DELIVERABLE

D1.1 – Specification of Industrial Use Cases

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Abstract (few lines):	This deliverable focuses on the description of the Use-Cases: their overview, their KPIs and requirements

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Definitions, Acronyms and Abbreviations

Acronym	Title
BIM	Building Information Modeling
C2	Command and Control
COTS	Commercial Off-The-Shelf
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

Executive Summary

Deliverable D1.1 aims at presenting all the use cases that will drive the project. Those use cases are composed of several demonstrators (2 to 3). The variety of contexts, applications and services provided require a thorough introduction of these demonstrators. Each demonstrator provides an overview, how it contributes to C4D objectives and how it will be implemented. In order to evaluate the impact of the work carried out during the project, they define indicators (KPIs) and the mission scenarios. In addition, a requirement gathering is performed to state the high-level needs that will be further decomposed in later deliverables. Deliverable D1.2 will further build the indicator to obtain a suitable benchmark. Deliverable D2.2 will present the state of the art of the different domains necessary to build the systems to achieve the demonstrators.

1 Introduction

Drones/UAVs can perform air operations that manned aircrafts struggle with, and their use brings significant economic savings and environmental benefits whilst reducing the risk to human life. Drone-based service and product innovation, as driven by increased levels of connectivity and automation, is limited by the growing dependence on poorly interoperable proprietary technologies and the risks posed to people, to other vehicles and to property. SESAR JU identified that issue has a high impact on European innovation, which demands R&D investments and incentives for the convergence of shared technologies and markets as a remedy. Actions creating globally harmonized, commercially exploitable yet widely accessible R&D ecosystems should be publicly performed.

The goal of Comp4Drones is to build a framework of tools and components that allows to build UAV systems. It relies on a composable architecture in which component providers bring the features thanks to their components. However, the design, development and verification processes require to be demonstrated in real-life experiments. Those demonstrators shall encompass a significant part of the variety of applications for the domain.

This deliverable focuses on presenting the demonstrators and justify their relevance as means to challenge the harmonised framework. The demonstrators are grouped in use cases that represent high-level class of applications (i.e., transport, construction, logistics, surveillance, inspection and agriculture). This document details, for each demonstrator, its context and how it allows to address the top-level objectives of C4D project.

Solution providers will build systems using the components from the component providers in order to fulfil the demonstrator missions. This deliverable identifies the initial components that will be integrated and validated in each use case and demonstrator. Although, the level of realisation shall be assessed. Hence, each demonstrator defines Key Performance Indicators (KPIs) that will allow this measure. KPIs have been defined at Business and Technical level in order for the project to assess its impact in those two perspectives.

In order to have a more precise description of their needs, the demonstrators are gathering the features they depend upon expressed as requirements. Those requirements will be furthered developed and refined in the technical-workpackage deliverables. Although, they are already effective at defining the demonstrators, their scope and challenges.

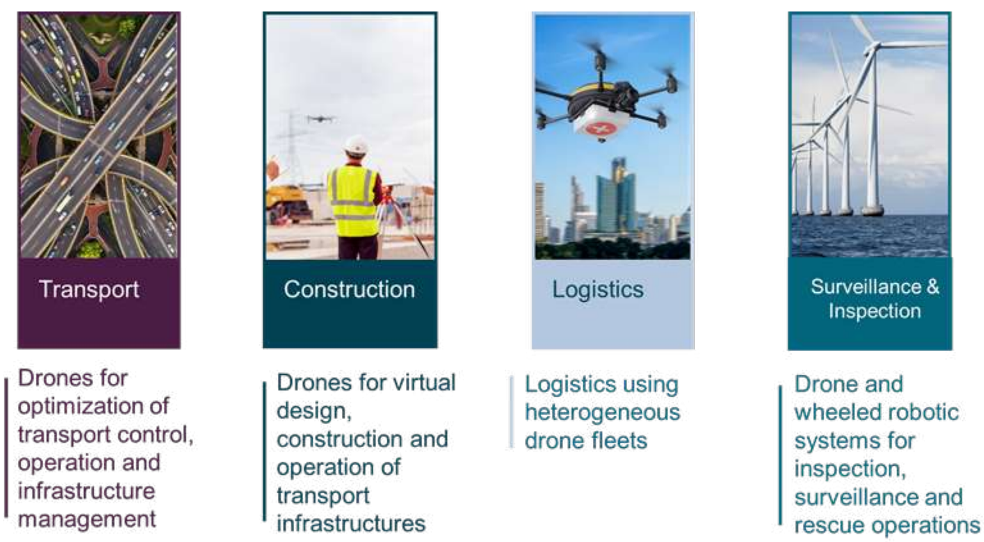
2 Use Cases Overview

2.1 Presentation of the Use Cases theme

Demonstration and validation activities are essential to ensure the quality and relevance of innovations. COMP4DRONES achievements will be benchmarked and demonstrated through the following domain specific use cases. These use cases are composed of several demonstrators (from 2 to 3) that will be detailed in the next sections:

