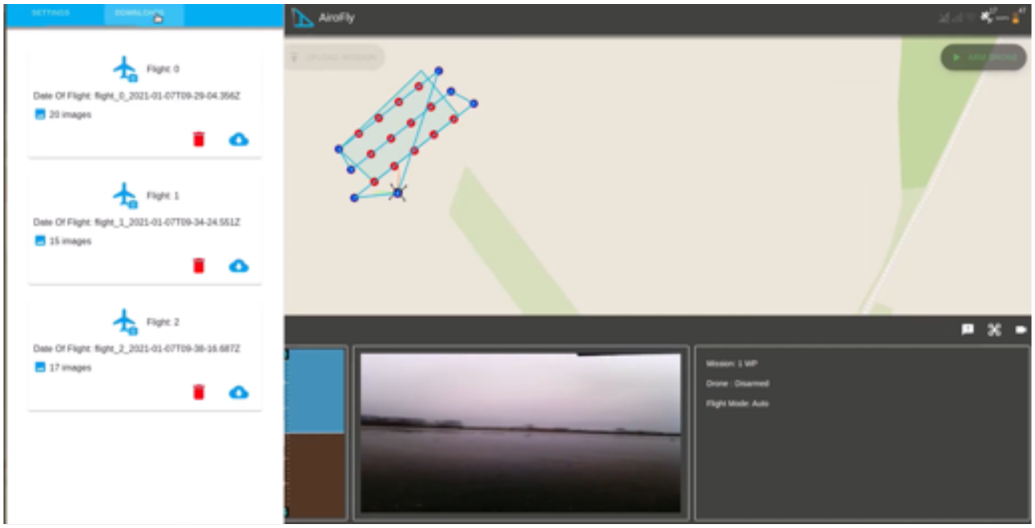
In this use case following modes of operation will be demonstrated:

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.

7.3 System Requirements, KPI´s and Metrics

7.3.1 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 52 UC4 D1 List of KPIs

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

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

7.3.3 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 54 UC4 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	Description	Priority (H/M/L)	Source	Success Criteria, KPI´s or metrics
UC4-PRF-03	Safe BVLOS flight	Perform safe flights under BVLOS STS-02 conditions	H	Airobot	UC4-D1-KPI-02

Table 55 UC4 D1 List of Regulatory Requirements

7.4 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)

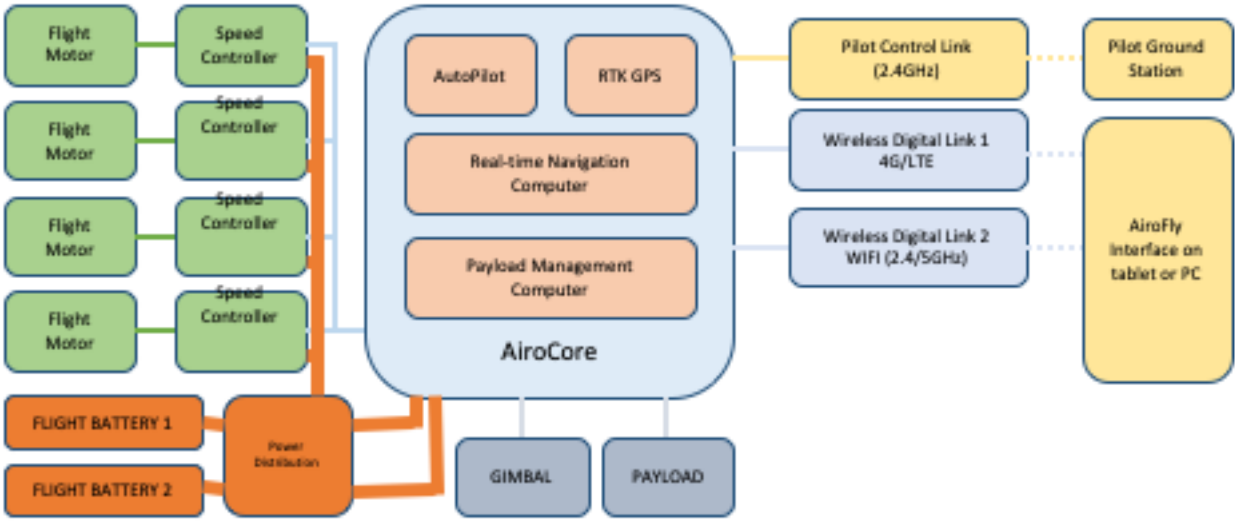
Table 56 UC4 D1 List of Functionalities

7.5 Components

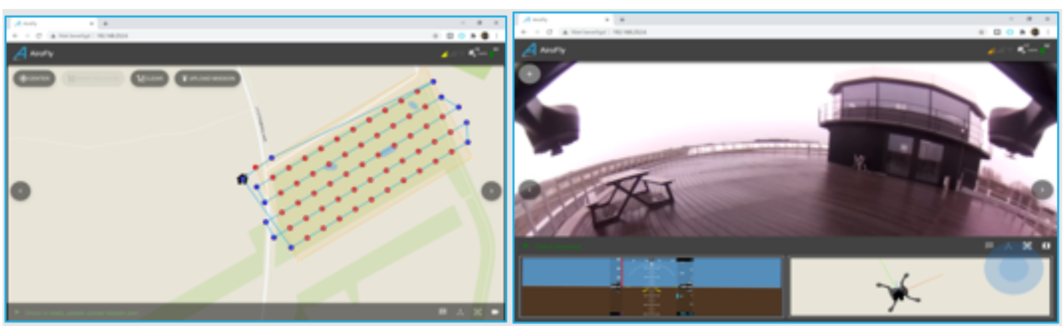
- **Component 1 - Airobot Mapper with AiroCore**

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.

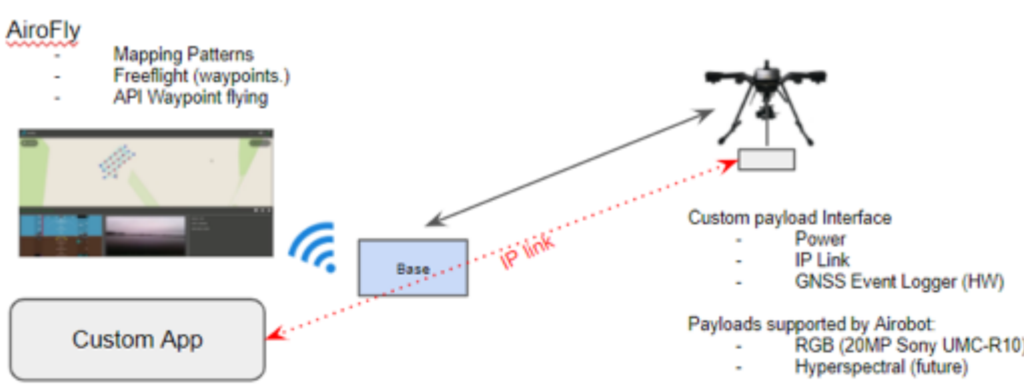
Airobot adds the AiroCore and other features to turn this drone into an automated BVLOS drone, controlled via 4G. After power on, the drone automatically creates a secure link via 4G to a server hosted by Airobot. Only an operator with the right credentials can get access to the drone via the same server.



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**

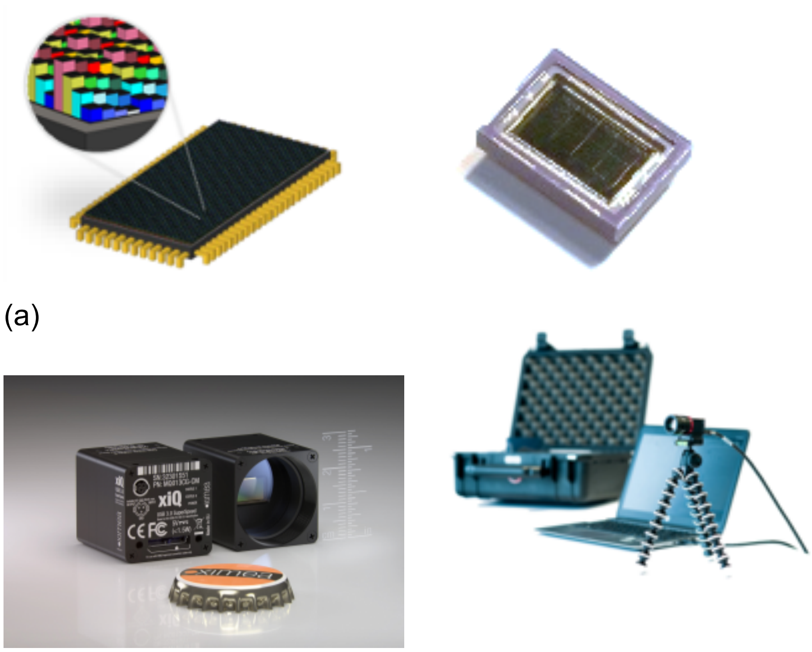
Hyperspectral cameras can improve detection of material imperfections. The hyperspectral payload will be based on imec's UAV platform: (dual) mosaic sensors/cameras with Ximea breakout board and Jetson TX2 board. Regarding the software blocks, we will reuse Airobot's server-based interface for ground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

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 19 (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.

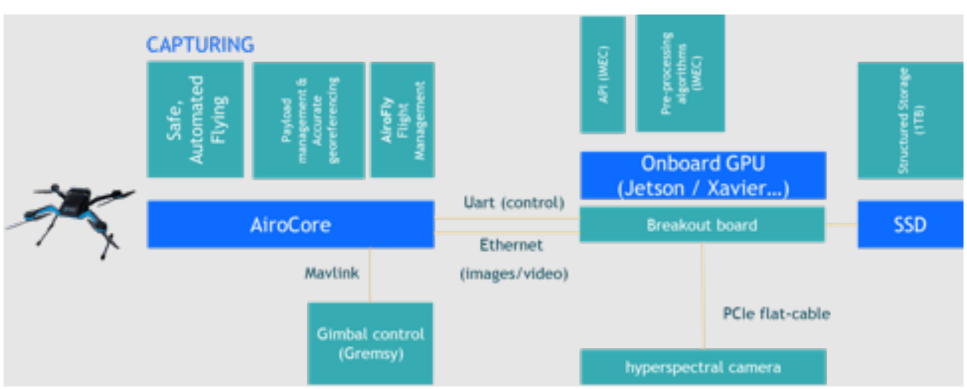


Figure 20: System architecture of UAV payload with compute enabled system

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

Figure 21: 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.

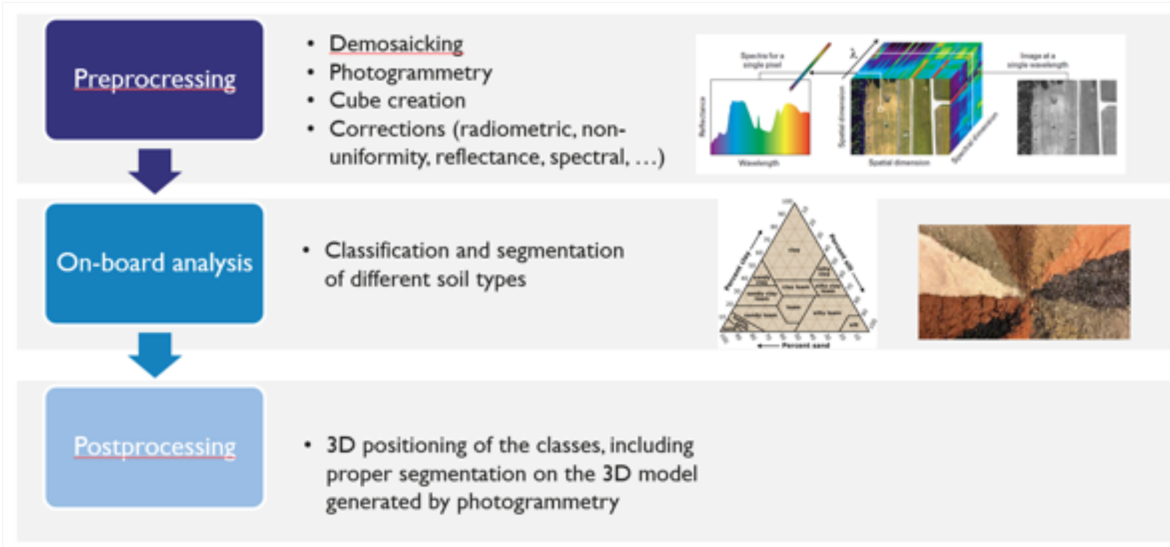


Figure 22: The hyperspectral imaging processing pipeline.

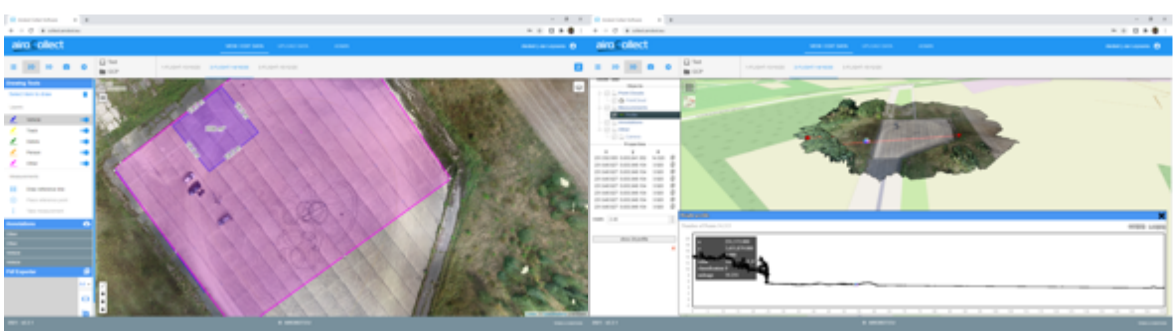
The pre-processing consists of four different sub-modules. First, a demosaicking algorithm is developed to estimate a multispectral image with full spatial-spectral definition. Second, a hyperspectral image cube is created. Third, several corrections are carried out: radiometric, non-uniformity, reflectance, 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 those 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 57 UC4 D1 Components List

7.6 Traceability matrices

7.6.1 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 58 UC4 D1 Requirements and functionalities traceability matrix

7.6.2 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 59 UC4 D1 Components and functionalities traceability matrix

7.7 IVV System Plan

7.7.1 Components Verification

7.7.1.1 COMP01 – WP4-34 - Airobot Mapper with AiroCore

7.7.1.1.1 Strategy

The Airobot Mapper with AiroCore strategy is defined by following areas:

- **Component validation in the lab** – Check that the subcomponents of the Airobot Mapper function correctly, while the drone is stationary.
- **Performance testing at DronePort** – Demonstrate that the Airobot Mapper can perform a full mission at DronePort (where flights with experimental aircraft are possible)
- **Field testing** – Demonstrate the Airobot Mapper on an actual construction site

7.7.1.1.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	C	As part of the *Component validation* focus area, the validity of the users requirements, system and sub-systems requirements is reviewed and evaluated.
Lab testing	Test Bench	AiroFly SW, test scenarios	As part of the *Component and integration testing* focus area, all the individual components are tested on a test bench with a stationary drone.
Performance testing	DronePort	Airobot Mapper, test scenarios	As part of the *Performance testing* focus area, the functionality required from the Airobot Mapper will be validated at the DronePort test facility.
Final validation	Operational environment	Airobot Mapper, Flight Plan, requirements	As part of the *Acceptance testing* focus area, the component is tested and evaluated in a realistic environment

7.7.1.1.3 Means

Tools/methods	Linked procedures
Traceability analysis	Requirements validation
Test Setup The Airobot Mapper will be installed in the lab, and can have access to GNSS signals from outside. Additionally, a SIL setup is available for testing the autopilot and flight planning related features.	Lab testing
Experimental Test Flight – DronePort 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.	Performance testing
Acceptance Test Flight – Construction SIte A flight test will be performed at a construction site 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.	Final Validation

7.7.1.1.4 Results

Expected outputs	Linked procedures
Verification matrices • All user requirements shall be linked to at least one system requirements • All system requirements shall be linked to at least one sub-system requirements • All requirements shall have a validation status set to "validated" and the associated validation mean shall be explicited • All requirements shall have a verification status set to "verified" and the associated verification mean shall be explicited	Requirements validation
Component validation report The validation results shall provide a proof that all the components of the Airobot Mapper are compliant with their specification. Any deviation shall be documented and justified.	Lab Testing
Performance test results The performance test results shall provide a proof that a remotely managed mapping flight can be performed safely in a controlled environment. A set of georeferenced images, collected in a mapping pattern, which can be used to generate orthomosaics and pointclouds.	Performance testing
Flight test results The flight test results shall provide a proof that a remotely managed mapping flight can be performed safely in an operational environment. A set of georeferenced images, collected in a mapping pattern, which can be used to generate orthomosaics and pointclouds	Component validation

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

7.7.1.2.1 Strategy

The Airobot VTOL Mapper with AiroCore strategy is defined by following areas:

- **Component validation in the lab** – Check that the subcomponents of the Airobot VTOL Mapper function correctly, while the drone is stationary.
- **Performance testing at DronePort** – Demonstrate that the Airobot VTOL Mapper can perform a full mission at DronePort (where flights with experimental aircraft are possible)
- **Field testing** – Demonstrate the Airobot VTOL Mapper on an actual construction site

7.7.1.2.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	Requirements	As part of the *Component validation* focus area, the validity of the users requirements, system and sub-systems requirements is reviewed and evaluated.
Lab testing	Test Bench	AiroFly SW, test scenarios	As part of the *Component and integration testing* focus area, all the individual components are tested on a test bench with a stationary drone.
Performance testing	DronePort	Airobot VTOL Mapper, test scenarios	As part of the *Performance testing* focus area, the functionality required from the Airobot Mapper will be validated at the DronePort test facility.

Final validation	Operational environment	Airobot VTOL Mapper, Flight Plan, requirements	As part of the *Acceptance testing* focus area, the component is tested and evaluated in a realistic environment

7.7.1.2.3 Means

Tools/methods	Linked procedures
Traceability analysis	Requirements validation
Test Setup The Airobot VTOL Mapper will be installed in the lab, and can have access to GNSS signals from outside. Additionally, a SIL setup is available for testing the autopilot and flight planning related features.	Lab testing
Experimental Test Flight – DronePort 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.	Performance testing
Acceptance Test Flight – Construction SIte A flight test will be performed at a construction site 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.	Final Validation

7.7.1.2.4 Results

Expected outputs	Linked procedures
Verification matrices • All user requirements shall be linked to at least one system requirements • All system requirements shall be linked to at least one sub-system requirements • All requirements shall have a validation status set to "validated" and the associated validation mean shall be explicited • All requirements shall have a verification status set to "verified" and the associated verification mean shall be explicited	Requirements validation
Component validation report The validation results shall provide a proof that all the components of the Airobot Mapper are compliant with their specification. Any deviation shall be documented and justified.	Lab Testing
Performance test results The performance test results shall provide a proof that a remotely managed mapping flight can be performed safely in a controlled environment. A set of georeferenced images, collected in a mapping pattern, which can be used to generate orthomosaics and pointclouds.	Performance testing
Flight test results The flight test results shall provide a proof that a remotely managed mapping flight can be performed safely in an operational environment. A set of georeferenced images, collected in a mapping pattern, which can be used to generate orthomosaics and pointclouds	Component validation

7.7.1.3 COMP03 – WP4-34 - IMEC Hyperspectral Payload

7.7.1.3.1 Strategy

7.7.1.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)

7.7.1.3.3 Means

Tools	Methods	Linked procedure(s)

7.7.1.3.4 Results

Outputs	Linked procedure(s)

7.7.1.4 COMP04 – WP4-35 - IMEC Hyperspectral Processing Chain

7.7.1.4.1 Strategy

7.7.1.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)

7.7.1.4.3 Means

Tools	Methods	Linked procedure(s)

7.7.1.4.4 Results

Outputs	Linked procedure(s)

7.7.1.5 COMP05 – WP4-35 - Airobot AiroCollect cloud processing infrastructure

7.7.1.5.1 Strategy

The Airobot AiroCollect cloud processing verification strategy is defined by following areas:

- **Performance testing** – Upload hyperspectral data of test datasets, recorded at DronePort, and compare the result with manually processed results.
- **Field Data testing** – Upload hyperspectral data of test datasets, recorded at a construction site, and compare the result with manually processed results.

7.7.1.5.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	Requirements doc.	As part of the *Component validation* focus area, the validity of the users requirements, system and sub-systems requirements is reviewed and evaluated.
Performance testing	DronePort	Hyperspectral data recorded at droneport	As part of the *Performance testing* focus area, the functionality required from the cloud processing infrastructure will be validated at the DronePort test facility.
Final validation	Operational environment	Hyperspectral data recorded at construction site	As part of the *Acceptance testing* focus area, the component is tested and evaluated in a realistic environment

7.7.1.5.3 Means

Tools/methods	Linked procedures
Traceability analysis	Requirements validation
Comparison with manually processed data The hyperspectral data will be processed both manually as well as by the cloud processing infrastructure. Both results will be compared with each other. To be successful, the automatic results should match the manually processed results.	Performance testing & Final Validation

7.7.1.5.4 Results

Expected outputs	Linked procedures
Verification matrices • All user requirements shall be linked to at least one system requirements	Requirements validation

• All system requirements shall be linked to at least one sub-system requirements • All requirements shall have a validation status set to "validated" and the associated validation mean shall be explicited • All requirements shall have a verification status set to "verified" and the associated verification mean shall be explicited	
Performance test results The performance test results shall provide a proof that the AiroCollect software will be able to accept the hyperspectral cubes, recorded at DronePort, generated by the IMEC hyperspectral payload and show the results from the IMEC hyperspectral processing chain An ortho-mosaic of hyperspectral data.	Performance testing
Final validation results The performance test results shall provide a proof that the AiroCollect software will be able to accept the hyperspectral cubes recorded at DronePort, generated by the IMEC hyperspectral payload and show the results from the IMEC hyperspectral processing chain. An ortho-mosaic of hyperspectral data	Final validation

7.7.2 Functionality Verification

7.7.2.1 UC4-D1-FUN – 01 – Hyperspectral Camera Payload

7.7.2.1.1 Strategy

7.7.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)

7.7.2.1.3 Means

Tools	Methods	Linked procedure(s)

7.7.2.1.4 Results

Outputs	Linked procedure(s)

7.7.2.2 UC4-D1-FUN – 02 Accurate Georeferencing of data

7.7.2.2.1 Strategy

The accurate georeferencing of data shall be verified following these areas:

- **Performance testing** – Tests will be performed at DronePort with georeferenced markers as validation points.
- **Field testing** – Tests will be performed at a construction site with georeferenced markers as validation points.

7.7.2.2.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	Requirements doc.	As part of the *Component validation* focus area, the validity of the users requirements, system and

			sub-systems requirements is reviewed and evaluated.
Performance testing	DronePort	Orthomosaic based on processed hyperspectral data recorded at droneport, the surveyed location of certain makers or features in the image	As part of the *Performance testing* focus area, the functionality required from the accurate georeferecing will be validated at the DronePort test facility.
Field testing	Operational environment	Orthomosaic based on processed hyperspectral data recorded at a construction site, the surveyed location of certain makers or features in the image	As part of the *Acceptance testing* focus area, the function is tested and evaluated in a realistic environment

7.7.2.2.3 Means

Tools/methods	Linked procedures
Traceability analysis	Requirements validation
Comparison with surveyed data The coordinates of several makers & features will be measured using RTK GNSS surveying. The georeferenced hyperspectral data recorded during the tests will be processed into georeferenced orthomosaics. The coordinates of the features & markers in these orthomosaics will be compared with the manual surveyed ones.	Performance testing & Field testing

7.7.2.2.4 Results

Expected outputs	Linked procedures
Verification matrices • All user requirements shall be linked to at least one system requirements • All system requirements shall be linked to at least one sub-system requirements • All requirements shall have a validation status set to “validated” and the associated validation mean shall be explicited • All requirements shall have a verification status set to “verified” and the associated verification mean shall be explicited	Requirements validation
Performance test results The performance test results shall provide a proof that the correctly georeferenced hyperspectral data can be generated. List of positions of surveyed markers/features at DronePort and the corresponding ones in the hyperspectral orthomosaics.	Performance testing
Field test results The performance test results shall provide a proof that the correctly georeferenced hyperspectral data can be generated. List of positions of surveyed markers/features at the Construction site and the corresponding ones in the hyperspectral orthomosaics.	Field Testing

7.7.2.3 UC4 –D1-FUN- 03 Onboard hyperspectral cube generation

7.7.2.3.1 Strategy

7.7.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)

7.7.2.3.3 Means

Tools	Methods	Linked procedure(s)

7.7.2.3.4 Results

Outputs	Linked procedure(s)

7.7.2.4 UC4-D1-FUN – 04 Offline detailed data processing

7.7.2.4.1 Strategy

7.7.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)

7.7.2.4.3 Means

Tools	Methods	Linked procedure(s)

7.7.2.4.4 Results

Outputs	Linked procedure(s)

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

7.7.2.5.1 Strategy

The Flight Planning functionality will be verified as following:

- **Function validation in the lab** – Check that the flight planning is working in the lab, while the drone is stationary.
- **Performance testing at DronePort** – Demonstrate that the flight planning works during a full mission at DronePort (where flights with experimental aircraft are possible)

7.7.2.5.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	Requirements	As part of the *Function validation* focus area, the validity of the users requirements, system and sub-systems requirements is reviewed and evaluated.
Lab testing	Test Bench	test scenarios	The functionality is tested on a test bench with a stationary drone.

Performance testing	DronePort	Airobot Mapper, test scenarios	As part of the *Performance testing* focus area, the flight planning will be validated at the DronePort test facility.

7.7.2.5.3 Means

Tools/methods	Linked procedures
Traceability analysis	Requirements validation
Test Setup The Airobot Mapper will be installed in the lab, and can have access to GNSS signals from outside. Additionally, a SIL setup is available for testing the autopilot and flight planning related features. A standard mapping flight pattern at DronePort (simulate stockpile mapping)	Lab testing
Experimental Test Flight – DronePort A flight test will be performed at DronePort to demonstrate that flight planning is possible. The drone will be prepared by an operator in the field. The operator will enter the mapping flight pattern and launch the drone if everything is safe. The drone will perform its mission and after the flight the position logs of the drone will be compared with the flight plan.	Performance testing

7.7.2.5.4 Results

Expected outputs	Linked procedures
Verification matrices • All user requirements shall be linked to at least one system requirements • All system requirements shall be linked to at least one sub-system requirements • All requirements shall have a validation status set to “validated” and the associated validation mean shall be explicited • All requirements shall have a verification status set to “verified” and the associated verification mean shall be explicited	Requirements validation
Function validation report The validation results shall provide a proof that a stockpile & large site mapping pattern can be executed in a simulated environment.	Lab Testing
Performance test results Demonstration that a stockpile & large site mapping pattern can be executed	Performance testing

7.7.2.6 UC4-D1-FUN -06 Remotely Managed BVLOS flight

7.7.2.6.1 Strategy

The Remotely Managed BVLOS functionality will be verified as following:

- **Function validation in the lab** – Check that remote access is working in the lab, while the drone is stationary.
- **Performance testing at DronePort** – Demonstrate that a remotely managed BVLOS works during a full mission at DronePort (where flights with experimental aircraft are possible)

7.7.2.6.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	Requirements	As part of the *Function validation* focus area, the validity of the users requirements, system and sub-systems requirements is reviewed and evaluated.
Lab testing	Test Bench	test scenarios	The functionality is tested on a test bench with a stationary drone.
Performance testing	DronePort	Airobot Mapper, test scenarios	As part of the *Performance testing* focus area, the flight planning will be validated at the DronePort test facility.

7.7.2.6.3 Means

Tools/methods	Linked procedures
Traceability analysis	Requirements validation
Test Setup The Airobot Mapper will be installed in the lab, and can have access to GNSS signals from outside. Additionally, a SIL setup is available for testing the autopilot and flight planning related features. A remote operator will log into the drone using a 4G connection, enter a standard mapping flight pattern at DronePort (simulate stockpile mapping) and execute the flight.	Lab testing
Experimental Test Flight – DronePort 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. Once completed, the operator in the field will remove the propellors and batteries from the drone and take it back inside After the flight, the flight logs are downloaded and validated that the drone has executed the planned flight..	Performance testing

7.7.2.6.4 Results

Expected outputs	Linked procedures
Verification matrices • All user requirements shall be linked to at least one system requirements • All system requirements shall be linked to at least one sub-system requirements • All requirements shall have a validation status set to "validated" and the associated validation mean shall be explicited • All requirements shall have a verification status set to "verified" and the associated verification mean shall be explicited	Requirements validation
Function validation report The validation results shall provide a proof that a stockpile & large site mapping pattern can be executed in a simulated environment during a BVLOS flight with a local operator as back-up, managed by a remote operator.	Lab Testing
Performance test results Demonstration that a stockpile & large site mapping pattern can be executed, during a BVLOS flight with a local operator as back-up managed by remote operator.	Performance testing

7.7.3 System Validation

7.7.3.1 Strategy

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. The verification strategy for both scenarios is the same.

7.7.3.2 Scenario 1

7.7.3.2.1 Procedures

Procedures	Environment	Planned inputs	Objectives
Final validation	Operational environment	Airobot Mapper, Automatic Cloud Processing Chain, Flight Plan, requirements	Demonstrate that the platform is able to complete a hyperspectral mapping of a 1 Ha site within 30min (UC4-D1-KPI-01) Demonstrate the software workflow to manage the mapping process; organize and geo-reference the collected hyperspectral data with an accuracy less than 10cm. (UC4-D1-KPI-02) Demonstrate automatic hyperspectral image-based soil classification using AI technology with an accuracy of 80%

			compared to human classification. (UC-D1-KPI-03) Demonstrate the added value of hyperspectral measurements for automatic classification of soil types on construction sites in realistic conditions (UC-D1-KPI-04) 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 (UC4-D1-KPI-05) 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. (UC4-D1-KPI-06)

7.7.3.2.2 Means

Tools/methods	Linked procedures
Traceability analysis	Requirements validation
Acceptance Test Flight – Construction Site A flight test will be performed at a construction site 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. 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 hyperspectral data. After the flight, the remote operator will download the logged images and transfers them to the AiroCollect cloud software with integrated hyperspectral processing capabilities. The resulting classified hyperspectral data will be compared with manual classified results.	Final Validation

7.7.3.2.3 Results

Expected outputs	Linked procedures
Verification matrices • All user requirements shall be linked to at least one system requirements • All system requirements shall be linked to at least one sub-system requirements • All requirements shall have a validation status set to “validated” and the associated validation mean shall be explicited • All requirements shall have a verification status set to “verified” and the associated verification mean shall be explicited	Requirements validation
Field Validation test results Demonstration that that the listed business and technical KPIs are met.	Final Validation

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

8.1 Current state of the technology

8.1.1 Introduction

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.

8.1.2 State of the Art

This challenge requires a number of advances with regard to the state of the art. Currently there exist no UAV's performing all functions related to autonomous flying without GPS, detection of victims, collaborating between different types of drones. The current state of the technology can best be described by means of a decomposition in various areas and the improvement steps for the state of the art in those areas.

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 have equal information. 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.

Another area where state of the art will be progressed is the following: 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.

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 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. As in our demonstrator the drones need to navigate autonomously inside a building, 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). Here, cameras and radar are complementary sensors that 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 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.

The drones need to have good imaging algorithms, for example to detect victims or hazardous situations. Current state-of-the-art HDR imaging algorithms typically target on images/videos captured from stationary cameras. The algorithms developed in the project 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 method achieves, despite the low requirements on resources, results comparable to state-of-the-art de-ghosting methods.

Bio-inspired localization algorithms. To go beyond the state of the art, in the project we will 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.

Relevant for the use case in a GPS hampered environment is the Simultaneous Localization and Mapping (SLAM) problem. This 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. In the project we investigate SLAM algorithms on the drone's on-board computer.

The drones require real time and predictable behaviour, but on the other hand would like to use the environment put forward by utilizing ROS/ROS2. This is challenging because of non-real-time underlying hardware, no control on the host OS scheduler, unpredictable dynamic memory allocation, high resource requirement, and unpredictable execution model. In the demonstrator, 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 at predictable and composable robotic development at both the hardware and software level.

The use case demonstrator describes a scenario where the connectivity between drones and base stations is limited. When 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. To further improve the communications, we investigate multi-link (-path/-home) networking. This 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. The project investigates 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.

Lastly, the drone needs to maintain a long lifetime. The main idea of the DronePort "autonomous battery management for a fleet of drones" – system is novel and suitable hardware, software or approach to do that, is not available. Also the main subsystems of our solution will advance the state of the art. . 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.

This demonstrator is aiming at TRL level 4-5 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. This implies there will be no full integration of all functions in a system prototype demonstration, but relevant functionalities will be demonstrated in a non-integrated scenario..

8.2 Use Case Concept of Operation

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 drones will enter the environment and start exploring. The drones will start outside to have a clear starting point from positioning point of view.
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. When the drone is too far away from the base station to have direct communications, it will use intermediate nodes (either the rover or another drone) and employ a store-and-forward mechanism to realise end-to-end communications.
5. The drone continuously monitors the different communication channels and selects the best one for communications.
6. 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.
7. At some point the drone notices that the battery is getting empty. It returns to a recharging station and swaps batteries.
8. 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.

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 Figure 27 below.

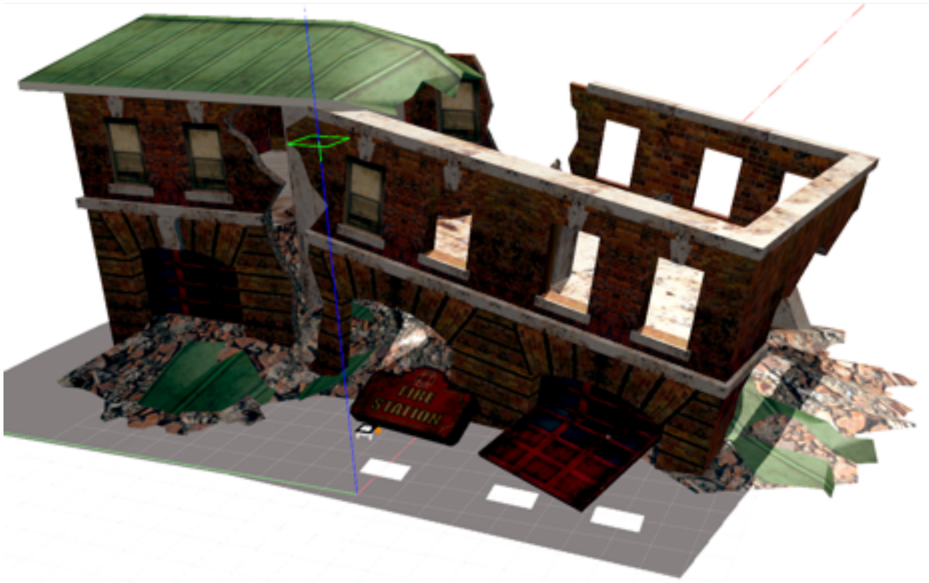


Figure 23 Collapsed building virtual recreation

8.3 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. Annex 1 lists all requirements that are considered to have an influence on the development of the systems and its components. In turn, these requirements will be related to the technological KPIs defined for the demonstrated functionality, although not always all the requirements can be related to a KPI, since it can be a type of requirement imposed by the boundary conditions, the regulation or by integration needs.

8.3.1 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 loss

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

Table 60 UC4 D2 List of KPIs

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

Requirement ID	Short Description	Description	Priority (H/M/L)	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	SmartMotion, 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 refueling 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	H	UWB,SmartMotion	UC4-KPI-12

		MAVLink messaging protocol.			
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 61 UC4 D2 List of Main Requirements

8.4 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 62 shows 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 62 UC4 D2 List of Functionalities

8.5 Components

The following are the components addressed in this demonstration:

1. Attractor based navigation (WP4-20): Navigation in a relative frame of reference, locked to a beacon on a (moving) base platform.
2. Cooperative Planner (WP4-10). This component provides support for cooperation between drones and rovers, on a (global) planning level.
3. Map Enhancement (WP4-14). There are various sources for the creation of information-rich maps/grids, which can be used for SLAM and navigation. This component explicitly focuses on a generic way of providing query-like access to this information.
4. Shared reference frame (WP4-22). Shared reference frame definition. Base station needs to share its pose/position estimate with all other drones during operation. Localization challenge, when beacons are moving in the map-frame.
5. Visual analytics (WP4-15). Visual analytics module for mission control and system monitoring. A hardware-in-the-loop simulation environment can be used as a base for such a GUI.
6. HDR & Multi Spectral Imaging (WP4-43). This component will provide optimized multiplatform library for HDR (High Dynamic Range) imaging. HDR video acquisition is an important feature of modern surveillance, traffic monitoring, and other applications that exploit cameras.
7. 3D SLAM algorithms (WP4-38). Optical based SLAM algorithms require intensive computing power and processing complexity that need to be able to run on real-time GPU embedded (onboard) hardware.
8. Bio-inspired localization algorithms (WP4-23). Exploring grid cells with the long-term ambition of utilizing them for localization solution for future drones.
9. Hardware accelerated Optical flow and SLAM. (WP4-24) Developing SLAM algorithms with reduced computing complexity and consequential power.
10. Sensory fusion in FPGA (Vision + Radar) (WP4-01). This component exploits sensory fusion between a dynamic vision sensor (DVS240) and a radar (24Ghz) for robust real-time collision avoidance.
11. Resilient Communication (WP5-20). Making communications resistant against failing nodes or links by using a store-and-forward mechanism.
12. Spiking Neural Networks & Sensory Fusion for drone navigation (WP4-01). By exploiting complementary sensors (vision 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)
13. Droneport traffic control (WP4-19). Droneport (DP) Traffic control is system for multiple drone coordination during battery management.
14. Link manager and scheduler (WP5-12). Monitor connection availability and quality of the different base communication channels for drone use.
15. Link state Application Programming Interface (WP5-13). API to communicate connection quality and availability as well as available unused resources.

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 cooperatio n 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 cooperatio n, 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

ANYWI	WP5	Link manager and scheduler	UC4 D2	COMP14 WP5-12	Improve mission autonomy , mission safety	SC2.1	MO2. 1	O2
ANYWI	WP5	Link state Application Programming Interface	UC4 D2	COMP15 WP5-13	Improve mission autonomy , mission safety	SC2.1	MO2. 1	O2

Table 63 UC4 D2 List of Components

8.6 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:	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.

Table 64 UC4 D2 List of Tools

8.7 Traceability matrices

8.7.1 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 modeling 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 refueling process.							x	x		X	
UC4-DEM2-FNC-13	shall plan the refueling 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 modeling 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 65 UC4 D2 Requirements and functionalities traceability matrix

8.7.2 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 66 UC4 D2 Components and functionalities traceability matrix

8.8 IVV system 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, focusing 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.

8.8.1 Components Verification

8.8.1.1 COMP01- WP4-20 - Attractor based navigation

8.8.1.1.1 Strategy

The Attractor-based navigation component allows a drone to localize itself in reference to a (potentially moving) beacon. Several technological means have been looked at, with a prototype developed using UWB antenna, for triangulation and time-of-flight distance measurements. Validation of this component will be achieved through demonstrating navigation and landing of a drone using this prototype.

8.8.1.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulations	In a simulated indoor environment, a drone is flown around and towards a rover-based landing platform with the UWB beacon antennas.	Flight and landing mission	Measure the distance for navigation and landing localisation in reference to the UWB beacon
Realistic	In an outdoor environment (for safety) flying a drone around and towards a prototype UWB beacon base.		Measure the distance for navigation and landing localisation in reference to the prototype UWB beacon.

8.8.1.1.3 Means

Tools	Methods	Linked procedure(s)
Simulation environment (ROS, Gazebo & PX4)	Measure the distance for navigation and landing localisation in reference to the UWB beacon.	Simulations
1 Drone (available at ALM) Prototype UWB beacon (4 antenna)	Measure the distance for navigation and landing localisation in reference to the prototype UWB beacon.	Realistic

8.8.1.1.4 Results

Outputs	Linked procedure(s)
Measure the distance for navigation and landing localisation in reference to the UWB beacon.	All tests

8.8.1.2 COMP02 – WP4-10 - Cooperative Planner

8.8.1.2.1 Strategy

The Cooperative Planner is a strategy for the cooperation between multiple drones, including the implementation of required components for communication, shared situational awareness and a "play-book" with planning strategies. As such, the verification of this component consists of many runs of simulated drones, showcasing the effectiveness of the cooperative planning on various example tasks. This will be combined with actual flight tests of at least two drones, performing an exploration mission, validating that the simulations are sufficiently accurate.

8.8.1.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulations	In a simulated environment, run several multiple drone flights, given a shared (exploration) mission. The availability of inter-drone communication will be strictly controlled, for example, in some runs only communication between close neighbours will be allowed.	Starting positions, prior knowledge, mission objectives, communication capabilities, strategies	Measure the efficiency, in mission achievement duration, resource usage, and general mission safety
Realistic	To validate the level of realism in the simulations, a real flight-test will be conducted with at least 2 drones, in an outdoor environment (=practical reasons)		Compare the mission accomplishment behaviour and approach between the simulated runs and the real flight.

8.8.1.2.3 Means

Tools	Methods	Linked procedure(s)
Simulation environment (ROS, Gazebo & PX4)	Measure the efficiency, in mission achievement duration, resource usage, and general mission safety	Simulations
2 Drones (available at ALM)	Compare the mission accomplishment behaviour and approach between the simulated runs and the real flight.	Realistic

8.8.1.2.4 Results

Outputs	Linked procedure(s)
Measure of the efficiency in mission achievement duration	All tests

8.8.1.3 COMP03 – WP4-14 - Map Enhancement Service

8.8.1.3.1 Strategy

The Map Enhancement service provides a dynamic representation of shared situational awareness between drones and within a given drone. This service will be verified to be effective by running multiple simulations, in which multiple drones will cooperate on a shared mission. While performing the mission, the formation of the maps and especially the quality of map prediction will be measured. An important measurement is also the usability of the maps, for the human operator and for enhanced localisation of the drone(s).

8.8.1.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulations	In a simulated environment, run several multiple drone flights, given a shared (exploration) mission. The availability of inter-drone communication will be strictly controlled, for example, in some runs only communication between close neighbours will be allowed.	Starting positions, prior knowledge, mission objectives, communication capabilities, strategies, the simulated indoor environment (obstacles, rooms, doors, etc.)	Measure the quality and usability of the formed map information, especially regarding future, predicted, situations.
Realistic	To validate the level of realism in the simulations, a real flight-test will be conducted with at least 2 drones, in an outdoor environment, encapsulated by a simulated indoor environment. (=practical reasons)		Compare the map between the simulated runs and the real flight.

8.8.1.3.3 Means

Tools	Methods	Linked procedure(s)
Simulation environment (ROS, Gazebo & PX4)	Measure the quality of the formed map information, especially regarding future, predicted, situations.	Simulations
2 Drones (available at ALM)	Compare the map between the simulated runs and the real flight.	Realistic

8.8.1.3.4 Results

Outputs	Linked procedure(s)
Measure of the map quality and usability	All tests

8.8.1.4 COMP04 – WP4-22 - Shared reference frame

8.8.1.4.1 Strategy

The Shared Reference Frame is a relatively minor component, with a clear purpose: Provide an updated standard ROS TF setup, which provides flexibility between the "world" map frame and the root frame of the entire TF tree. This is important to allow multiple drones to confidently localise themselves in respect to the others (=vital for safety) in an indoor, GNSS-compromised, environment.

8.8.1.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulations	In a simulated environment without GNSS availability, run several multiple drone flights, given a shared (exploration) mission. The availability of inter-drone communication will be strictly controlled, for example, in some runs only communication between close neighbours will be allowed.	Starting positions, communication capabilities, the simulated indoor environment (obstacles, rooms, doors, etc.)	Measure the precision of the TF transformations
Realistic	To validate the level of realism in the simulations, a real flight-test will be conducted with at least 2 drones, in an outdoor environment, encapsulated by a simulated indoor environment. (=practical reasons)		Compare the TF tree between the simulated runs and the real flight.

8.8.1.4.3 Means

Tools	Methods	Linked procedure(s)
Simulation environment (ROS, Gazebo & PX4)	Measure the precision of the TF transformations	Simulations
2 Drones (available at ALM)	Compare the TF tree between the simulated runs and the real flight.	Realistic

8.8.1.4.4 Results

Outputs	Linked procedure(s)
Measure of the TF tree precision	All tests

8.8.1.5 COMP05 - WP4-15 - Visual Analytics

8.8.1.5.1 Strategy

Visual Analytics are an approach to user interfacing, providing the human operator with better visual cues as to what the drones are perceiving, predicting & planning. Advanced AR techniques are used to provide overlay views in camera feeds. As user interfacing is a relative subjective matter, validation is somewhat harder to make measurable and quantifiable. As (within C4D) only direct development and test users are foreseen to be using the Visual Analytics component, validation will be limited to a simple survey among these users.

8.8.1.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulations	Simulated drones flights in a dynamically changing environment, for example: changing smoke/lighting, with drones providing feedback on concentration levels.	Starting positions, the simulated environment (smoke, dirt, etc.)	Survey the user experience

8.8.1.5.3 Means

Tools	Methods	Linked procedure(s)
Simulation environment (ROS, Gazebo & PX4)	Survey the user experience	Simulations

8.8.1.5.4 Results

Outputs	Linked procedure(s)
Survey the user experience	All tests

8.8.1.6 COMP06 –WP4-43 - HDR & Multi Spectral Imaging

8.8.1.6.1 Strategy

The research and development of HDR processing algorithms is divided into tests and experiments:

- Testing of algorithms on the synthetic data (e.g. rendered from simulated environment)
- Testing of algorithms on datasets. This step provides a lot of information on how algorithms behave in varying scenes.
- Experiments using specific camera in simulated and controlled environment.

8.8.1.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Synthetic data and datasets testing.	Software	Publicly available datasets	Determine improvements for HDR processing algorithms
Controlled captured data testing	Software	Captured raw camera stream in controlled environment	Determine improvements for HDR processing algorithms according to a specific camera
Real captured data testing	Software	Captured raw camera stream from an actual drone	Verify the applicability of HDR processing algorithms in the drone environment.

8.8.1.6.3 Means

Tools	Methods	Linked procedure(s)
OpenCV library	Engineering	All stages of the development

8.8.1.6.4 Results

Currently, there are no results as the work corresponds to novel tone mapping algorithm proposal. The current focus is on the "Synthetic data and datasets testing" and "Controlled captured data testing" as the algorithm is proposed and properties and quality of the proposed algorithm is evaluated on various HDR datasets (available and captured).

8.8.1.7 COMP07 - WP4-38 - Simultaneous localization and mapping

8.8.1.7.1 Strategy

Same info as section COMP01- WP4-20 - Attractor based navigation

8.8.1.7.2 Procedures

Same info as section COMP01- WP4-20 - Attractor based navigation.

8.8.1.7.3 Means

Same info as section COMP01- WP4-20 - Attractor based navigation.

8.8.1.7.4 Results

Same info as section COMP01- WP4-20 - Attractor based navigation.

8.8.1.8 COMP08 – WP4-23 - BIO-INSPIRED LOCALIZATION ALGORITHMS

8.8.1.8.1 Strategy

The development of bio-inspired localization algorithms is structured into experiments that are set up to facilitate the emergence of grid cells and infrastructure for reinforcement learning. The overall strategy of the component development and validation can be organized in the following objectives/tasks:

- Repeat SoA grid-cell emergence results as reported in [Banino 2018].
- Set up the custom simulation environment using such software stacks as Gazebo and ROS and use it to deploy rover for the initial development of 2D navigation algorithm and ANN topology exploration.
- Explore grid-cell emergence in 3D navigation scenario with known trajectories and agent pose.
- (if previous objective successful) Extend previously developed simulation setup to drone agent and navigation in 3D to examine the applicability of grid-cells for drone agent navigation.
- (optional) Apply (and improve) previously trained models to drone-in-loop setup where drone agent is used in a cage equipped with indoor positioning system and its camera input is sent to the trained model which attempts to navigate the drone.

8.8.1.8.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Gazebo simulation of a 2D agent	Controlled software simulation	Camera video stream from a simulated rover	Determine improvements for navigation algorithm when adding grid cell networks
DNN training targeting 3D position estimation for assessing emergence of grid-cells	Software	Angular and linear velocities	Explore the emergence of grid-cell neurons for 3D agents
Gazebo simulation of a 3D agent	Controlled software simulation	Camera video stream from a simulated drone	Determine improvements for navigation algorithm

			when adding grid cell networks
(optional) Controlled test in drone cage equipped with indoor positioning system	Controlled physical environment	Camera video stream from an actual drone	Verify the applicability of DNN-based navigation for drones

8.8.1.8.3 Means

Tools	***Methods***	***Linked procedure(s)***
TensorFlow/PyTorch frameworks	Engineering	All stages of the development
Gazebo/ROS simulation environment	Modelling, simulation and testing	Gazebo simulation of a 2D agent Gazebo simulation of a 3D agent
Drone test cage with indoor positioning system for ground-truth estimation	Engineering, testing and analysis	Controlled test in drone cage equipped with indoor positioning system

8.8.1.8.4 Results

Outputs	**Linked procedure(s)**
There are no tangible results yet as the work corresponds to novel fundamental ideas in agent navigation. The current focus is on the part of the 2nd procedure of the strategy (initial development of 2D navigation algorithm and ANN topology exploration.	

8.8.1.9 COMP09 – WP4-24 - Hardware accelerated Optical flow and SLAM

8.8.1.9.1 Strategy

The development of Hardware accelerated Optical flow and SLAM component can be segregated into two distinct views: 1) development of the component and 2) validation of the component. Both stages are being conducted simultaneously as the validation supplies new requirements for the development stage.

As for the development of the accelerator component, initially the challenge is split into two major tasks: 1) Acceleration of the optical flow algorithm and drone localization, 2) Partial acceleration of the SLAM computation.

Each of the development stages are accommodated with:

1. Software-in-Loop (SiL) tests – the algorithm is tested against stock data sets using conventional libraries and tools, such as OpenCV and Python.
2. Functional simulations of the accelerator – the developed digital circuits are tested following modern circuit testing methodology using such libraries as UVVM and VUnit.
3. Hardware-in-Loop (HiL) tests – the developed circuit (accelerator) is implemented in the FPGA portion of a heterogeneous SoC and interfaced with software running on a host PC for physical tests of the accelerator.
4. Extended Hardware-in-Loop (extended HiL) tests – same as simple HiL tests but instead of a host PC, the inputs to the accelerator are fed from an actual drone flying in the drone cage, while the outputs are used for localization and mapping depending on the algorithm.
5. (optional) Integration test – the component is integrated into EDI heterogeneous SoC-based reference platform for onboard validation.

8.8.1.9.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Software-in-Loop (SiL) tests	Controlled software	Available data sets	To validate and finetune algorithm
Functional simulation of the accelerator	Controlled software simulation	Software generated test vectors	To functionally verify the designed digital circuit
Hardware-in-Loop (HiL) tests	PC and SoC communicating via network stack	Available data sets	To functionally verify the designed accelerator, estimate its performance
Extended Hardware-in-Loop (extended HiL) tests	SoC and drone communicating via network stack, PC mostly used for logging (the drone is artificially made slower to accommodate for delays)	Realtime video feed from a drone camera	To verify components capabilities in a physical use case
(optional) Integration test	Component integrated as a part of the drone's autonomous flight offboard system	Realtime video feed from a drone camera	To showcase component's suitability for the use case and for potential exploitators of the technology

8.8.1.9.3 Means

Tools	Methods	Linked procedure(s)
OpenCV	Modelling and engineering	Software-in-Loop (SiL) tests
UVVM, VUnit, Modelsim, GHDL	Simulation	Functional simulation of the accelerator
ZMQ communications library	Testing and analysis	Hardware-in-Loop (HiL) tests Extended Hardware-in-Loop (extended HiL) tests
Real-Time-Control-Loop-Monitoring (RTCLM) library	Testing and analysis	Extended Hardware-in-Loop (extended HiL) tests (optional) Integration test
Drone test cage with indoor positioning system for ground-truth estimation	Engineering, testing and analysis	Extended Hardware-in-Loop (extended HiL) tests (optional) Integration test

8.8.1.9.4 Results

This subchapter presents any kind of deliverables or outputs (completed checklists, reports, results, validation, compliance or verification matrices …) from the completion of IVV activities for components/system functionalities.

Outputs	Linked procedure(s)
Optical flow accelerator component functionally verified	Functional simulation of the accelerator
Optical flow accelerator capable of processing 300 fps with VGA resolution images, while localization from the output of the accelerator is capable of distinguishing a rotation of up to 9 degrees (error always below 0.4 degrees) and translation of up to 24 pixels (error always below 0.16 pixels)	Software-in-Loop (SiL) tests Functional simulation of the accelerator Hardware-in-Loop (HiL) tests
Scientific article on optical flow acceleration co-processor (Accepted: DSD2021)	Software-in-Loop (SiL) tests Functional simulation of the accelerator Hardware-in-Loop (HiL) tests
Video demonstrations of the optical flow accelerator	Hardware-in-Loop (HiL) tests

[Banino 2018] Banino, A., Barry, C., Uria, B., Blundell, C., Lillicrap, T., Mirowski, P., ... & Kumaran, D. (2018). Vector-based navigation using grid-like representations in artificial agents. Nature, 557(7705), 429-433.

8.8.1.10 COMP10 – WP4-01 - Sensory Fusion in FPGA

8.8.1.10.1 Strategy

The development of application specific integrated circuits (ASIC) in the context of advanced drone functions is carried following product design phases that requires prototyping and proofs of concept prior to production. Our development is driven by the needs in the use cases scenarios of advanced functionality with limited power and computing budged (edge constrained systems).

1. First, we identify functions that needs to be accelerated and executed on-board. We have identified the need of enhancing sensory systems by a) fusing radar and camera and b) by introducing neural network-based object detection, classification, and tracking.
2. We exploit relevant datasets (publicly available) and we collect our own dataset to best match a hard-case for the system functions in questions.
3. Based on the dataset, we develop neural network algorithms that can solve the tasks. We then optimize these algorithms by performing quantization, pruning, binarization and by exploring spiking neural network solutions.
4. We then write register-transfer level (RTL) description of the system functionalities. We verify the performance of the RTL hardware for accelerating the neural network workloads. The development of the hardware acceleration platform is carried using a standard digital flow development.
5. We perform testing in FPGA and in heterogenous SoC platform. These testing are useful for verification of the hardware blocks and can be readily used in drone’s platforms that can carry an FPGA board (embedded systems).
6. Additionally, we have designed a digital prototype Application Specific Integrated Circuit (ASIC) in 28nm TSMC technology. This chip is used to test and verify the functionality of the spiking neural network accelerator.

8.8.1.10.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Collection of radar and camera dataset	Uncontrolled city environment	Camera, radar 24Ghz, from a moving bicycle	Collect realistic data from un (uncontrolled) city-like environment while driving a bicycle in Eindhoven (NL) for testing and training neural network models.
Neural network training on fused data, camera, and radar for robust object detection	Software	Camera video stream and radar video stream	Explore the network architectures to best match the sensory fusion task.
Design, Implementation, and Test in Register-transfer level (RTL)	Cadence and Xilinx development tools	Architecture description and behavioural models	Efficiently implement digital hardware block for the acceleration of neural network workloads
Test the neural network accelerator in SoC FPGA and measure performance	Controlled laboratory environment	Camera video stream and radar video stream	Verify the applicability of the neural network accelerator for robust object detection, classification and tracking.
Design prototype ASIC containing test circuits and structures of the neural network accelerator	Cadence	RTL architecture description	Verify in an Application Specific Integrated Circuits the proposed neural network architecture. Develop chip in 28nm digital technology.

8.8.1.10.3 Means

Tools	Methods	Linked procedure(s)
TensorFlow/PyTorch frameworks	Engineering	All stages of the development
Design, Implementation, and Test in Register-transfer level (RTL).	Engineering.	Test hardware design against neural network algorithm
SoC FPGA , radar, camera.	Engineering, testing and analysis	Controlled test of hardware blocks in the laboratory, using dataset inputs and real-time live data.

8.8.1.10.4 Results

Outputs	Linked procedure(s)
Neural network architecture verified in FPGA with standard and already available datasets.	Functional simulation of the accelerator, measured performance
Object detection accelerator running Yolo neural network capable of processing 20/40 fps with 240x240 resolution images while performing object classification.	Test the neural network in SoC FPGA.

Scientific article on spiking neural network architecture in FPGA for multi-sensory data analytics (Accepted: DSD2021 - https://dl.acm.org/doi/abs/10.1145/3444950.3444951)	Test the neural network in SoC FPGA.
Video demonstrations of the optical flow accelerator running on a realistic city-like environment. https://youtu.be/yZIWU7uPuQM	Collection of radar and camera dataset.
Patent on « Radar Detection Sensor, System and Method" , **EP 20174295.4** filed on **May 13, 2020**	Neural network training on fused data, camera, and radar for robust object detection.
Chip prototype test: ASIC designed (taped out at IMEC's costs in 28nm digital technology) that implement near- sensor machine learning tasks (classification of radar signals with low-latency and with extreme low power). Publication available online : J.Stuijt et al. «uBrain : an event-driven and fully synthesizable architecture for spiking neural networks« Frontiers in Neuroscience, Hardware for Artificial Intelligence, 2021.	Design, Implementation, and Test in Register-transfer level (RTL).

8.8.1.11 COMP11 – WP5-20 - Resilient communication

8.8.1.11.1 Strategy

The WP5-20 component IVV strategy assumes at start-up that the nodes running DTN are in contact with the base station to receive their time synchronization. After that, they can move out of connection to the base station. The tests are carried out in two phases. First preliminary tests to establish correctness of the configuration and then final tests, to verify that the functionality is according to plan.

Preliminary tests:

First we perform preliminary testing of the configuration.

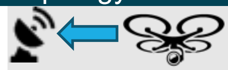
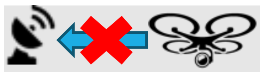
- In order to do this we first create an ad-hoc network between base station and nodes, and verify the connections between the reachable nodes via the standard 'ping' command.
- Then on each node DTN is started. By checking on the log files it can be verified whether the DTN daemon is correctly running on base station and drones, and in particular whether neighbour discovery is working. Via the same method it can also be checked whether the time synchronization is carried out correctly.
- When this works, we check whether each of the drones can receive a 'DTN ping' and send an answer, and whether we can send short messages with the commands: 'DTN send' and 'DTN receive'.

Final tests

When these tests are carried out successfully, we move on to the final test scenarios described in

Table 8.67.

Table 8.67: Robust Communication Network Test Scenarios WP5-20-TNL

Link Type	Topology	Description
Direct		There is a direct link from source to destination. Bundles are directly transferred to the destination
Multi-Hop		There is no direct link from source to destination. However, there is a path to the destination via one or more node. The Bundle is first transferred to the intermediate node(s) and then transferred to the destination.
No Link		There is no link nor a path from source to destination. Bundles are stored on the source node until a path to the destination becomes available.
Custody		There is no path to the destination but non-destination nodes (i.e. custody nodes) are reachable. Depending on the routing protocol, the bundle is transferred to the custody node and both stored on the source and custody node until the destination becomes available.

8.8.1.11.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Verify connections between nodes in wireless ad-hoc network	Wireless ad-hoc network	Simple ‘ping’ commands.	Verify that the different nodes in the network have established connectivity.
Verify correct functioning of DTN deamon	Wireless ad-hoc network. DTN running	Commands to enable looking into the logfiles where neighbouring nodes are indicated.	Verify that the DTN neighbours have established a neighbouring relationship in a network.
Verify correct functioning of DTN communication	Wireless ad-hoc network. DTN running	‘dtnping’ messages are sent between neighbouring nodes.	Verify that the input messages are received, that output messages are generated, sent and received.
Direct communication	Wireless ad-hoc network. DTN running. Full connectivity.	The ‘dtnsend’ command is used to transfer a file from source to destination.	To verify direct communication by sending a file from source to destination, where source and destination have a direct connection (are within one hop of each other).
Multi-Hop communication	Wireless ad-hoc network. DTN running. Limited connectivity (typically realised by removing antennas).	The ‘dtnsend’ command is used to transfer a file from source to destination.	Verify communication over an existing path with multiple hops. Method is to send a file from source to destination, where source and destination are connected via an intermediate node (‘custody node’).

No Link storage	Wireless ad-hoc network. DTN running. Limited connectivity	The 'dtnsend' command is used to transfer a file from source to destination.	Verify that when there is no link nor a path from source to destination, then bundles are stored on the source node. When a connection to the destination becomes available again, the information is received.
Send video to destination	Wireless ad-hoc network. DTN running. Full connectivity.	Video input from a connected camera.	Verify that transmitted video is received, when there is no link nor a path from source to destination, then video-frames are stored on the source node. When a connection to the destination becomes available again, the stream is received again.
Send video to destination	Wireless ad-hoc network. DTN running. Limited connectivity	Video input from a connected camera.	Verify that transmitted video is received, when there is no link nor a path from source to destination, then video-frames are stored on the intermediate node. When a connection to the destination becomes available again, the stream is received again.

8.8.1.11.3 Means

Tools/methods	Linked procedures
Engineering reviews	Requirements validation
Traceability analysis	Requirements validation
Integration testing (preliminary, single node)	Test & Integration
Integration testing (final, network)	Test & Integration

8.8.1.11.4 Results

Expected outputs	Linked procedures
The different nodes in the network have established verifiable connectivity.	Component validation
The DTN neighbours have established a verifiable neighbouring relationship in a network.	Component validation
The input messages are received, that output messages are generated, sent and received.	Component validation
Direct communication is possible by sending a file from source to destination, where source and destination have a direct connection (are within one hop of each other).	Component validation
Communication over an existing path with multiple hops is possible.	Component validation
When there is no link nor a path from source to destination, then bundles are stored on the source node. When a connection to the destination becomes available again, the information is received.	Component validation
Transmitted video is received when there is no link nor a path from source to destination. In this case video-frames are stored on the source node. When a connection to the destination becomes available again, the stream is received again.	Component validation
Transmitted video is received when there is no link nor a path from source to destination. In this case video-frames are stored on the intermediate node. When a connection to the destination becomes available again, the stream is received again.	Component validation

8.8.1.12 COMP12 – WP4-01 Spiking Neural Networks & Sensory Fusion for drone navigation

8.8.1.12.1 Strategy

Our contributions feature a set of tools to enhance autonomous navigation onboard micro air vehicles (MAVs) for indoor applications.

- Autonomous navigation onboard drones first require a decent obstacle detection and avoidance scheme to handle the complexity of natural, indoor environments. This implies dealing with varying conditions such as light intensity, moving objects, etc.

In this respect, we propose to use a novel approach that makes use of neuromorphic cameras, i.e., event-based cameras (such as the DVS240 from IniVation). These cameras stream data in a totally asynchronous manner, and encode the visual information in terms of variations in contrasts. These sensors are inherently suitable for drone applications because of their dynamical properties as they stream events (i.e., contrast variations) at extremely high speed (1-2kHz).

Along with such sensors, we use FMCW Radars to improve detection in dim-light conditions, as well as untextured features such as uniform walls which are extremely hard to detect with visual sensors.

For both sensors, we propose an efficient and robust method to detect, track, and avoid both static and moving obstacles in complex environments [1, 2]. These two pipelines are merged to optimize performance for indoor applications.

- A dataset has been proposed to test the proposed solution and was made open-source for the Comp4Drones partners and general public [3].
- We also provide a neuromorphic solution for altitude control of MAVs during landing and take-off, using a tiny spiking neural network to ensure smooth and safe landing of the MAV using the divergence of the ventral optic flow field [4].
- Lastly, a toolbox for neuromorphic computing in robotics was developed to facilitate the use of spiking neural networks onboard drones and robots and thus, increase the impact of this booming field of research on robotic research and development [5].

Supporting publications:

[1] Dinaux, R., Wessendorp, N., Dupeyroux, J., & de Croon, G. (2021). FAITH: Fast iterative half-plane focus of expansion estimation using event-based optic flow. *arXiv preprint arXiv:2102.12823. Accepted for publication in Robotics and Autonomous Letters (RA-L).*

https://arxiv.org/pdf/2102.12823.pdf

https://github.com/tudelft/faith

[2] Wessendorp, N., Dinaux, R., Dupeyroux, J., & de Croon, G. (2021). Obstacle Avoidance onboard MAVs using a FMCW RADAR. *arXiv preprint arXiv:2103.02050. Accepted for publication in the IEEE/RSJ International Conference on Intelligence Robots and Systems (IROS'2021).*

https://arxiv.org/pdf/2103.02050.pdf

https://github.com/tudelft/radar_nav

[3] Dupeyroux, J., Dinaux, R., Wessendorp, N., & de Croon, G. (2021) The Obstacle Detection and Avoidance Dataset for Drones. *Submitted*.

https://github.com/tudelft/ODA_Dataset

https://doi.org/10.4121/14214236.v1

[4] Dupeyroux, J., Hagenaars, J., Paredes-Vallés, F., & de Croon, G. (2021). Neuromorphic control for optic-flow-based landings of MAVs using the Loihi processor. *arXiv preprint arXiv:2011.00534. Accepted for publication in IEEE International Conference on Robotics and Automation (ICRA'2021).*

https://arxiv.org/pdf/2011.00534.pdf

https://github.com/tudelft/loihi

[5] Dupeyroux, J. (2021). A toolbox for neuromorphic sensing in robotics. *arXiv preprint arXiv:2103.02751. Submitted for publication in the IEEE/RSJ International Conference on Intelligence Robots and Systems (IROS'2021).*

https://arxiv.org/abs/2103.02751

https://github.com/tudelft/SpikeCoding

8.8.1.12.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Optic Flow estimation using DVS Camera	ROS 1	- Raw events from event-based camera (DVS240)	Using the plane-fitting algorithm, local optic flow (OF) is processed and forms the first step towards any visual-based autonomous MAV control, including navigation.
Event-based Optic Flow derotation	ROS 1	- Local OF provided by the previous procedure - IMU measurements from DVS240	To compensate for the rotations of the MAV (roll, pitch), the 2D OF is derotated using the IMU rates.
Estimation of the Focus of Expansion	ROS 1	- Derotated OF provided by the previous procedure	The FAITH algorithm [1] is used to estimate the course of the MAV (i.e., focus of expansion FOE).
Obstacle detection using DVS input	ROS 1	- Derotated OF - FOE	Using a standard DBSCAN process, we combine clusters of an estimate the presence of obstacles with respect to the FOE. The method has been successfully demonstrated onboard a real drone (footages available online, see ref [1]).
Radar-based obstacle detection	ROS 1	- Raw radar data	Radar data are processed to extract the angular position, velocity and the radial distance of surrounding obstacles. Obstacles are considered whenever the estimated distance falls within a range of interest [2].
Radar-based obstacle avoidance	ROS 1	- Obstacle velocity - Obstacle angle - Obstacle distance	The obstacle information is used to perform an avoidance strategy based on the Velocity Obstacles algorithm [2]. The method has been successfully demonstrated onboard a real drone (footages available online, see ref [2]).
Autonomous landing using a spiking neural network and visual	Python ROS 1	- Optic flow from downward facing camera - IMU	The proposed neuromorphic controller allows autonomous landing of MAVs using OF. The method has been successfully

input from a standard camera			demonstrated onboard a real drone (footages available online, see ref [4]).
Toolbox for neuromorphic coding applied to sensing in robotics	ROS 1 Python Matlab	- Floating point continuous values	The toolbox offers a wide range of different algorithms for encoding and decoding of spikes to adapt to the existing sensors in robotics (IMU, radar, sonar, camera, microphones, etc.) [5].

8.8.1.12.3 Means

Tools	Methods	Linked procedure(s)
ROS Framework	*Engineering*	*ROS is used to implement all the proposed solutions.*
Python	*Engineering, simulation, tests and analysis*	*Software development, tests and analysis on both simulation and real data (using the dataset [3]).*
Matlab	*Engineering, simulation, tests and analysis*	*Software development, tests and analysis on both simulation and real data (using the dataset [3]).*
OptiTrack	*Tests*	*The OptiTrack motion capture system that equips the CyberZoo of the Delft University of Technology was used to perform tests of the proposed components, as well as demonstrations.*

8.8.1.12.4 Results

Outputs	Linked procedure(s)
Autonomous obstacle detection and avoidance onboard drones using a neuromorphic camera.	State-of-the-art performance (both processing cost and accuracy) as compared to other methods that use visual information (neuromorphic or standard). 80% success.
Autonomous obstacle detection and avoidance onboard drones using a FMCW radar.	Successfully demonstrated onboard the MAV with 100% success in detection & avoidance.

8.8.1.13 COMP13 – WP4-19 DronePort traffic control

8.8.1.13.1 Strategy

The development strategy of the DronePort traffic control component concentrates to the following tasks:

1. Setup and simulation environment employing the Gazebo/ROS environment and use it to deploy one or multiple DronePort platform instances and one or more drones. Each of the DronePort platform instances and drones in the simulated environment use PX4 SITL system.
2. Perform tests in the simulated environment
   - Communication tests between DronePort and associated drones.
   - Withdrawal from the planned mission form battery exchange and mission resumption.
   - Landing on the DronePort platform using visual servoing with ArUco fiducial markers.
3. After successful test in the simulated environment perform test in real environment.

8.8.1.13.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Gazebo simulation of the DronePort platform	Controlled simulated environment	DronePort platform with unique ID and ArUco fiducial marker	Spawning simple DronePort platform with unique ArUco fiducial marker. Each instance of the DronePort platform will be linked to unique PX4 SITL controller within Gazebo using DronePort gazebo plugin.
Landing on the DronePort Platform	Controlled simulated environment	Position of the DronePort platform in the simulated environment and Camera video stream from a simulated drone	The simulated drone controlled by PX4 SITL flight controller will land on the simulated DronePort platform.
Prediction of the need for battery replacement and mission replanning	Controlled simulated environment	Simulated drone battery status, planned mission and position in the simulated environment	The DronePort traffic control subsystem of the DronePort will perform predictions of the drones battery state and based on the knowledge of the planned mission and current position it will schedule the mission abortion and landing on the DronePort platform
Mission resumption	Controlled simulated environment	Known original mission plans of the simulated drones and DronePort platform position	The DronePort traffic control subsystem will orchestrate resumption of the drones mission after successful landing on the DronePort platform.
Final validation	Operational environment	Known position of the drones and DronePort platforms, known mission plans of the drones, estimated status of the drones batteries	After successful testing in the simulated environment, the DronePort traffic control component will be tested with real drones and DronePort platforms where there will be also the battery compartment exchange tested.

8.8.1.13.3 Means

Tools/methods	Linked procedures
Gazebo/ROS simulation environment	Simulation of the DronePort platform and drones
PX4 SITL and DronePort Gazebo plugin	Control of the simulated components

8.8.1.13.4 Results

Expected outputs	Linked procedures
Successful spawning, operation and communication of the DronePort and drones	Gazebo simulation of the DronePort platform
Propper landing on the DronePort platform	Landing on the DronePort Platform
Successful test of the traffic control subsystem with no unexpected drone mission interruption (e.g. drone crash due to the depleted	Prediction of the need for battery replacement and mission replanning

battery, crash of two or multiple drones due improper mission replanning)	
All the drones associated to the DronePort will fulfil fully their originally planned mission only with interruption for landing on the DronePort platform for battery exchange	Mission resumption
All	Final validation

8.8.1.14 COMPONENT WP5-12 - Link manager and scheduler

8.8.1.14.1 Strategy

ANYWI develops 2-part SW solution, link manager and scheduler, for reliable communication between UAV and ground. The aim is to integrate commercial of the shelf communications link technology such as 802.11, LTE or other wireless technologies in such a way as to enable adoption in mid-sized specific category drones (under U-SPACE considerations) as Command, Control and Communications (C^3) links. The Link Manager is responsible for discovery and prioritization of existing wireless links. By contrast, the Scheduler decides packet-by-packet which link to send packets across, based on information reported by the Link Manager to the Scheduler and interested applications.

In order to achieve this, strategy is first to identify regulation needed to derive functional and safety requirements as well as stakeholders needs, which should later shape operational system functionality represented by system architecture. Rest of process is focused on software development, which should follow industry standards in that regard. Running software components in simulation environment is included in SW integration and verification phase. Moreover, simulator may also provide system performance indicators to be compared against similar single communication technology solutions.

8.8.1.14.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	International and EU avionics regulations, industry standards/guidelines for avionics software, stakeholders need.	Identify relevant regulations, rules and standards, stakeholders needs and expectations, and derive requirements from it.
Architecture verification	N/A	Functional, operational and safety requirements.	Verify that architecture provides functionality in accordance with specified requirements.
SIL testing	Simulator	SW components, simulation tool and test scenarios.	Simulation tool with dedicated test scenarios is developed as part of SW integration and verification testing within V-cycle in WP06. Test scenarios are defined according to initial requirements in order to test each component functionality individually and collectively.
Performance testing	Simulator	SW components, simulation tool and test scenarios.	Simulation tool contains test scenarios to obtain system performance metrics.

8.8.1.14.3 Means

Tools/methods	Linked procedures
Engineering reviews	Requirements validation, architecture verification.
Behaviour driven development (BDD) method used for definition of test scenarios.	SIL testing, performance testing.
Simulation The validation toolkit serves as simulator for component's environment simultaneously tracking its outputs to check if they match expected ones, thereby validating components or system as hole. Also, by being able to track component's outputs toolkit can serve as a performance tracker as well.	SIL testing, performance testing.

8.8.1.14.4 Results

Expected outputs	Linked procedures
Requirements table • Every requirement shall have link to at least one for regulation article, standard, guideline, or stakeholder need.	Requirements validation
Architecture verification report • All operational functionalities should be identified and can be traced to requirements table. Any additional functionality that does not match requirements table should contain explanation.	Architecture verification
SIL test results • The test results shall confirm functionalities of SW parts presented by architecture. • The test results shall confirm functionalities of overall system presented by architecture. • The test results may identify bottlenecks or weak points which can be translated into new requirements. The SIL test results shall provide a proof that the SW components are compliant with its specification. Any deviation shall be documented and justified.	SIL testing
Performance test results • The performance test results shall enable quantitative and qualitative collection of system performance metrics. The performance test results shall provide a proof that the SW parts are compliant with its specification. Any deviation shall be documented and justified. The performance test results may be used to compare developed system with other market solutions used for same purposes.	Performance testing

8.8.1.15 COMPONENT WP5-13 - Link state Application Programming Interface

8.8.1.15.1 Strategy

ANYWI develops a SW solution, link state API, which enables reporting on connection quality and availability as well as available unused resources (such as unused links) to support on-board applications, with prioritized communication. This set of information is consumed by WP05-12 component called link manager. Therefore, link state API and link manager work in tight collaboration, meaning largely same methods used by WP05-12 apply to WP05-13 as well. The overall system architecture may include both components.

Strategy is first to identify regulation needed to derive functional and safety requirements as well as stakeholders needs, which should later shape operational system functionality represented by system architecture. Rest of process is focused on software development, which should follow industry standards in that regard. Running software components in simulation environment is included in SW integration and verification phase.

8.8.1.15.2 Procedures

Procedures	Environment	Planned inputs	Objectives
Requirements validation	N/A	International and EU avionics regulations, industry standards/guidelines for avionics software, stakeholders need.	Identify relevant regulations, rules and standards, stakeholders needs and expectations, and derive requirements from it.
Architecture verification	N/A	Functional, operational and safety requirements.	Prove that architecture provides functionality in accordance with specified requirements.
SIL testing	Simulator	SW components, simulation tool and test scenarios.	Simulation tool with dedicated test scenarios is developed as part of SW integration and verification testing within V-cycle in WP06. Test scenarios are defined according to initial requirements in order to test component functionality.

8.8.1.15.3 Means

Tools/methods	Linked procedures
Engineering reviews	Requirements validation, architecture verification.
Behaviour driven development (BDD) method used for definition of test scenarios.	SIL testing, performance testing.
Simulation The validation toolkit serves as simulator for component's environment simultaneously tracking its outputs to check if they match expected ones, thereby validating components or system as hole. Also, by being able to track component's outputs toolkit can serve as a performance tracker as well.	SIL testing.

8.8.1.15.4 Results

Expected outputs	Linked procedures
Requirements table Every requirement shall have link to at least one for regulation article, standard, guideline, or stakeholder need.	Requirements validation
Architecture verification report All operational functionalities should be identified and can be traced to requirements table. Any additional functionality that does not match requirements table should contain explanation.	Architecture verification
SIL test results • The test results shall confirm functionalities of SW parts presented by architecture. • The test results shall confirm functionalities of overall system presented by architecture. • The test results may identify bottlenecks or weak points which can be translated into new requirements. The SIL test results shall provide a proof that the SW component is compliant with its specification. Any deviation shall be documented and justified.	SIL testing

8.8.2 Functionality Verification

8.8.2.1 UC4-D2-FUN-01-02 – Neuromorphic image processing, optic flow, object detection and avoidance

8.8.2.1.1 Strategy

An important aspect of the Use-case 4 Demonstrator 2 is the multiple drone approach to exploration, inspection, and monitoring missions. To identify interesting targets, we develop efficiently implementation of neural network accelerators that can perform object detection, and image classification directly on-board of the drone. First, we develop accelerated hardware models in RTL and execute those in FPGA for verification and deployment. The same digital designs can then be integrated in application specific integrated circuits (ASIC). Our design strategy consists of phases that requires prototyping and proofs of concept prior to production. Our development is driven by the needs in the use cases scenarios of advanced functionality with limited power and computing budged (edge constrained systems).

1) First, we identify functions that needs to be accelerated and executed on-board, FUN-01, FUN-02 (optic flow, object detection and avoidance, and neuromorphic image processing). We have identified the need of enhancing sensory systems by a) fusing radar and camera and b) by introducing neural network-based object detection, classification, and tracking.
2) We exploit relevant datasets (publicly available) and we collect our own dataset to best match a hard-case for the system functions in questions.
3) Based on the dataset, we develop neural network algorithms that can solve the tasks. We then optimize these algorithms by performing quantization, pruning, binarization and by exploring spiking neural network solutions.
4) We then write register-transfer level (RTL) description of the system functionalities. We verify the performance of the RTL hardware for accelerating the neural network workloads. The development of the hardware acceleration platform is carried using a standard digital flow development.
5) We perform testing in FPGA and in heterogenous SoC platform. These testing are useful for verification of the hardware blocks and can be readily used in drone's platforms that can carry an FPGA board (embedded systems).

6) Additionally, we have designed a digital prototype Application Specific Integrated Circuit (ASIC) in 28nm TSMC technology. This chip is used to test and verify the functionality of the spiking neural network accelerator.

8.8.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Collection of radar and camera dataset	Uncontrolled city environment	Camera, radar 24Ghz, from a moving bicycle	Collect realistic data from un (uncontrolled) city-like environment while driving a bicycle in Eindhoven (NL) for testing and training neural network models.
Neural network training on fused data, camera, and radar for robust object detection	Software	Camera video stream and radar video stream	Explore the network architectures to best match the sensory fusion task.
Design, Implementation, and Test in Register-transfer level (RTL)	Cadence and Xilinx development tools	Architecture description and behavioural models	Efficiently implement digital hardware block for the acceleration of neural network workloads
Test the neural network accelerator in SoC FPGA and measure performance	Controlled laboratory environment	Camera video stream and radar video stream	Verify the applicability of the neural network accelerator for robust object detection, classification and tracking.
Design prototype ASIC containing test circuits and structures of the neural network accelerator	Cadence	RTL architecture description	Verify in an Application Specific Integrated Circuits the proposed neural network architecture. Develop chip in 28nm digital technology.

8.8.2.1.3 Means

Tools	Methods	Linked procedure(s)
TensorFlow/PyTorch frameworks	Engineering	All stages of the development
Design, Implementation, and Test in Register-transfer level (RTL).	Engineering.	Test hardware design against neural network algorithm
SoC FPGA , radar, camera.	Engineering, testing and analysis	Controlled test of hardware blocks in the laboratory, using dataset inputs and real-time live data.

8.8.2.1.4 Results

Outputs	Linked procedure(s)
Neural network architecture verified in FPGA with standard and already available datasets.	Functional simulation of the accelerator, measured performance
Object detection accelerator running Yolo neural network capable of processing 20/40 fps with 240x240 resolution images while performing object classification.	Test the neural network in SoC FPGA.
Scientific article on spiking neural network architecture in FPGA for multi-sensory data analytics (Accepted: DSD2021 - https://dl.acm.org/doi/abs/10.1145/3444950.3444951)	Test the neural network in SoC FPGA.
Video demonstrations of the optical flow accelerator running on a realistic city-like environment. https://youtu.be/yZIWU7uPuQM	Collection of radar and camera dataset.
Patent on « Radar Detection Sensor, System and Method" , **EP 20174295.4** filed on **May 13, 2020**	Neural network training on fused data, camera, and radar for robust object detection.
Chip prototype test: ASIC designed (taped out at IMEC's costs in 28nm digital technology) that implement near- sensor machine learning tasks (classification of radar signals with low-latency and with extreme low power). Publication available online : J.Stuijt et al. «uBrain : an event-driven and fully synthesizable architecture for spiking neural networks« Frontiers in Neuroscience, Hardware for Artificial Intelligence, 2021.	Design, Implementation, and Test in Register-transfer level (RTL).

8.8.2.2 UC4-D2-FUN-04 – Aerial platform

8.8.2.2.1 Strategy

As part of the use case demonstrator, it is required to develop a fleet of micro air vehicles (MAVs). For this goal to be successfully completed, we aim at fulfilling the following constraints:

- the size of the MAV shall not exceed 30 cm of maximum length;
- the weight of the MAV shall not exceed 500 g with the battery;
- the autopilot software must rely on open-source platforms;
- the autonomy of the MAV shall be of at least 15 minutes;
- the MAV shall be considered as low-cost (inferior to 1000EUR, event-based cam excluded).

8.8.2.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Hardware	Real world	Manual control Autonomous control	The drone design is used in autonomous applications such as obstacle avoidance and navigation. The autopilot developed allows the user to either manually control the drone or switch to any form of custom-made autonomous control, such as landing, and obstacle avoidance as exhibited in the TUD contribution to COMP12 WP4-01.

8.8.2.2.3 Means

Tools	Methods	Linked procedure(s)
iNav-based open-source autopilot*	The autopilot software used for the MAV flight control is powered by the iNav open-source autopilot. The software is meant to run on the Kakute F7 embedded micro-controller.	Software

* https://github.com/iNavFlight/inav/wiki (this was not developed within the Comp4Drones project).

Below we provide a list of the hardware components required to reproduce the MAV used in the context of the Use Case 4 – Demonstrator 2 of the Comp4Drones project. Also, we provide the average price of these items

- **Main frame**

  GEPRC FPV Frame Kit Mark4 – 5 inches (*60EUR*)

- **Battery**

  Tattu FunFly 4S 100C 1800mAh (*30EUR*)

- **Actuators**

  Turnigy D2205-2600KV CCW (*30EUR*)

  Ethix S5 (2CW+2CCW) propellers (*5EUR*)

- **Autopilot**

  Kakute Tekko ESC COMBO v1.5 Holybro (*85EUR*)

  Master BEC BOY C1690 (3A 5-6V) (*20EUR*)

  FrSky XM+ Receiver (*15EUR*)

  TBS (TeamBlachSheep) Race wires (*15EUR*)

- **Joystick**

  FrSky Taranis X9 Lite ACCESS EU LBT (*110EUR*)

  Tattu 250mAh 2S 7.4V LiPo Accu (*25EUR*)

- **Electronics**

  Intel Up Core 4GB / 64GB eMMC (*175EUR*)

  300Mbps Mini Wireless N USB Adapter (*15EUR*)

- **Sensors**

  TFMini - Micro LiDAR Module (Qwiic) (*40EUR*)

The proposed design results in a total price of **615 euros**. It must be mentioned that in case of use in the context of event-based vision applications, the average price of such cameras is found to be of 3000 euros.

8.8.2.2.4 Results

Outputs	Linked procedure(s)
The output is the design of a MAV (Fig. 1) that exhibits the following characteristics: - 260 mm x 200 mm x 100 mm - less than 500 g - up to 25 minutes of autonomy - open-source autopilot powered by iNav	The design has been successfully used in different experiments as outlined in the output of TUD contribution to COMP12 WP4-01.

Figure 24 Top view of the proposed MAV UC4-D2-FUN-05 – Vehicle platform equipped with all sensors (event-based camera, micro lidar) and electronics (Intel Up Core), as exploited for output generation in TUD contribution to COMP12 WP4-01. Credits: Julien Dupeyroux (MAVLab, Delft University of Technology).

8.8.2.2.5 Strategy

TU/e is developing a Rover platform for demonstrating the methods and techniques with respect to UC4-D2. The Rover will be equipped with sensors (e.g. lidar, IMU) and actuators (e.g. motors). As a hardware/software platform, we use CompROS platform. In essence, it is a combination of real-time ROS 2 running on CompSOC. In general, it offers a framework for composable ROS2 based architecture for real-time embedded robotic development. Validation of this functionality will be done through running a ROS2 based control application in the hard time side of the platform, while a navigation stack runs in the soft real-time side of the platform.

8.8.2.2.6 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Single rover implementation	In a well-defined physical environment, the rover is supposed to reach a destination while reacting to the dynamic obstacles in a hard real-time way.	Starting positions, prior knowledge, mission objectives, communication capabilities, strategies	Measure the accuracy of moving the rover inside the environment, and the predictability of the hard real-time control application.

8.8.2.2.7 Means

Tools	Methods	Linked procedure(s)
CompROS, ROS2, Rviz	Measure the accuracy of moving the rover inside the environment, and the predictability of the hard real-time control application.	Single rover implementation

8.8.2.2.8 Results

Outputs	Linked procedure(s)
Measure the accuracy of moving the rover inside the environment, and the predictability of the hard real-time control application.	All tests

8.8.2.3 UC4-D2-FUN-06– Robust Networking

8.8.2.3.1 Strategy

The strategy to verify and validate functionality of system is to use the system in a number of test scenarios, based on requirements of the UC4-D2-COMP11 (WP5-20). The complete functionality of the system is based on two parts: (a) the transfer of real-time video into packets in the DTN format; (b) the robust transmission of packets; (c) the decoding and displaying of the packets.

8.8.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
DTN connectivity	Real-life environment (no simulation)	Simple 'ping' commands, commands to enable looking into logfiles, 'dtnping' and 'dtnsend commands'	Demonstrate system capability to send and receive DTN packets.
Video to DTN	Real-life environment (no simulation)	Real-time video stream	Verify that video is correctly transferred via DTN packets.
DTN to Video	Real-life environment (no simulation)	Stream of DTN packets containing video	Verify that video is correctly received via DTN packets.
End to end transmission of video	Real-life environment (no simulation)	Real-time video stream	Demonstrate that video can be sent end-to-end via DTN.

8.8.2.3.3 Means

Tools	Methods	Linked procedure(s)
Displays, equipment. Network sniffers.	Real-life tests based on actual implementation.	All procedures from Procedure section table.

8.8.2.3.4 Results

Outputs	Linked procedure(s)
Verified robust end-to-end video streaming functionality.	All procedures from Procedure section table.

8.8.2.4 UC4-D2-FUN-07 – Drone to Ground GW

8.8.2.4.1 Strategy

The strategy to verify and validate functionality of system is to develop dedicated simulation tool (aka validation toolkit) consisting of test scenarios based on requirements of components WP05-12 and WP05-13. Requirements consider bigger picture, or the UC3-D1-FUN-07 functionality as hole.

8.8.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Handover	Simulated environment	The scenario emulates two wireless links with some fixed range, and a handover region where both links provide some connectivity. We simulate this by starting with zero percent packet loss on one link (A), and 100 percent packet loss on the other (B). We hold this pattern for some time T1, then proceed to linearly reduce packet loss to zero percent on link B over the time span T2. Shortly after this starts (a delay of T3), we linearly increase packet loss to 100 percent on link A over the same time period T2. When link A has reached 100 percent packet loss and link B is at zero percent, we hold that pattern for a while (T1) before ending the test.	Demonstrate system capability to monitor links quality and switch between them accordingly.
Fail-over	Simulated environment	Start out by having both links at zero percent packet loss and hold that for a time span T1. We then immediately introduce 100 percent packet loss on one of the links and hold that new pattern for a time span T2.	Demonstrate system recovery from sudden link quality deterioration one of the available links.
Connection Loss	Simulated environment	As a variant of the previous fail-over scenario, we start out with two links at zero percent packet loss, but then drop both links to 100 percent loss at the same time.	Demonstrate system ability to identify full loss of connection (e.g. entering tunnel) and speed of reporting it.

Flapping Link	Simulated environment	Simulate link alternation between reporting its status as up and down (e.g. hardware failure). We simulate this by alternating one of the links between 100 percent and zero percent packet loss for periods T2. We precede this with a period T1 in which both links exhibit zero percent packet loss.	Outcomes: 1) Demonstrate lower throughput and higher latency when using simple round-robin scheduler. 2) Demonstrate favouring stable link when using more advanced scheduler. This depends on highly on the time periods involved - we expect that further mitigation techniques for this scenario may have to be explored.

8.8.2.4.3 Means

Tools	Methods	Linked procedure(s)
Simulation tool (aka validation toolkit) developed in WP06.	Defining test scenarios which should be able to provide inputs to system as described in Procedures section above and monitor its outputs in order to validate functional requirements.	All procedures from Procedure section table.

8.8.2.4.4 Results

Outputs	Linked procedure(s)
Demonstrate system functionalities which are aligned with overall UC3-D1-FUN-05 functionality.	All procedures from Procedure section table.

8.8.2.5 UC4-D2-FUN-09 – Simultaneous localization and mapping

8.8.2.5.1 Strategy

An important part of the use-case scenario is the mapping of an unknown, in-door, (and therefor GNSS-impaired) cluttered environment. As there is no global positioning available, localisation of the drone(s) is similarly important. This makes the application of advanced SLAM algorithms, enhanced by rich mapping information, a core functionality of the use-case. Validation of this functionality will be done through (large-scale) simulation and demonstrated in a video deliverable.

8.8.2.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulations	In a simulated, environment, run several multiple drone flights, given a shared (exploration) mission.	Starting positions, prior knowledge, mission objectives, communication capabilities, strategies	Measure the accuracy and quality of the produced maps of the environment and the accuracy of the position of the drone(s).

8.8.2.5.3 Means

Tools	Methods	Linked procedure(s)
Simulation environment (ROS, Gazebo & PX4)	Measure the accuracy and quality of the produced maps of the environment and the accuracy of the position of the drone(s).	Simulations

8.8.2.5.4 Results

Outputs	Linked procedure(s)
Measure the accuracy and quality of the produced maps of the environment and the accuracy of the position of the drone(s).	All tests

8.8.2.6 UC4-D2-FUN-10 – Failsafe online reconfiguration

8.8.2.6.1 Strategy

The robot must work in safety critical environments and should be able to reconfigure itself based on the environmental situation. Performing the dynamic configuration in a safety critical environment should be done in a way that the provided guarantees and analysability of other running components is not affected. To this end, the idea is to guarantee that the hard real-time control applications (both ROS2 components in the CompROS platform, and non-ROS control applications) can be dynamically loaded/ unloaded to the running system without affecting the timing behaviour of other running components.

8.8.2.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Virtual Execution Platform (VEP) reconfiguration	In an instance of CompSOC platform, the VEPs should be loaded/unloaded dynamically considering the communication and memory mapping.	Prepared compiled applications to be loaded/unloaded in VEPs in the run-time.	Measure the reconfiguration time, and check the interference between the components.

8.8.2.6.3 Means

Tools	Methods	Linked procedure(s)
CompSOC platform.	Measure the reconfiguration time, and check the interference between the components.	Virtual Execution Platform (VEP) reconfiguration

8.8.2.6.4 Results

Outputs	Linked procedure(s)
Measure the reconfiguration time, and check the interference between the components.	All tests

8.8.2.7 UC4-D2-FUN-11 – Decision strategies for drone fleet

8.8.2.7.1 Strategy

An important aspect of the Use-case 4 Demonstrator 2 is the multiple drone approach to exploration, inspection and monitoring missions. Main reasoning behind this aspect is the expected reduction in mission elapsed time, reducing the time needed to find victims in an emergency response scenario.

Other contributing reasons are mission robustness: Less impact of needing to recharge/swap batteries and the option for bringing in different types of drones (heterogenous fleet). These benefits require a good functioning strategy for making those drones cooperate effectively. As such a “cooperative planner” component has been introduced, aimed at fulfilling this functionality. Besides testing that component, we also validate this functionality at a higher abstraction level. This will mostly be done through simulation, reported through a video deliverable.

One important aspect that will be validated is the ease for an operator to control the fleet.

8.8.2.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Simulations	In a simulated environment, run several multiple drone flights, given a shared (exploration) mission.	Starting positions, prior knowledge, mission objectives, communication capabilities, strategies	Measure the efficiency, in mission achievement duration, resource usage, and general mission safety Control ability for the operator of the drone fleet.

8.8.2.7.3 Means

Tools	Methods	Linked procedure(s)
Simulation environment (ROS, Gazebo & PX4)	Measure the efficiency, in mission achievement duration, resource usage, and general mission safety Control ability for the operator of the drone fleet, tested through a survey questionary.	Simulations

8.8.2.7.4 Results

Outputs	Linked procedure(s)
Measure of the efficiency in mission achievement duration	All tests
Control ability for the operator of the drone fleet.	All tests

9 UC5-Demo1: Agriculture: Wide Crop Demonstrator

9.1 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.

9.2 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 25).Figure 26Figure 27

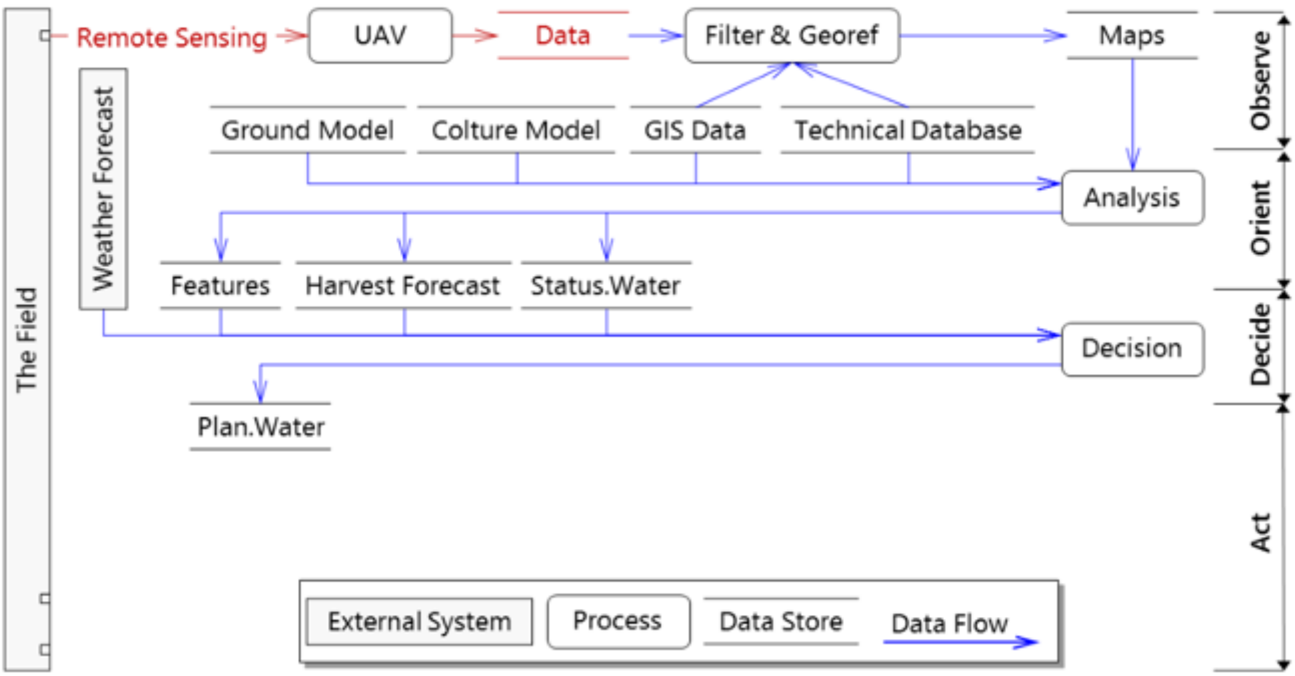


Figure 25 UC5 – D1 Scenario 5.1.1

- Scenario 5.1.2: smart drone to determine where actions are needed. Intervention is still manual but distributed locally (see Figure 26).

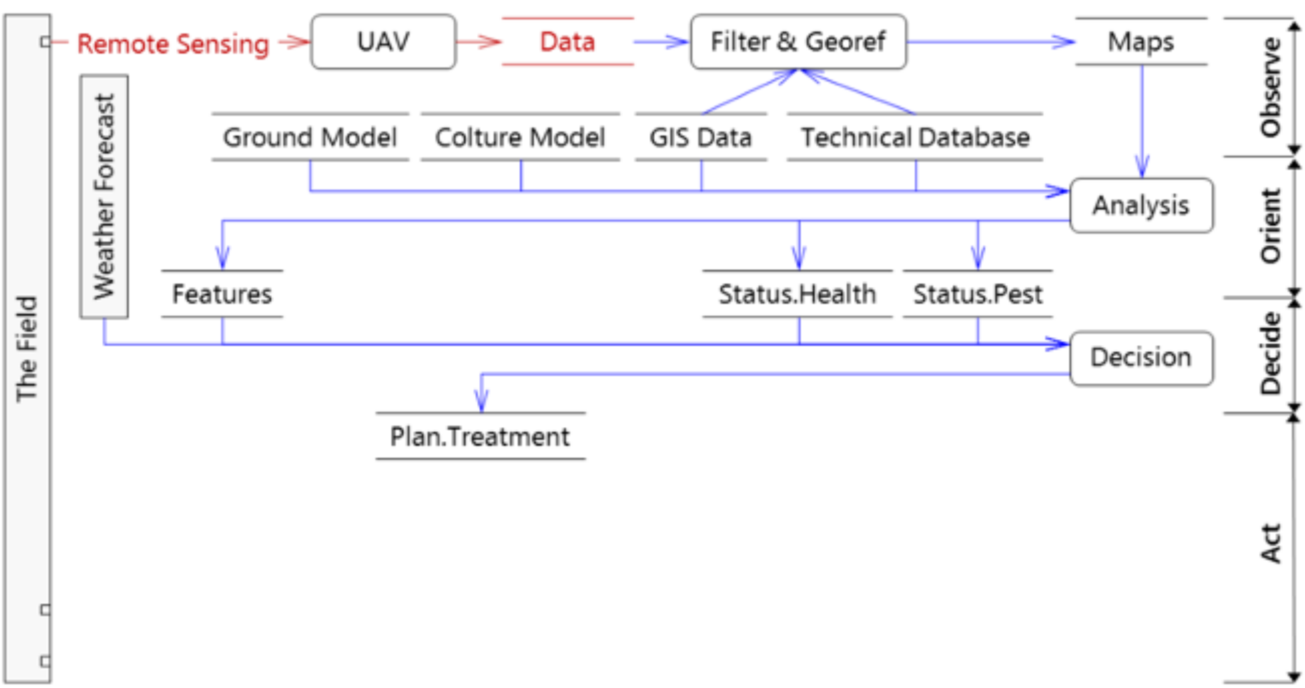


Figure 26 UC5 – D1 Scenario 5.1.2

- 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 27).

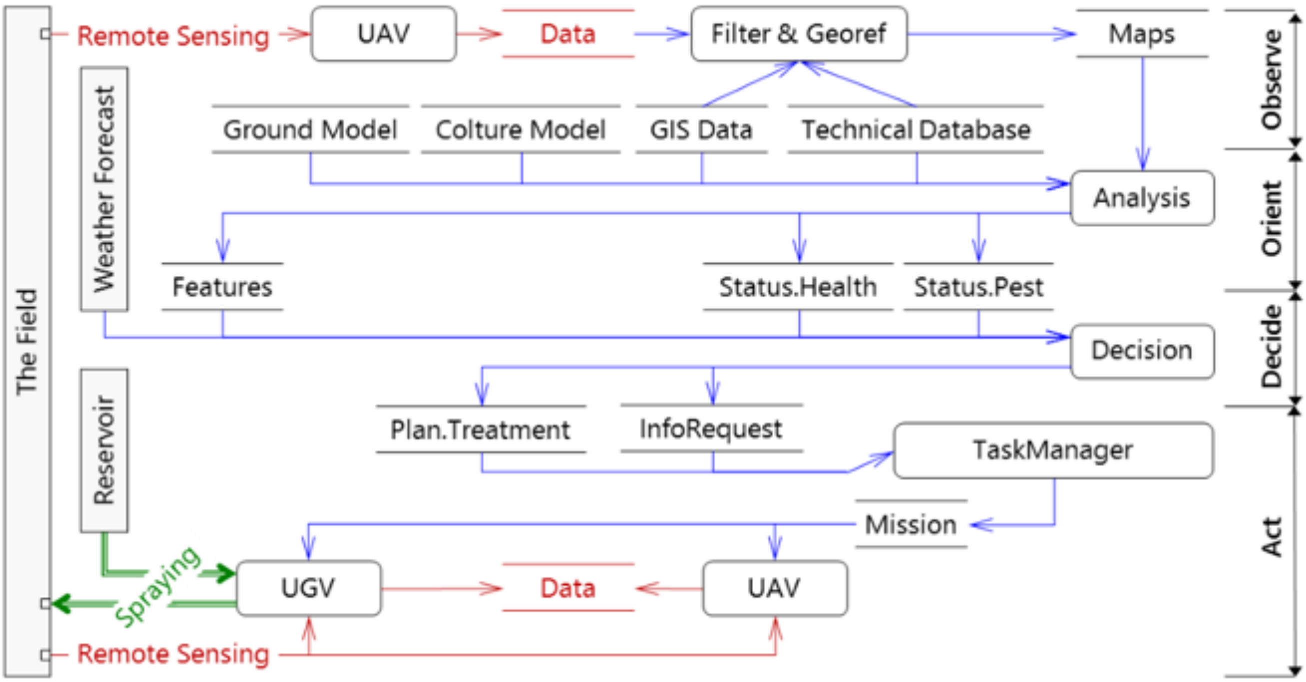


Figure 27 UC5 – D1 Scenario 5.1.3

The analysis of these scenarios, especially of scenario 5.1.3, has highlighted some situations in which it might be necessary to have a very precise localization of an object (for instance at plant level for local treatment). Therefore, alongside the main DEMO, an additional PoC is under development:

- A smart drone will be equipped with a SLAM component and an GPS anti-spoofing component and will be evaluated for its resilient positioning capabilities. Specifically, the drone will be able to locate itself even in presence of sporadic failures of the GPS signal and will be able to detect some spoofing attacks to the GPS.

Please, notice that this PoC is not meant to be an additional scenario. It is a branch of scenario 5.1.3 that contributes to better satisfy the "*KPI – T3: Accurate SLAM technique implementation / no-GPS positioning system"* (see Table 68). In future it could be part of an extension of the main DEMO.

9.3 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.

9.3.1 Technical KPI`s and Metrics

Table 68depicts 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)	• 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 in performance and resource consumption (FPGA slices)		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 (UC5-DEM10-KPI-007**)**	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 68 UC5 D1 List of KPIs

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

Table 69maps 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, also notice 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 69 UC5 D1 List of Main Requirements

9.3.3 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 UDANET MODIS	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 UDANET MODIS ABI	KPI - T4

Table 70 UC5 D1 List of Drone Integration Requirements

9.4 Functionalities identification

- The characterizing functionalities of this demonstrator are identified starting from the three scenarios identified above and are connected to the features (F) identified in deliverable D1.1, in section "*Key Concept and Technologies*" of UC5 Demo1. Table 71 depicts 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 with respect to deliverable D1.2, the number of functionalities has decreased since some functionalities have been merged into some more generic ones.

ID	Functionality	Description	System function
UC5-D1-FUN – 01	Processing platform based on COTS FPGA SoCs	This functionality tackles processing platforms based on COTS FPGA SoCs: A modular onboard companion computer infrastructure. Heterogeneous HW/SW processing platform models. (see F1.2 in D1.1)	System and Environment Status – Intelligent Data Handling 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 F1.1 in D1.1)	Advanced on-board information processing capabilities
UC5-D1-FUN - 03	Drone/rover cooperation	This functionality tackles the aspects of Drone/rover cooperation: UAV-UGV identification, communication, and positioning. UAV-UGV safe cooperation. Embedded discrete-time controller (See F2 and F4 in D1.1.)	Coordination – UAV and UGV: • Communication. • 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	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	Positioning

	sensing capabilities	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)	

Table 71 UC5 D1 List of Functionalities

9.5 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.

With respect to deliverable D1.2, the component C18 (WP5-09-ABI - Communication scheme for unified system management) from Abinsula has been added to the component table.

Table 72 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 modeling and simulation accuracy	SC4.1	MO4.1	O4
UNIMORE	WP3	Onboard Programmable and Reconfigurable	COMP05 (WP3-22, WP3-28)	Easy to design, develop, and deploy applications	SC1.1 SC1.2	MO1.3	O1

UNISS		Compute Platform Design Methodology		Easy to develop applications for heterogeneous platforms	SC1.2 SC4.1	MO1.3 MO4.1	O1 O4
				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
ABI	WP5	Communication scheme for unified system management	COMP18 (WP5-09-ABI)	Ease of integration	SC1.1	MO1.1	O1
				Lightweight communication	SC3.1	MO3.1 MO3.2	O3
				Robust communications	SC3.1	MO3.1 MO3.2	O3

Table 72 UC5 D1 List of components

9.6 Tools

Table 73 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 73 UC5 D1 List of Tools

9.7 Traceability matrices

9.7.1 Requirements vs. functionalities

Table 74maps 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	FUN 01	FUN 02	FUN 03	FUN 04	FUN 05	FUN 06
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	
UC5-DEM10-FNC-012	The system shall provide a unified monitoring and management interface.			X			

Table 74 UC5 D1 Requirements and functionalities traceability matrix

9.7.2 Functionalities vs. Components

FUNCTIONALITY	C1	C2	C3	C4	C5	C6	C7	C8	C9	C 10	C 11	C 12	C 13	C 14	C 15	C 16	C 17	C 18
F1					X		X						X					
F2			X															
F3						X				X	X					X	X	X
F4								X				X		X				
F5				X														
F6	X	X							X						X			

Table 75 UC5 D1 Components and functionalities traceability matrix

9.8 IVV system 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.

9.8.1 Components Verification

9.8.1.1 COMP01 –WP3-20a - Highly Embedded Customizable Platform for SLAM technique

9.8.1.1.1 Strategy

The component aims to achieve following objectives:

- C01.OBJ1: Provide a standalone platform to act as emergency GPS signal provider to the Drone Control System.

To implement the component in a proper manner, have been defined following IVV

- C10.IVV1: The algorithms are embedded in a HW standalone Single Board Computing Unit.
- C10.IVV2: The algorithms and the sensors platform are tested on our drone platform, a PX Hawk 4 system.

9.8.1.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Validation of the predicted coordinates	Laboratory	Sensor data collected during drone movements	C10.IVV1/1

9.8.1.1.3 Means

Tools	Methods	Linked procedure(s)
PixHAWK PX4	Visualization of the predicted coordinates against the ground truth and estimation of the drone accuracy	P1
Single Board Computing Unit	Providing interfaces with auxiliary sensors and outputting correct GPS signal to PixHawk	P1

9.8.1.1.4 Results

Outputs	Linked procedure(s)
A general-purpose component capable of locating the drone even in presence of a failure of the GPS signal	P1

9.8.1.2 COMP02 –WP3-20b - Simultaneous Localization and Mapping Algorithms

9.8.1.2.1 Strategy

The component aims to achieve following objectives:

- C02.OBJ1: Verify the algorithm is capable of properly locating the drone within the map even without the GPS signal. The algorithm will use odometry, geomagnetic measurements and measure of distance from fixed points in the map.

To implement the component in a proper manner, have been defined following IVV

- C10.IVV1: The algorithm is implemented and debugged in Python. The algorithm has been tested on synthetic data in a Python environment.
- C10.IVV2: The algorithm is implemented and debugged in Python. The algorithm is test on our drone platform, a PX Hawk 4 system.

9.8.1.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Validation of the predicted coordinates	Laboratory	Sensor data collected during drone movements	C10.IVV1/1

9.8.1.2.3 Means

Tools	Methods	Linked procedure(s)
PX HAWK 4	Visualization of the predicted coordinates against the ground truth and estimation of the drone accuracy	P1

9.8.1.2.4 Results

Outputs	Linked procedure(s)
A general-purpose component capable of locating the drone even in presence of a failure of the GPS signal	P1

9.8.1.3 COMP03 – WP3-36a - AI modules for video analytics

9.8.1.3.1 Strategy

This component implements advanced AI based approaches to elaborate images and video flows collected by a drone to monitor crop and to infer relevant information concerning plants status. In particular, the goal is to detect and classify targets, artichoke and grape plants in this case (C03.OBJ1)

9.8.1.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Convolutional Neural Network development and training to detect plants.	Laboratory	Training set composed of images collected by drones (alternatively already available online)	C07.IVV1
P2: Tests will be done after the conclusion of the training phase. Retraining activities will be done if needed	Laboratory and/or on field	Images collected by drones (alternatively already available online) and neural network trained	C07.IVV2

9.8.1.3.3 Means

Tools	Methods	Linked procedure(s)
Tensorflow	Development & Training	P1
Video flows or images collected by end user	A subset of available images will not be used for training purpose. Instead, they will be used for tests: detected information (like presence of a plant) is compared against a ground truth (manual detection of the plants done by the end user).	P2

9.8.1.3.4 Results

Outputs	Linked procedure(s)
Neural Network properly trained to detect relevant information. Detection accuracy can be considered as performance metrics	P1 and P2

9.8.1.4 COMP04 – WP3-36b - Smart and Predictive Energy Management System

9.8.1.4.1 Strategy

This component has the main objective of extracting rules in the generation of trajectories for a predetermined mission to go from a starting point to an end point. The reference trajectories concern both the position and speed profiles and possibly on a part of the orientation and have a characterization that emerges from an energy type analysis (C04.OBJ4).

9.8.1.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Energetic optimal control problem formulation and implementation	Laboratory	UAV and mission characteristics (starting and final point)	C07.IVV1
P2: Energetic reference generation profiles from the analysis of P1 results	Laboratory	Optimal control problem defined in P1 results	C07.IVV2

9.8.1.4.3 Means

Tools	Methods	Linked procedure(s)
Matlab-Simulink	Development & Test	P1, P2

9.8.1.4.4 Results

Outputs	Linked procedure(s)
Optimal references to be tracked in a mission	P1 and P2

9.8.1.5 COMP05 –WP3-22; WP3-28 - Onboard Programmable and Reconfigurable Compute Platform Design Methodology

9.8.1.5.1 Strategy

This component deals with two different objectives:

- C05.OBJ1: Ease the development and deployment of ready-to-use application-specific reconfigurable HW accelerators on an FPGA overlay.
- C05.OBJ2: Ease the management of the HW accelerator from the SW point-of-view by means of using OpenMP clauses.

In order to verify the correctness of this component, three different IVV objectives have been defined, each of them verified by means of a different procedure:

- C05.IVV1: Verify the usability of HW accelerators generated with the methodology. This IVV will be validated in the laboratory using basic examples of accelerators (P1).
- C05.IVV2: Verify the reconfigurability support of the HW accelerators generated with the methodology. This IVV will be validated in the laboratory using a multi-functional image processing accelerator (P2).
- C05.IVV3: Verify the usability of the methodology when implementing a real application extracted from the use-case. This IVV will be validated in the laboratory using COMP13 (P3).

9.8.1.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: automatic deployment and management of simple HW accelerators	Laboratory	Dataflow-like application definitions of three simple applications HDL associated with each dataflow actor composing the application accelerator	C05.IVV1
P2: automatic deployment and management of	Laboratory	Dataflow-like application definition of a Sobel-Roberts border detector	C05.IVV2

reconfigurable HW accelerators		HDL associated with each dataflow actor composing the application accelerator	
P3: automatic deployment and management of a real use-case application on the compute platform	Laboratory	Dataflow-like application definition of the COMP13 application accelerator HDL associated with each dataflow actor composing the application accelerator	C05.IVV3

9.8.1.5.3 Means

Tools	Methods	Linked procedure(s)
QuestaSim	To test and simulate the generated HW accelerators embedded within the onboard programmable and reconfigurable compute platform	P1 P2 P3
Testbench	To provide stimuli to the simulator and be able to check the correctness of the outputs	P1 P2 P3

9.8.1.5.4 Results

Outputs	Linked procedure(s)
Application specific HW accelerators embedded within the onboard programmable and reconfigurable compute platform: versatility, scalability, lines of code that are automatically generated for both HW and SW parts	All tests

9.8.1.6 COMP06 – WP3- 24a - Efficient Digital Implementation of Controller on FPGAs

9.8.1.6.1 Strategy

The proposed component aims to provide an efficient implementation strategy of digital controllers for UAV on FPGA. The proposed methodology is focused on retiming and pipelining which allows:

1. lower execution times, and hence smaller sampling times, than its naive implementation;
2. to take into account the energetic aspects of the controller implementations, and not only the controller performance.

The efficiency of the proposed methodology is verified by introducing the following IVV objectives:

- C06.IVV1: Verify the better performances in terms of execution times.
- C06.IVV2: Verify the possible reduction in terms of energetic consumption.

The defined IVV will be validated in laboratory by using the following procedure:

- A robust sampled—data control strategy for the autonomous navigation of UAVs will be implemented with different techniques on an FPGA which will be interfaced to an advanced simulation platform in order to evaluate the performances in terms of execution time and energetic consumption (P1).

9.8.1.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Verification of the proposed implementation procedure in terms of execution time and energy consumption.	Laboratory	Different implementation strategies of a proposed robust control algorithm will be compared with the pipeline-based approach here proposed. The performances preservation of the implemented robust controller, which is based on the algorithms proposed in COMP 14, will be also evaluated when different implementation approaches are used.	IVV1, IVV2

9.8.1.6.3 Means

Tools	Methods	Linked procedure(s)
Advanced simulation platforms	To test the different implementation strategies with the pipeline-based approach here proposed.	P1
FPGAs	To implement a proposed robust sampled—data control with different techniques. The FPGA will be interfaced with the advanced simulation platform introduced above.	P1

9.8.1.6.4 Results

Outputs	Linked procedure(s)
Performance results w.r.t. timing constraints, sample rate and system implementation improvements	P1

9.8.1.7 COMP07 –WP3-24b - Mixed-Criticality Design Space Exploration

9.8.1.7.1 Strategy

The component aims to achieve two different objectives:

- C07.OBJ1: C07.OBJ1: Easy design and deployment of a heterogeneous HW /SW processing platform.
- C07.OBJ2: C07.OBJ2: Improve performance and resource consumption through processing platform performance analysis based on a model-driven approach to find alternative configuration paths.

To verify the correctness of this component, two different IVV objectives were defined, each verified with a different procedure:

- C07.IVV1: C07.IVV1: Verify the architecture/mapping proposed by the HW /SW partitioning, architecture definition and mapping activity to satisfy the specified input constraints (P1).
- C07.IVV2: Verification of performance and resource consumption improvement using the timing SystemC simulator(P2).

9.8.1.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Design Space Exploration alternative solution verification considering the input constraints	Laboratory	SystemC models generated from the CSP model using Model2Text transformations	C07.IVV1
P2: Performance and resource consumption improvement analysis of a heterogeneous HW/SW processing platform	Laboratory	Heterogeneous parallel HW platform and system behaviour models described in SystemC	C07.IVV2

9.8.1.7.3 Means

Tools	Methods	Linked procedure(s)
HEPSYCODE	Design heterogeneous HW/SW processing platform based on COTS FPGAs platforms	P1, P2
HEPSIM2	Simulate heterogeneous HW/SW processing platform using SystemC environment	P1, P2

9.8.1.7.4 Results

Outputs	Linked procedure(s)
Scalability analysis, timing performance metrics and results, power/energy consumptions, schedulability and feasibility analysis	P1, P2

9.8.1.8 COMP08 – WP4-44 - Embedded AI obstacle detection and avoidance

9.8.1.8.1 Strategy

The main objective of this component is:

- C08.OBJ1, provide to a ground rover the capability to react to unknown obstacles along the path during a mission;

To develop and implement the component in a proper manner, the following IVV procedures have been defined:

- C08.IVV1, the DeepNN part of the component is developed in Python for the training phase. The whole component is validated in simulated environment using GAZEBO simulator and ROS;
- C08.IVV2, the component is ported in C++ in order to be integrated on board a vehicle and validated in a real scenario exploiting ROS facilities for data exchange between sensors and main board with DeepNN engine.

9.8.1.8.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: test on simulated environment	Simulator	Simulated: • laser/camera data • inertial measurement • relative distance and angle between vehicle and target position	C08.IVV1
P2: test on real scenario	In the field	Real: • Laser/camera data • inertial measurement • relative distance and angle between vehicle and target position provided by a GPS RTK	C08.IVV2

9.8.1.8.3 Means

Tools	Methods	Linked procedure(s)
GAZEBO Simulator	Simulation & Testing	P1
Tensorflow/TensorRT	Development & Training	P1
ROS	Integration & Testing	P1, P2

9.8.1.8.4 Results

Outputs	Linked procedure(s)
Vehicle is able to navigate in an unknown environment, without the knowledge of the map, reacting to the different obstacles.	P1, P2

9.8.1.9 COMP09 – WP4-11 – Resilient Positioning

9.8.1.9.1 Strategy

The main objective of this component is:

- C09.OBJ1, provide to a flying drone a resilient positioning system unaffected by GPS signal losses

To develop and implement the component in a proper manner, the following IVV procedures have been defined:

- C09.IVV1, a positioning algorithm is based on an ultrasound transceiver, mounted on a Single Board Computing Unit, coupled with ultrasound emitter beacons that provide initial positioning estimation.
- C09.IVV2 a SLAM algorithm sporting a Kalman filter acting on IMU sensors and ultrasound data.
- C09.IVV3 a ML model trained to identify spoofing attempts is deployed in the Single Board Computing Unit and tells the system to provide correct GPS data when attack or signal losses occurs.

9.8.1.9.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Validation of the predicted coordinates	Laboratory/Open Field	Sensor data collected during drone movements	C09.IVV1 C09.IVV2
P2: Validation of anti-spoofing capabilities	Laboratory	Interference to GPS signal through SDR	C09.IVV3

9.8.1.9.3 Means

Tools	Methods	Linked procedure(s)
PX HAWK 4	Visualization of the predicted coordinates against the ground truth and estimation of the drone accuracy	P1 P2

9.8.1.9.4 Results

Outputs	Linked procedure(s)
A general-purpose component capable of locating the drone even in presence of a failure of the GPS signal	P1 P2

9.8.1.10 COMP10 – WP4-18-TEK- Transponder for drone-rover

9.8.1.10.1 Strategy

The component aims to achieve following objectives:

- C10.OBJ1: Verify the algorithm that drives the UAV toward a target position on autonomous fly. The target position is given relatively to the distance from an "anchor". The distance is calculated using a fixed Ultra-Wideband (UWB) node (a transceiver and a controller) and an UWB node that 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.

To implement the component in a proper manner, have been defined following IVV

- C10.IVV1: 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. This first IVV will be validated in laboratory.
- C10.IVV2: 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).

9.8.1.10.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Test validation algorithm on Python implementation	Laboratory	The target position given relatively to the position of an UWB anchor.	C10.IVV1
P2: Test validation algorithm on on-board computer installation	Laboratory / In the field	The target position given relatively to the position of an UWB anchor.	C10.IVV2

9.8.1.10.3 Means

Tools	Methods	Linked procedure(s)
CoppeliaSim. Development environments for the Crazyflie platform.	Simulation & Testing & engineering reviews	P1
Development environments for the on-board computer based on ARM.	Testing & engineering reviews	P2

9.8.1.10.4 Results

Outputs	Linked procedure(s)
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)	P1, P2

9.8.1.11 COMP11 – WP4-40 - High Accurate GNSS receiver, improving and notifying drone position

9.8.1.11.1 Strategy

This component tackles three main objectives:

- C11.OBJ1: offering an autonomous geolocation system capable of easily integrating with systems equipped with network protocols known as MQTT

The IVV strategy for this component consists of one main step that verify the parts related to the above described objective:

- C11.IVV1: Check the ease of installation of the component on board the drone and connectivity with network interfaces via NBiot cellular connection

Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: visualization of data from the component to the cloud mqtt dashboard	Laboratory	Input data (component dependent): examples are latitude, longitude, altitude	C11.IVV1
P2: visualization of data from the component to the cloud mqtt dashboard	In the field	Input data (component dependent): examples are latitude, longitude, altitude	C11.IVV1

9.8.1.11.2 Means

Tools	Methods	Linked procedure(s)
switching on of the component on board the drone	Testing & engineering reviews	P1
Unidirectional communication with any MQTT dashboard service	Testing & engineering reviews	P2

9.8.1.11.3 Results

Outputs	Linked procedure(s)
The transponder periodically sends the position of the UAV to a service that displays the track on the screen	P1, P2

9.8.1.12 COMP12 – WP4-08 - Path Planning Algorithms

9.8.1.12.1 Strategy

The proposed component provides a set of algorithms aimed at computing the path that a UAV has to follow in order to perform a given mission within a given environment described by a map.

In particular, the proposed approach will compute the path that satisfies complex constraints given in a formal way. Examples of missions to be performed are:

- The drone shall reach a given target point by avoiding given static obstacles and minimizing the travelled path
- The drone shall reach a given target point in a given time interval by taking into account physical constraints like the maximum acceleration and/or the maximum speed.

The proposed algorithm should be able to consider also multiple drones at the same time by exploiting optimization techniques based on formal languages like the Signal Temporal Logic.

The performance of the proposed algorithm will be verified by introducing the following IVV objectives:

- C12.IVV1: verify the efficacy of the proposed algorithm in the “nominal” scenarios, i.e., when the given map and obstacles perfectly describe the environment and no disturbances are active;
- C12.IVV2: verify the efficacy of the proposed algorithm under perturbed scenarios, i.e., when uncertainties due to the description of obstacles and environment in general are considered and when wing gusts are present.

The defined IVVs will be validated in laboratory through advanced simulation platforms (procedure P1).

9.8.1.12.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
C12.P1: validation of the effectiveness of the proposed path planning algorithm	Laboratory	Different scenarios and mission descriptions will be provided in order to evaluate the effectiveness of the proposed algorithm under different conditions	C12.IVV1, C12.IVV2

9.8.1.12.3 Means

Tools	Methods	Linked procedure(s)
Advanced simulation platforms, AirMPL (tool developed within WP6)	*Robotic simulators (e.g., Gazebo) will be used to validate the performances of the proposed algorithm under realistic scenarios.*	*C12.P1*

9.8.1.12.4 Results

Outputs	Linked procedure(s)
Simulation of complex missions performed by drones under different scenarios. Quantitative characterization of drones' behaviour in terms of mission specification satisfaction.	*C12.P1*

9.8.1.13 COMP13 – WP4-09 - Application-Specific Accelerator

This component is not under development yet, the roadmap for its definition is defined in detail 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.

9.8.1.14 COMP14 – WP4-33 - Autonomy, cooperation, and awareness

9.8.1.14.1 Strategy

The proposed component provided a set of algorithms for the autonomous cooperation of UAVs when operating in critical environments (e.g., in the presence of hard wind). In particular, distributed control strategy for swarms of UAVs based on the leader-follower and leaderless consensus approach are proposed allowing to take into account:

1. time-varying formations and switching topologies
2. the collision avoidance between the members of the swarm
3. the rejection of environmental perturbations, and measurement uncertainties.

The performances of the proposed control algorithms will be verified by introducing the following IVV objectives:

- C14.IVV1: Verify the efficacy of the proposed control algorithms in the cases in which: (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 possible configuration are time-varying.
- C14.IVV2: Verify the capability of the proposed control algorithms to attenuate the effects of actuation disturbances and measurements errors.

The defined IVV will be validated in laboratory by using the following procedure:

- The proposed control algorithms will be tested in laboratory on advanced simulation platforms in different scenarios. The proposed robust sampled—data control strategy will be compared with the non—robustified one (P1).

9.8.1.14.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Validation of the performances of the proposed control algorithms	Laboratory	Different scenarios and bad environments will be addressed in order to evaluate the capabilities of the swarm to accomplish complex tasks when the proposed robust control strategy is used. The performances of the proposed robust control strategy will be compared with the non-robustified ones.	IVV1, IVV2

9.8.1.14.3 Means

Tools	Methods	Linked procedure(s)
Advanced simulation platforms	To simulate different scenarios and asses the performances of the proposed robust sampled—data control strategy. Such performances will be compared with the case of non—robustified controller.	P1

9.8.1.14.4 Results

Outputs	Linked procedure(s)
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	P1

9.8.1.15 COMP15 – WP5-07-MODIS - GPS Spoofing Detection Module

9.8.1.15.1 Strategy

- The proposed component provide a GPS spoofing attack detector based on machine learning classifiers. The algorithm is capable of detecting short-range attacks via the analysis of the SNR. The module extracts the features from the NMEA sentences.

The performances of the proposed component will be verified by introducing the following IVV objectives:

- C15.IVV1: Verify the efficacy of the proposed algorithms in terms of detection capabilities of the spoofing attacks. Specifically accuracy, false positives and false negatives will be measured on the collected dataset.

The defined IVV will be validated in laboratory by using the following procedure:

- The proposed algorithms will be tested in laboratory in a Python environment (P1).
- The proposed component will be also tested on our drone platform PX HAWK 4 (P2) under real spoofing attacks generated with a SDR (P2).

9.8.1.15.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Validation of the proposed detection algorithm or detecting spoofing attacks	Laboratory	Different attack and non-attack scenarios to measure the detection rate of the component, its accuracy and related metrics	C15.IVV1

9.8.1.15.3 Means

Tools	Methods	Linked procedure(s)
PX HAWK 4 + SDN software	Test the component under different attack and visualize internal output on a file	P1 and P2

9.8.1.15.4 Results

Outputs	Linked procedure(s)
A general-purpose component capable of detecting some kind of spoofing attacks.	P2

9.8.1.16 COMP16 – WP5-08-ROT - Lightweight Cryptography

9.8.1.16.1 Strategy

The component aims to achieve two different objectives:

- C16.OBJ1: provide security services of data, confidentiality, integrity and authenticity, in drone-to-rover and rover-to-infrastructure communications

- C16.OBJ2: provide an Intrusion Detection System to prevent unauthorized access to the network

To implement the component in a proper manner, two IVV objectives have been defined:

- C16.IVV1: verify the encryption and decryption procedures. This IVV will be validated in laboratory with two network entities. (P1)
- C16.IVV2: verify the Intrusion Detection System operations. This IVV will be validated in laboratory with three network entities. (P2)

9.8.1.16.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: encryption or decryption of a message exchanged between entities	Laboratory	A Plain Text to encrypt or a Cipher Text to decrypt.	C16.OBJ1
P2: detection of an unauthorized intrusion attempt	Laboratory	An entity attempting to intrude on the network.	C16.OBJ2

9.8.1.16.3 Means

Tools	Methods	Linked procedure(s)
C software	Simulation and test the component's cryptographic scheme and verification of the outputs	P1 P2

9.8.1.16.4 Results

Outputs	Linked procedure(s)
Data processing, both encryption and decryption, successfully verified	P1
Intrusion attempts detected and network access denied	P2

9.8.1.17 COMP17 – WP5-05-TEK - LPWAN for Identification, Tracking, and Emergency Messages

9.8.1.17.1 Strategy

The component aims to achieve following objectives:

- C17.OBJ1: Verify the Low Power Wide Area Network (LPWAN) as communication infrastructure for vehicle identification and tracking, as well as for low throughput messages. Objective of this component is to use the UAV or UGV that become a "thing in the network" and implement a Web Application to show all vehicles and offer other services to higher level systems such as UTM (Unmanned Aircraft System Traffic Management).

To implement the component in a proper manner, have been defined following IVV.

- C17.IVV1: To verify the transceiver integration on the UAV and the basic transmission to/from the network server (a test network can be used).
- C17.IVV2: To verify the UAV tracking, the operating messages exchange, the network server services, the application server (a test network can be used).
- C17.IVV3: 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

9.8.1.17.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Test transceiver on basic transmission to/from the network	Laboratory		C17.IVV1
P2: Test UAV tracking	Laboratory / In the field		C17.IVV2, C17.IVV3

9.8.1.17.3 Means

Tools	Methods	Linked procedure(s)
Development environments for the transceiver LoRa board	Testing & engineering reviews	P1, P2
Development environments for the on-board computer based on ARM	Testing & engineering reviews	P2
Development environments for Web Application using MQTT communication protocol with LoRaWAN network server “TheThingsNetwork”	Testing & engineering reviews	P2

9.8.1.17.4 Results

Outputs	Linked procedure(s)
Messages exchanges LoRa node - Network	P1
Tracking vehicles (UAV, UGV) position on a geo referenced map opened on a common web browser.	P2

9.8.1.18 COMP18 – WP5-09-ABI - Communication scheme for unified system management

9.8.1.18.1 Strategy

This component tackles three main objectives:

- C18.OBJ1: Offering a flexible and extensible communication system that eases the integration of different and heterogeneous components.
- C18.OBJ 2: Offering a communication system that offers bidirectional communication among the heterogeneous components and the cloud, and properly handles both different kinds of data.
- C19.OBJ 3: Offering a robust communication, working with different protocols and offering a unified management and visualization of the data.

The IVV strategy for this component consists of three main steps that verify the parts related to the above described objectives:

- C18.IVV1: Verify flexibility with respect to different interfaces by simulating the connection with different kind of components.
- C18.IVV2: Verify proper bidirectional communication and data handling by on-field testing the connection with different components, once at the time.
- C18.IVV3: Verify the unified management and visualization of data by on-field testing the connection with different components all together.

These IVV activities are directly related to the IVV steps (procedures P1, P2 and P3), that are mainly executed by means of simulation and testing.

In particular, the dashboard embeds a series of series of scripts for simulation and verification purpose. These scripts are going to exploited in procedure P1.

If simulations in P1 succeed it is possible to proceed with procedure P2, that involve the testing in real environment of the communication link with the specific component.

If testing in procedure P2 succeed it is possible to proceed with procedure P3 that involves the testing in real environment of the communication link with all the components connected, included the new added one.

Please, notice that the different procedures involve feedback loop of simulation (or testing) and engineering review and every procedure has to succeed before going on. Please, also notice that every time the gateway and the dashboard are updated with a new component all the procedures have to be executed.

9.8.1.18.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: visualization of data from the component	Laboratory	Input data (component dependent): examples are telemetry, stream video, classification data	C18.IVV1
P2: reception of data from the component to the Dashboard and transmission of a trigger	In the field	Input data (component dependent): examples are telemetry, stream video, classification data Output data (component dependent): examples are trigger, coordinates	C18.IVV2
P3: reception and visualization in the Dashboard of data from the different components and trigger transmission	In the field	Input data (component dependent): examples are telemetry, stream video, classification data Output data (component dependent): examples are trigger, coordinates	C18.IVV3

9.8.1.18.3 Means

Tools	Methods	Linked procedure(s)
Embedded scripts in the Dashboard	Simulation & engineering reviews	*P1*
Bidirectional communication with one component at the time	Testing & engineering reviews	*P2*
Bidirectional communication with multiple components in a real environment	Testing & engineering reviews	*P3*

9.8.1.18.4 Results

Outputs	Linked procedure(s)
D5.2	P1, P2, P3
D5.4	P1, P2, P3

9.8.2 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.

Functionalities and components verification are strongly interlaced. Indeed, one or more components can concur to the satisfaction of a functionality or some sub-functionalities. Therefore, the functionalities can be verified by means of one or more IVV activities that are connected to one or more of the components previously described.

For the sake of clearness, to ease the readiness without having to jump among the different tables of this chapter, for each functionality it is reported a small table that illustrates for each sub-functionality (if any) the related IVV activities and the components that satisfy them.

9.8.2.1 UC5-D1-FUN01 – Processing Platform

9.8.2.1.1 Strategy

This functionality is related to the processing platforms based on COTS FPGA SoCs. Under its umbrella there are two different sub-functionalities, directly linked to different components:

A modular onboard companion computer infrastructure. This sub-functionality will deal with intelligent data handling, as well as the system and environmental status. To be precise, it will include the IVV activities associated to COMP05 and COMP13:

- FUNC01.IVV1: ease the data handling on an onboard companion computer by providing an infrastructure where the HW accelerators are automatically plugged within an FPGA overlay, which, in turn, is managed from the SW side using OpenMP clauses. This activity is tightly related with the ones presented for COMP05 and the ones foreseen for COMP13, where the use-case HW accelerator will be provided.

Heterogeneous HW/SW processing platform models. This sub-functionality concerns the design and verification of HW/SW processing platforms using model-driven engineering, SystemC simulator and design space exploration activities to check alternative partitioning, allocation and HW/SW platforms. It will include component COMP07 IVV activities as follows:

- FUNC01.IVV2: System design and deployment using model-driven engineering approaches. This activity is closely related to COMP07 and to C07.IVV1.
- FUNC01.IVV3: Heterogeneous parallel HW /SW processing platform resource utilization and performance improvement. This activity is closely related to COMP07 and to C07.IVV2.

UC5-D1-FUN01- processing platforms based on COTS FPGA SoCs			
Sub-functionality	**IVV Activities**	**Related Component**	**Partner**
Companion computer infrastructure	FUNC01.IVV1	COMP05, COMP13	UNISS-UNIMORE
Heterogeneous HW/SW processing platform models.	FUNC01.IVV2	COMP 07	UNIVAQ
	FUNC01.IVV3	COMP 07	UNIVAQ

9.8.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: automatic deployment and management of simple HW accelerators	*Laboratory*	Same as COMP05	FUNC01.IVV1
P2: automatic deployment and management of reconfigurable HW accelerators	*Laboratory*	Same as COMP05	FUNC01.IVV1
P3: automatic deployment and management of a real use-case application on the compute platform	*Laboratory*	Same as COMP05	FUNC01.IVV1
P4: usage of a real use-case application on the compute platform on a real scenario	*Outdoor controlled*	Dataflow-like application definition of the COMP13 application accelerator HDL associated with each dataflow actor composing the application accelerator	FUNC01.IVV1
P5: Design and deployment of heterogeneous parallel HW/SW processing platform	*Laboratory*	Same as C07.P1	FUNC01.IVV2
P6: Performance and resource improvement analysis	*Laboratory*	Same as C07.P2	FUNC01.IVV3

9.8.2.1.3 Means

Tools	Methods	Linked procedure(s)
QuestaSim	To test and simulate the generated HW accelerators embedded within the onboard programmable and reconfigurable compute platform	P1 P2 P3
Testbench	To provide stimuli to the simulator and be able to check the correctness of the outputs	P1 P2 P3
Design, simulation and verification of heterogeneous parallel HW/SW processing platform	Performance analysis of the heterogeneous processing platform with the tool developed in WP6 (HEPSYCODE and HEPSIM) over different simulation scenarios.	P5 P6

9.8.2.1.4 Results

Outputs	Linked procedure(s)
Modular infrastructure for onboard companion computer	P1, P2, P3
Use-case specific HW accelerator on the infrastructure	P4
Alternative configuration paths (tasks allocation, mapping, binding and schedulability plan) with different applications and HW/SW FPGA-based SoC platforms.	P5, P6

9.8.2.2 UC5-D1-FUN02- On board video acquisition and processing

9.8.2.2.1 Strategy

- FUN02.IVV01: check availability of a video stream/images with adequately quality. This activity is needed in order to verify the availability of the correct input for COMP03
- FUN02.IVV02: plants detection and extraction of information about their status. This corresponds to the output of COMP03

UC5-D1-FUN02- On board video acquisition and processing			
Sub-functionality	IVV Activities	Related Component	Partner
Precise tree crowns definition for water management and harvest forecast	FUN02.IVV01	COMP 03	AITEK-UDANET-MODIS
	FUN02.IVV02	COMP 03	AITEK-UDANET - MODIS

9.8.2.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1 - Validation of the sub-functional capability to detect relevant information about the plant	Laboratory and/or field	Same as COMP03	FUN02.IVV01 and FUN02.IVV02

9.8.2.2.3 Means

Tools	Methods	Linked procedure(s)
COMP03	*Simulation, testing and engineering reviews*	*P1*

9.8.2.2.4 Results

Outputs	Linked procedure(s)
Visualization of the correct information detected by applying video acquisition and processing	**P1**

9.8.2.3 UC5-D1-FUN03- Drone/rover cooperation

9.8.2.3.1 Strategy

This functionality is related to the proper and safe communication and cooperation of the drone and the rover in the system. Under its umbrella there are different sub-functionalities, directly linked to different components:

UAV-UGV identification, communication, and positioning. This sub-functionality concerns the efficient communication of the components in the system, as well as the identification and positioning of the drone and the rover. It is going to include the IVV activities of components COMP10, COMP 17 and COMP18 as follows:

- FUNC03.IVV1: inter-components communication and management through a unified system management. This activity is strongly related to COMP18, and to the IVV activities of COMP 18 verification (That is WP5-09-ABIdeveloped in WP5).
- FUNC03.IVV2: Identification and communication through Low Power Wide Area Network (LP-WAN) medium range system. This activity is related to COMP17 (That is WP5-05-TEK developed in WP5).
- FUNC03.IVV3: Guided by the GPS the UAV approaches the UGV to land on it. Then, if the UGV is not in the field of view of the dedicated video camera that controls the landing, the positioning algorithm drives the UAV to the correct position. The algorithm uses the drone-rover distance that is measured using the Ultra-Wideband (UWB) transceivers with which both vehicles are

equipped. This activity is related to COMP10 (that is WP4-18 developed in WP4), as well as to COMP17 for vehicles identification and UAV command.

UAV-UGV safe cooperation. This sub-functionality concerns the safe communication of drone and rover. It is going to include the IVV activities of component COMP16:

- FUNC03.IVV4: 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.

Embedded discrete-time controller. This sub-functionality concerns the efficient implementation of digital discrete-time controllers. It is going to include the IVV activities of component COMP06:

- FUNC03.IVV5: Efficient digital implementation of discrete–time controllers on FPGAs will be integrated;
- FUNC03.IVV6: Compensation and rejection of environmental perturbations, measurement uncertainties;
- FUNC03.IVV7: Management functionalities of critical situations, with improved situation awareness, will be guaranteed; Predictive power autonomy awareness approaches will be released

These IVV activities are directly related to the procedures described in the following section.

UC5-D1-FUN03- Drone/rover cooperation			
Sub-functionality	**IVV Activities**	**Related Component**	**Partner**
UAV-UGV identification, communication, and positioning	FUNC03.IVV1	COMP18	ABI
	FUNC03.IVV2	COMP17	TEKNE
	FUNC03.IVV3	COMP10 COMP17	TEKNE
UAV-UGV safe cooperation	FUNC03.IVV4	COMP16	ROT
Embedded discrete-time controller	FUNC03.IVV5	COMP06	UNIVAQ
	FUNC03.IVV6	COMP06	UNIVAQ
	FUNC03.IVV7	COMP06	UNIVAQ

9.8.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: reception and visualization in the Dashboard of data from the different components and trigger transmission	*In the field*	Same as COMP 18	FUNC03.IVV1
P2: Test using simulation of message to process (encryption or decryption) and detection of an intrusion attempt.	Laboratory	Same as COMP 16	FUNC03.IVV4
P3: Assessment of the component for UC needs.	In the field	Same as COMP 16	FUNC03.IVV4
P4: On the UAV is installed the component COMP17. On the UGV is installed a reduced configuration of COMP17 because the GPS position is the only needed data. The goal is to verify FUNC03.IVV2 by (1) tracking the position of both vehicles that communicate with the Cloud Server through the LoRa-WAN network, (2) monitoring the UAV status, and (3)	*In the field*	Same as COMP 17	FUNC03.IVV2

commanding the UAV. The procedure is related with FUNC02.IVV2 (COMP17).			
P5: On the UAV is installed the component COMP10 that measure the distances and drives the vehicle. On the UGV is installed a reduced configuration of COMP10 because only the distance measurement needed. The procedure verifies the correctness of the autonomous UAV positioning with respect to the UGV, such that the landing pad mounted on the latter is in the field of view of the dedicated video camera that drives the UAV landing. For completeness, an open-source landing system will be integrated. The procedure is related with part of FUNC03.IVV3 (COMP10).	*Can be an industrial building with tens of meter of free space.*	Same as COMP 10	FUNC03.IVV3
P6: The procedure completes the verification of the system that results from FUNC03.IVV3 (COMP10 and COMP17). Through COMP17 the UAV is commanded to approach the UGV (whose position is known—see P5) by using the GPS and then, by using COMP10, to correctly positioning with respect the UGV so that the autonomous landing is possible.	*In the field*	Same as COMP10 and COMP17	FUNC03.IVV3
P7: Verification of the proposed implementation procedure in terms of execution time and energy consumption.	*Laboratory*	Same as COMP 06	FUNC03.IVV5
P8: Validation of the performances of the proposed control algorithms	*Laboratory*	Same as COMP 14	FUNC03.IVV6 FUNC03.IVV7

9.8.2.3.3 Means

Tools	Methods	Linked procedure(s)
Bidirectional communication with multiple components	Simulation, testing and engineering reviews	P1
C software	Simulation and test	P2, P3
C software	Simulation and test	P4, P5, P6
Advanced simulation platform	Simulation, testing and engineering reviews	P7, P8
FPGAs	Simulation, testing and engineering reviews	P7, P8

9.8.2.3.4 Results

Outputs	Linked procedure(s)
Visualization of data in the Dashboard	P1
Data processing, both encryption and decryption, successfully verified	P2
Intrusion attempts detected and network access denied	P3

Identification vehicles UAV and UGV, command and monitoring for approaching and precision landing of UAV	P4, P5, P6
Performance results w.r.t. timing constraints, sample rate and system implementation improvements	P7
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	P7, P8

9.8.2.4 UC5-D1-FUN04 - Automatic runtime Path planning

9.8.2.4.1 Strategy

Critical Situation management This sub-functionality concerns the critical situations management. It is going to include the IVV activities of component COMP14:

- FUNC04.IVV1: Critical situations management with compensation and rejection of environmental perturbations, measurement uncertainties with improved situation awareness, will be guaranteed; Predictive power autonomy awareness approaches will be released.

These IVV activities are directly related to the procedures described in the following section.

UC5-D1-FUN04- Automatic runtime Path planning			
Sub-functionality	**IVV Activities**	**Related Component**	**Partner**
Critical Situation management	FUNC04.IVV1	COMP 14	UNIVAQ

9.8.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: Validation of the performances of the proposed control algorithms	Laboratory	Same as COMP 14	FUNC04.IVV1

9.8.2.4.3 Means

Tools	Methods	Linked procedure(s)
Advanced simulation platforms	simulations, testing, engineering reviews	P1

9.8.2.4.4 Results

Outputs	Linked procedure(s)
Autonomous and cooperative flight of UAVs, managing of critical situation with improved situation awareness (obstacle avoidance, constrained communication), compensate and reject unknown environmental perturbations, and measurement uncertainties.	P1

9.8.2.5 UC5-D1-FUN05 - Energy Management System

9.8.2.5.1 Strategy

- FUN05.IVV01: elaboration of the optimal trajectories on the basis of the solution of the optimal control problem from an energetic point of view to carry out a mission. It is necessary offline activity to develop correctly COMP03.

- FUN05.IVV02: fast generation for position and speed energy references, as well as orientation to carry out the mission and to be tested with the use of controllers for their tracking and evaluating battery consumption.

UC5-D1-FUN05- Energy Management System			
Sub-functionality	**IVV Activities**	**Related Component**	**Partner**
Energetic references generator based on optimal control theory	FUN05.IVV01	COMP04	UDANET
	FUN05.IVV02	COMP04	UDANET

9.8.2.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1 - Validation of the performances of the proposed reference generator with control algorithms	Laboratory	Same as COMP04	FUN05.IVV01 and FUN05.IVV02

9.8.2.5.3 Means

Tools	Methods	Linked procedure(s)
COMP04	Simulation, testing and engineering reviews	P1

9.8.2.5.4 Results

Outputs	Linked procedure(s)
Definition of a reference generator of energy trajectories (position, velocities) suitably tested in the laboratory for the execution of the mission, for consumption and appropriate controllers	P1

9.8.2.6 UC5 – D1- FUN06 - Advanced SLAM algorithm and sensing capabilities

9.8.2.6.1 Strategy

- FUN06.IVV01: Elaboration of positioning data on a standalone embedded component
- FUN06.IVV02: SIL simulation of a SLAM algorithm in laboratory to test the efficacy of the procedure
- FUN06.IVV03: Field test of resilient positioning system composed of ultrasound emitter beacons and transceiver mounted onboard. (Due to CoVid limitations, we were able to test the system, but not to improve its accuracy yet).
- FUN06.IVV4: Field test of the spoofing detection module with simulated attack to GPS system. (Due to CoVid limitations, we were able to execute the test once, but the data provided was not enough to train the ML model).

UC5-D1-FUN06- Advanced SLAM algorithm and sensing capabilities			
Sub-functionality	**IVV Activities**	**Related Component**	**Partner**
Drone positioning in the mission area in presence of GPS failures	FUN06.IVV01	COMP01	MODIS
	FUN06.IVV02	COMP02	MODIS
	FUN06.IVV03	COMP09	MODIS
	FUN06.IVV04	COMP15	MODIS

9.8.2.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1 - Validation of the performances of the proposed reference generator with control algorithms	Laboratory	Same as COMP01	FUN06.IVV01 FUN06.IVV02 FUN06.IVV03 FUN06.IVV04

9.8.2.6.3 Means

Tools	*Methods*	*Linked procedure(s)*
COMP01	Simulation, testing and engineering reviews	P1

9.8.2.6.4 Results

Outputs	***Linked procedure(s)***
SW and HW modules to provide a standalone positioning system.	

9.8.3 System Validation

9.8.3.1 Use Case Concept of Operation9.2Strategy

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 *Section Use Case Concept of Operation 11.2.* In particular, the system validation will be carried out through the validation of the functionalities presented in section *Functionalities Identification* [9.4]. Please, notice that the functionality Func 05 is verified in laboratory due to the low TRL of the corresponding component. Therefore, currently it is not planned its involvement in the system validation.

Please, notice that not all the components presented in this deliverable have the same TRL. Indeed, while some components are the results of previous research and projects and are here extended and improved, others have been developed from scratch as result of new research lines. Therefore, some components are not mature enough to be integrated in a real use-case and can be tested only with in-laboratory tests. Furthermore, the COVID-19 situation prevents the possibility of travelling safely, and some integrations that require being physically in the same place are not possible. In this case, some components, although having a TRL high enough for real use case validation, cannot be integrated in the main demonstrator and will be demonstrated with stand-alone PoCs.

The validation plan is composed of 3 different missions, that can be here considered as IVV activities that will incrementally validate the proposed approach.

- **UC5-D1-IVV1**: validate the correct acquisition of images by drones. Images are then validated off-line by the agriculture expert. This IVV activity is connected to **Scenario 5.1.1.**
- **UC5-D1-IVV2**: analysis of 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. This IVV activity is connected to **Scenario 5.1.2.**
- **UC5-D1-IVV3**: validation of the safe cooperation and communication between UAV and UGV. 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.

This IVV activity is connected to **Scenario 5.1.3.**

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.

These IVV activities are directly related to the IVV steps (procedures P1, P2 and P3) reported in the following tables.

9.8.3.1.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
P1: on-board video acquisition and transmission to the control station	*In the field*	The same as: Func 02	UC5-D1-IVV1
P2: on-board video acquisition, elaboration and transmission to the control station.	*In the field*	The same as: Func 01 and Func 02	UC5-D1-IVV1 UC5-D1-IVV2
P3: data exchange among, UAV, UGV and control room.	*In the field*	The same as: Func 01, F02, Func 03, Func 03.1, Func 04, Func 06	UC5-D1-IVV1 UC5-D1-IVV2 UC5-D1-IVV3

9.8.3.1.2 Means

Tools	Methods	Linked procedure(s)
Reception of video flows or images collected by end user and visualized on the dashboard. (C software, communication links)	*The same as components: C03, C18*	*P1*
On-board execution. Reception of data, visualized on the dashboard and collected by the end user (FPGAs, advanced simulation, C software, communication links)	*The same as components: C03, C13 C18*	*P2*
On-board execution. Reception of data, visualized on the dashboard and collected by the end user and tracking of the position of both UAV and UGV (FPGAs, advanced simulation, C software, communication links)	*The same as components: C03, C06, C08, C10, C12, C13, C14, C15, C16, C17, C18*	*P3*

9.8.3.1.3 Results

Outputs	Linked procedure(s)
Image and Video collection and visualization in the Dashboard	P1
Image and Video acquisition, on board processing and data collection and visualization in the Dashboard	P2
Image and Video acquisition, on board processing and data collection and visualization in the Dashboard. Identification and safe coordination vehicles UAV and UGV.	P3

10 UC5-Demo2: Agriculture: Vineyard Demonstrator

10.1 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.

10.2 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 28).

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.

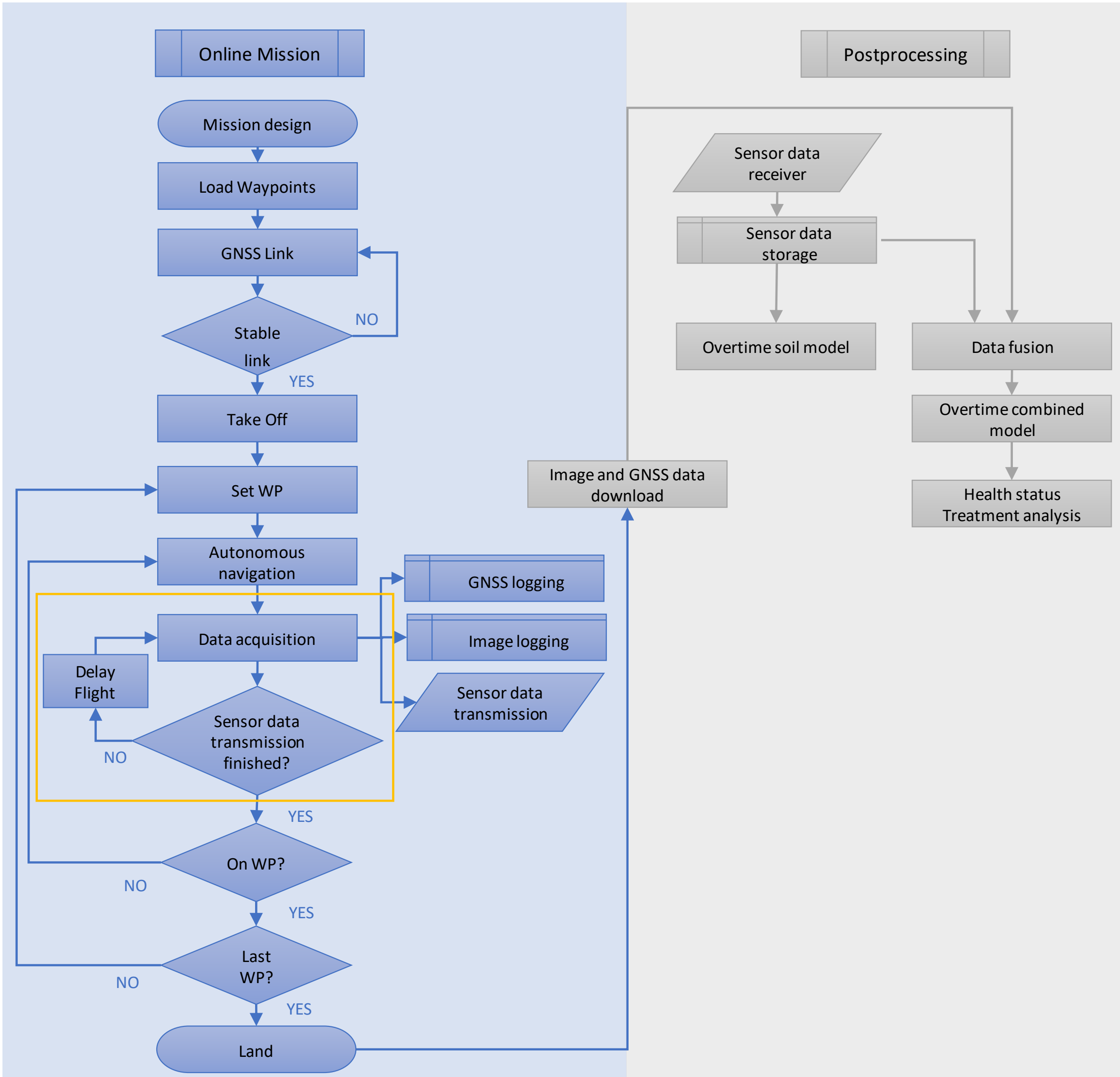


Figure 28 Use case 5 demonstrator 2 concept of operation

10.3 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 76) and their link to the main requirements defined for the use case5 demonstrator2.

10.3.1 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,	No need to go to the vineyard, to get the senor readings and check representative	Time savings per observation phase and condition of at least 50% is expected to be

	health and overall plant status. Based on data analysis performed by the overall drone-based application.	satisfactory conditions, such as health, growth and overall status of the plant manually. Full coverage of vineyard in less time than walkthrough.	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 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.	We assume to confirm a reduction of at least 25% of the number of landbound 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 76 UC5 D2 List of KPIs

10.3.2 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 communication channels (like TLS).	The SE shall accelerate cryptographic operations to establish secure communication channels (e.g. to support TLS handshake operation)	H	Component Provider	UC5-D2-KPI-05

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 77 UC5 D2 List of Main Requirements

10.3.3 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 78 UC5 D2 List of Drone integration Requirements

10.3.4 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 79 UC5 D2 List of Regulatory Requirements

10.4 Functionalities identification

Figure 29 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 80.

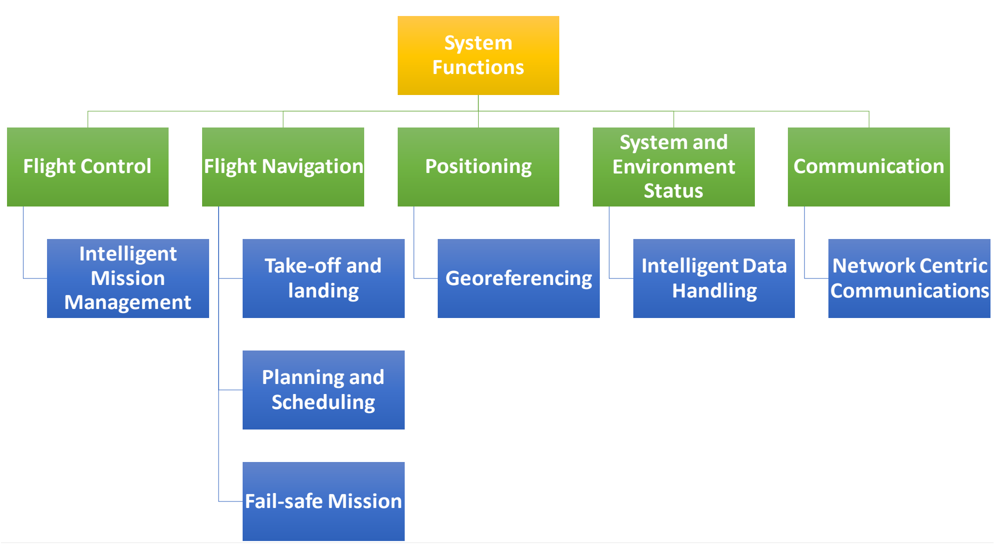


Figure 29 Drone System Functions

Figure 30 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.

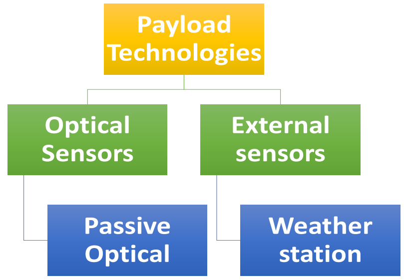


Figure 30 Payload Technologies

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 80 UC5 D1 List of Functionalities

10.5 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 81 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 that can be used for different settings within drone environments. 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 as well as identity privacy guarantees). 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 in a lab environment.

- **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.

As part of Comp4Drones project, we will design and develop Generic Autonomic Management as a component-based REST service 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	DEM 09	COMP 01 WP5-16-AIT	Improve network performance	SC3 .1	MO3 .1	O 3
FB	WP5	Autonomic Management Framework	DEM 09	COMP 02 WP5-17-FB	Improve network security	SC3 .1	MO3 .3	O 3
IFAT	WP5	Hardware Security Component	DEM 09	COMP 03 WP5-14-IFAT	Improve network security	SC3 .1	MO3 .3	O 3

Table 81 UC5 D2 List of components

10.6 Tools

To support the development process of drone components and systems, three tools from the field of system development (see Figure 31) are provided within this UC demonstrator, to reduce the design, validation and verification effort for the development of new drone components and systems (Table 81).

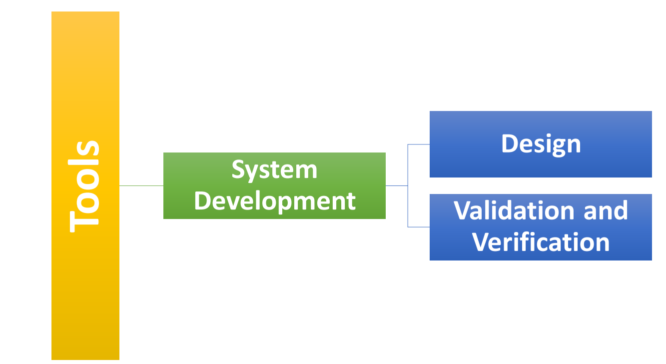


Figure 31 Tools for drone systems

- **TOOL01 WP6-01 - Workflow Engine**
  - A workflow engine will be established which allows the modeling 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 82 UC5 D2 List of Tools

10.7 Traceability matrices

10.7.1 Requirements vs. functionalities

The following Table 83) 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 83 UC1 D1 Requirements and functionalities traceability matrix

10.7.2 Functionalities vs. Components

This section describes which functionalities are implemented by certain components (see Table 84). 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 84 UC1 D1 Components and functionalities traceability matrix

10.8 IVV system plan

10.8.1 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

10.8.1.1 COMP01 - WP5-16-AIT - Cryptographic Primitives and Protocols

10.8.1.1.1 Strategy

The component COMP01-WP5-16-AIT is tested for correctness and validated running on the microcontroller, the (emulated) Secure Element and test backend server. Furthermore, evaluation of the overhead and the performance is done via benchmarks.

10.8.1.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Correctness test of cryptographic protocols used in COMP01-WP5-16-AIT	None, only on protocol level	The authentication and key-exchange primitives do not require any specific input.	Test of the correctness of the cryptographic protocols used in of COMP01-WP5-16-AIT
Validating the correctness of the interplay of implementation of COMP01-WP5-16-AIT	Raspberry Pi, (emulated) Secure Element, test backend server	The authentication and key-exchange primitives do not require any specific input. We will use	Test of the correctness of the interplay of implementation for

		simulated application data whenever required.	COMP01-WP5-16-AIT
Evaluation of overhead and the performance of COMP01-WP5-16-AIT via benchmarks	Raspberry Pi, (emulated) Secure Element, test backend server	The authentication and key-exchange primitives do not require any specific input. We will use simulated application data whenever required.	Evaluation of overhead and the performance for COMP01-WP5-16-AIT

10.8.1.1.3 Means

Tools	Methods	Linked procedure(s)
Raspberry Pi, ARM Cortex (M4), cryptographic libraries	Validation of correctness of the interplay of implementation and evaluation of overhead and performance	Validating the correctness of the interplay of implementation and Evaluation of overhead and the performance of COMP01-WP5-16-AIT

10.8.1.1.4 Results

Outputs	Linked procedure(s)
Correctness of cryptographic protocol	Correctness test of cryptographic protocols used in COMP01-WP5-16-AIT
Correct input-output behaviour for interplay of implementation of COMP01-WP5-16-AIT	Validating the correctness of the interplay of implementation of COMP01-WP5-16-AI
Overhead and the performance measures of COMP01-WP5-16-AIT via benchmarks	Evaluation of overhead and the performance of COMP01-WP5-16-AIT via benchmarks

10.8.1.2 COMP02 - WP5-17-FB - Autonomic Management Framework

10.8.1.2.1 Strategy

The component COMP02-WP5-17-FB is tested for correctness and validated in UC5 Demo2. The Generic Autonomic Management System (GAMS) is deployed at the gateway integrated in the drone. GAMS has a Shared Knowledge, which contains information related to traffic profiles, e.g., expected number of sensor data, which serve as a baseline for normal traffic behaviour. Such profiles can be provided by the industrial partners or can be generated from historical data. During runtime, GAMS monitors the communication between sensor nodes and the drone, compares the actual traffic with the baseline, and sends API calls if suspicious behaviors are detected, which may indicate: (i) possible attacks, or (ii) malfunction of sensor node. An actuator is then used to respectively: (i) change WLAN password of the drone and all sensor nodes except the affected one, or (ii) turn on a red light to notify a possible malfunction of sensor node (in our case we just create a log entry when the number of sensor data is below the lower set point).

After having finalized the implementation of the test case described above, we will implement another test case with GAMS integrated in the backend.

10.8.1.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test cases to validate the correctness of COMP02-WP5-17-FB (GAMS) implementation	Raspberry Pi integrated in the drone, sensor nodes	Sensor Data, System Requirements stored in the SharedKnowledge of GAMS	Validating the correctness of COMP02-WP5-17-FB (GAMS) implementation

10.8.1.2.3 Means

Tools	Methods	Linked procedure(s)
Raspberry Pi integrated in the drone, sensor nodes, Eclipse Arrowhead framework, web services to change the WLAN password in sensor nodes and in drone gateway	Simulating environment – two sensor nodes, one creates valid datasets, and one creates additional datasets (jammer). If GAMS is configured correctly, it should detect this problem and send an API Call to the drone and all sensor nodes, except the affected one, to change the WLAN password	Test cases to validate the correctness of COMP02-WP5-17-FB (GAMS) implementation

10.8.1.2.4 Results

Outputs	Linked procedure(s)
Depending on the adaptation policy, either an API call to invoke a web service for changing the WLAN password, or a Logging Action to create a log entry when the number of sensor data is below the lower set point	Test cases to validate the correctness of COMP02-WP5-17-FB (GAMS) implementation

10.8.1.3 COMP03 - WP5-14-IFAT - Hardware Security Component

10.8.1.3.1 Strategy

UC5-D2-FUN06 requires a hardware security component for supporting the TLS channel establishment. The functionality of this component is tested within this component (COMP03). The described tests cover the main functionality for generation and verification of ECDSA signatures. Therefore the contact-based communication at APDU layer is validated for correct behaviour and respective output of the hardware security component.

10.8.1.3.2 Procedures

The following procedures describe ECDSA signature generation and verification with respective input.

Procedure description	Environment	Planned inputs	IVV Objective(s)
ECDSA signature generation	Test on a Raspberry Pi with connected HSM and respective libraries installed	Dummy data for generating ECDSA signature	Test the correct behaviour of the HSM's signature generation command
ECDSA signature verification	Test on a Raspberry Pi with connected HSM and respective libraries installed	Dummy data for verifying ECDSA signature (same as for generating signature)	Test the correct behaviour of the HSM's signature verification command

10.8.1.3.3 Means

Tools	Methods	Linked procedure(s)
Raspberry Pi, HSM, HSM library	Verify correct behaviour of integrated HSM and respective library by evaluating the output or error value (manual or automatic test possible).	Both procedures (ECDSA signature generation, ECDSA signature verification)

10.8.1.3.4 Results

Outputs	Linked procedure(s)
Correctly HSM generated ECDSA signature	ECDSA signature generation
Successfully verified signature with HSM	ECDSA signature verification

10.8.2 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.

10.8.2.1 UC5-D2-FUN01 - Drone platform

10.8.2.1.1 Strategy

The drone platform is used to integrate a sensor that is communicating with the drone and the landbound sensors. Furthermore, visional sensors like multispectral camera and visual camera are used to collect necessary data for migration of different datasets.

10.8.2.1.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
The drone performs flights in laboratory and real environment and has possibility to operate autonomous	Real environment	Flight path and operation requirements	Real flights for data collection

10.8.2.1.3 Means

Tools	Methods	Linked procedure(s)
Drone equipped with payload (cameras and land bound sensor data transmission	Payload data is sent through link to remote location.	Real flights

10.8.2.1.4 Results

Outputs	Linked procedure(s)
Collected data (sensor readings) from land bound sensors and other sensors (visual)	Real flights

10.8.2.2 UC5-D2-FUN02- High resolution visual and multispectral camera

10.8.2.2.1 Strategy

High resolution visual and multispectral cameras for evaluating soil productivity and analysing plant health are used to collect data of plant leaves and soil.

10.8.2.2.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Image capture during predefined autonomous drone missions.	Real environment		Data collection for analysis

10.8.2.2.3 Means

Tools	Methods	Linked procedure(s)
Visual and multispectral cameras	Autonomous data collection and processing	Data collection, drone flights, processing

10.8.2.2.4 Results

Outputs	Linked procedure(s)
Ndvi maps, rgb images	Sensor data collection

10.8.2.3 UC5-D2-FUN03- Land-bound sensor

10.8.2.3.1 Strategy

The sensor nodes are tested for correctness in a real vineyard environment.

10.8.2.3.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Testing the sensor nodes by collecting data in the vineyards (temperature, humidity, etc.) and sending them to a Data Collection Unit (DCU) via drone as a gateway	Vineyard, sensor nodes, drone, Data Collection Unit (DCU)	Sensor data (temperature, humidity, etc.)	Testing sensor nodes in a real vineyard environment

10.8.2.3.3 Means

Tools	Methods	Linked procedure(s)
Sensor node (Raspberry Pi connected to several sensors, such as air temperature and humidity sensor, leaf wetness sensor, etc.), Raspberry Pi integrated in the drone, DCU (a Debian system installed in a virtual machine)	A web server is used to transfer sensor data from the sensor nodes to drone gateway via HTTPs. It has a python3 script that reads the sensor information and writes it in a .csv file. Drone gateway has also a web server that receives the .csv files from the sensor nodes and sends them to the DCU	Testing the sensor nodes by collecting data in the vineyards (temperature, humidity, etc.) and sending them to a Data Collection Unit (DCU) via drone as a gateway

10.8.2.3.4 Results

Outputs	Linked procedure(s)
Sensor data collected from the vineyard and transferred as .csv file to the DCU via drone gateway	Testing the sensor nodes by collecting data in the vineyards (temperature, humidity, etc.) and sending them to a Data Collection Unit (DCU) via drone as a gateway

10.8.2.4 UC5-D2-FUN04 - Data fusing and analysis

10.8.2.4.1 Strategy

Data processing of multispectral images will be combined with data of the landbound sensors in order to get more details of plant health and soil.

10.8.2.4.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Processes drone data and collected sensor data of landbound sensors	Real environment	Visual image data Sensor data Multispectral images	Fusion of datasets

10.8.2.4.3 Means

Tools	Methods	Linked procedure(s)
Fields- software	Postprocessing step to merge the data of the video and multispectral images, as well as the measurements of the sensor on the ground based on their geographical position.	Real flights

10.8.2.4.4 Results

Outputs	Linked procedure(s)
Customers data to analyse field health	Drone flights Data collection

10.8.2.5 UC5-D2-FUN05 - Trustworthy and reliable data collection

10.8.2.5.1 Strategy

The Eclipse Arrowhead web services invoked during the automated and secure onboarding procedure are tested for correctness and validated in UC5 Demo2. All use case components (device, systems and services) get unique IDs and digital certificates (X.509) through the onboarding procedure, which are separately stored in DeviceRegistry, SystemRegistry and ServiceRegistry systems of Eclipse Arrowhead framework. This will ensure a secure and trusted communication between the use case components.

For test purposes in the scope of Comp4Drones, the certificate is pre-installed by a special IFAT-tool into the IFAT-HSM. Only in a productive environment/release however, such a procedure would have to be integrated into the Arrowhead Framework.

10.8.2.5.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test cases to validate the automated and secure onboarding procedure provided by Eclipse Arrowhead IoT framework	Sensor nodes, drone, DCU, base station	Valid certificates of all use case components involved in the end-to-end communication	Validating the correctness of Eclipse Arrowhead onboarding procedure

10.8.2.5.3 Means

Tools	Methods	Linked procedure(s)
Eclipse Arrowhead web services invoked during the automated and secure onboarding procedure	Establishing a communication between sensor nodes and drone, and drone and base station to test if the onboarding procedure services are properly functioning	Test cases to validate the automated and secure onboarding procedure provided by Eclipse Arrowhead IoT framework

10.8.2.5.4 Results

Outputs	Linked procedure(s)
X.509-based authentication and authorization of all use case components involved in the end-to-end communication	Test cases to validate the automated and secure onboarding procedure provided by Eclipse Arrowhead IoT framework

10.8.2.6 UC5-D2-FUN06 - HW-Support for Secured Communication Establishment

10.8.2.6.1 Strategy

The HSM supported establishment of a TLS channel will be verified in this section. Further, it will be validated if the HSM-support is used during connection establishment, in contrast to pure software implementations of the channel establishment procedure. Meaning a cross-check of actual HSM usage is described.

10.8.2.6.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Establishment of HSM-supported TLS channel	Test on a Raspberry Pi with connected HSM and respective libraries installed	Respective client/drone and server certificates for connection establishment (client/drone certificate is linked to private key stored within the HSM)	Verify that the TLS communication channel is successfully established between two Raspberry Pis
Validation of actual HSM usage	Test on a Raspberry Pi with connected HSM and respective libraries installed	Respective client/drone and server certificates for TLS connection establishment (client/drone certificate is linked to private key stored within the HSM)	E.g. for drone system integrators to validate that connected HSM is actually used for TLS communication channel establishment instead of pure software implementation

10.8.2.6.3 Means

Tools	Methods	Linked procedure(s)
Raspberry Pi, HSM, HSM library	Verify successful TLS communication channel establishment (agnostic of underlying network connection)	Establishment of HSM supported TLS channel
Raspberry Pi, HSM, HSM library	Falsification of usage of pure software implementation	Validation of actual HSM usage

10.8.2.6.4 Results

Outputs	Linked procedure(s)
Successfully established communication channel which is ready to use for protected data exchange	Establishment of HSM supported TLS channel
Error message returning that TLS channel could not be established successfully with software implementation due to use of wrong private key. (Explanation: Since the private-key is generated inside of HSM, the pure software-TLS could have/use this key)	Validation of actual HSM usage

10.8.2.7 UC5-D2-FUN07 - Autonomic Computing based on MAPE-K Feedback Loop

10.8.2.7.1 Strategy

At this stage of the project, we have designed and developed Generic Autonomic Management System (GAMS) as part of Eclipse Arrowhead framework. In Arrowhead, each system should register its produced services in the ServiceRegistry system and should consume at least the other two mandatory core system, Authorization and Orchestrator.

Following is provided some background information of the mandatory core systems of Arrowhead. ServiceRegistry system provides the database, which stores information related to the currently actively offered services within the Arrowhead local cloud. These services can be invoked during runtime from other service consumers. Authorization system has a database that describes which application system can consume what services from which application systems (intra-cloud access rules) and a database that describes which other local clouds are allowed to consume what services from this cloud (inter-cloud authorization rules). Orchestrator system provides run-time binding between application systems. The purpose of the Orchestrator system is to provide application systems with orchestration information, where they need to connect to. The outcome of the Orchestration service includes rules that will tell the application system what service provider system(s) it should connect to and how. Such orchestration rules include accessibility information details of a service provider (e.g., network address and port), details of the service instance within the provider system (e.g., base URL, Interface Design Description specification and other metadata), authorization-related information (e.g., access token and signature) and additional information that is necessary for establishing connection.

Thus, it should be verified if GAMS is developed correctly and can properly interact with the core services of Arrowhead.

10.8.2.7.2 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
Test cases to validate the correctness of GAMS implementation in Eclipse Arrowhead framework	Sensor nodes, drone, DCU	The GenericAutonomicManagement service produced by GAMS, has a Publish operation that is used to send new sensor readings to the service triggered by a PublishSensorDataRequest. The input through sensors, or the lack thereof, feeds the MAPE-K control loop of GAMS and eventually triggers a change on an actuator.	Validating the correctness of GAMS implementation in Eclipse Arrowhead framework

10.8.2.7.3 Means

Tools	Methods	Linked procedure(s)
GAMS is integrated in the Raspberry Pi in the drone, Eclipse Arrowhead mandatory core systems are integrated in the DCU	GAMS produces the GenericAutonomicManagement service, which should be registered in the ServiceRegistry. As soon as the service is registered, any application system (sensor nodes producing sensor data) can invoke it by getting its endpoint from the Orchestrator system (if authorized from the Authorization system)	Test cases to validate the correctness of GAMS implementation as part of Eclipse Arrowhead framework

10.8.2.7.4 Results

Outputs	Linked procedure(s)
GenericAutonomicManagement service produced by GAMS can be consumed by application systems (in our use case, the sensor nodes)	Test cases to validate the correctness of GAMS implementation as part of Eclipse Arrowhead framework

10.8.3 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 plant 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.

10.8.3.1 Strategy

The strategy for system validation of the demonstrator is based on an extensive field test under real conditions. During this mission a vineyard is flown over and pictures of the plants and the soil are taken with a multispectral or RGB camera. Furthermore, the measurements from sensors on the ground at previously defined waypoints are collected and forwarded to a ground station, with the focus here on trusted communication.

The evaluation of the image and sensor data takes place in a post-processing step and is not part of the mission scenario.

10.8.3.2 Scenario 1

10.8.3.2.1 Procedures

Procedure description	Environment	Planned inputs	IVV Objective(s)
• UAV takes off • UAV follows a defined waypoint list for the image acquisition • UAV stops at specific waypoints to collect the	Real environment (vineyard)	Defined waypoint list to be able to cover whole vineyard (predefined waypoints for communication with the sensor nodes)	Validate the trusted and trustworthy transmission of sensor reading

data from land bound sensors • when the transfer is finished, the flight will resume (data submission to base station) • when the route is complete, and all sensor data have been read, the UAV lands			

10.8.3.2.2 Means

Tools	Methods	Linked procedure(s)
IFAT-HSM-component	Configure TLS communication establishment to use the “IFAT-HSM-component" as a “security-addon” instead of pure standard software-based TLS.	UC5-D2-FUN06
FB-GAMS-component, Eclipse Arrowhead	Configure GAMS to monitor the communication between sensor nodes and the drone and send API calls if unexpected situations occur, e.g., possible attacks or malfunction of sensor nodes. All communication should be done through Eclipse Arrowhead to ensure authentication and authorization.	UC5-D2-FUN03 UC5-D2-FUN05 UC5-D2-FUN07

10.8.3.2.3 Results

Outputs	Linked procedure(s)
Validation of the correct implementation of the communication channels through the transmission of sensor data as well as image data acquisition for postprocessing	Real flights

11 Conclusion

This deliverable describes the demonstrators included in the Comp4drones project, providing information on the technologies that are to be used including main technical requirements and functionalities of each demonstrator to meet different business KPIs and project objectives. All the information furnished within this document is related to each other and is connected to other deliverables, finally, as described the validation plan will allow monitoring of results and reporting of the achievements that are set by 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 certain challenges faced during the development of the components/tools, new requirements or changes in the validation plan is to be added to the final version.