- UC1 – Transport (Leader: INDRA - Spain): application of drones for optimization of transport control, operation and infrastructure management.
- UC2 – Construction (Leader: ACCIONA - Spain): smart application of drones for virtual design, construction and operation of transport infrastructures.
- UC3 – Logistics (Leader: TOTAL - France): logistic using heterogeneous drones' fleet.
- UC4 – Surveillances & Inspection (Leader: Thales - Netherlands): drone and wheeled robotic systems for inspection, surveillance and rescue operations with enhanced navigation and autonomous abilities.
- UC5 – Agriculture (Leader: AIT - Austria): smart and precision agriculture from drone to rover.

Nevertheless, COMP4DRONES framework could be used for other related application domains that should use autonomous or remotely piloted vehicles.



2.2 Measure Use Cases outcome

During the project it is necessary to assess the progress of the Use Cases, but most importantly to measure the contribution of the technical work-packages to the completion of the demonstrators. The end-users of the different demonstrators define Key Performance Indicators. In order to have relevant KPIs they must be SMART as defined by Basuki 2017[1]:

[1] Developing it security metrics with goal question metric approach and smart criteria, Augustono Basuki, December 2017. Link

- **Specific**—which means that metric that is collected measures specific attribute of a particular entity.
- **Measurable**—which means that the metric uses data that can realistically be obtained from existing processes and data repositories.
- **Actionable**—which means that the result can be acted upon, can provide decision support, thus facilitates improvement.
- **Relevant**—which means that the metric contributes to answering question that is based on the needs and requirements of the organization. This criterion is also consistent with GQM (Goal-Question-Metrics) method that states that metrics should be tied to a goal an organization is trying to achieve.
- **Timely**—which means that data for the metric must be available in a period of time that let them be acted upon.

2.3 Use cases boundary conditions and applicable regulations

Each demonstrator describes, in a dedicated section, its boundary conditions. The cover the operation limits but also the regulations the demonstrator will comply to. However, this analysis on the regulations is limited in this document since another deliverable is focused on this topic. For more information, please refer to: “***D2.5***-*Drones regulations compliance handbook*”

3 Requirements Gathering Methodology

This section reports the methodology adopted to define the requirements related to the COMP4DRONES use cases. In the following paragraphs the type of requirements, the adopted notation and the requirement code conventions are described. In this deliverable, the main requirements have been gathered for each UC. Besides an Excel file, provided with this deliverable, gathers all the requirements.

Requirements play major roles as they:

- Form the basis of system architecture and design activities
- Form the basis of system integration and verification activities
- Act as reference for validation and stakeholder acceptance
- Provide a means of communication between the various technical staff that interact throughout the project.

According to the IEEE Standard Glossary of Software Engineering Terminology[2], a requirement is:

1. A condition or capability needed by a user to solve a problem or achieve an objective
2. A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents
3. A documented representation of a condition or capability as in (1) or (2)

COMP4DRONES use Cases requirements are classified into the following types:

Functional Requirement	A requirement that specifies a function that a system, or system component, must be able to perform. A requirement specifying what the overall system, or a specific component, will be able to do. Statements of services that the system should provide, how the system should react to particular inputs and how the system should behave in particular situations. Among the functional requirements are also included security requirements relating to the security services offered by the system to users or other systems.
Non-Functional Requirement	A requirement specifying how the system or component will implement its functionality. In this document the following non-functional types of requirements are considered: • Interface Requirements • Performance Requirements • Security Requirements • Operational Requirements • Usability Requirements • Policies & Compliance Requirements • Design Constraints • Ethical Requirements • Other Requirements.

Table 1 - Requirements main types

[2] https://ieeexplore.ieee.org/document/159342/definitions#definitions

The classification between the different levels for the requirements has been established in the Deliverable D2.2 Methodology and Workflow.

3.1 Requirements Types

Requirement Type	Req ID	Requirement Description
Functional Requirement	**FNC**	Functional Requirements describe the behaviour and information that the solution will manage. In the case of a non-system solution, the behaviour typically refers to a workflow and the information refers to the inputs and outputs of the workflow. Additionally, the requirements describe how the data will be transformed and by whom. In the case of a system solution, the functional requirements describe the features and functionality of the system as well as the information that will be created, edited, updated, and deleted by the system.
Interface Requirement	**INT**	Interface requirements define how the system is required to interact or to exchange information with external systems (external interface), or how system elements within the system interact with each other (internal interface). Interface requirements include physical connections (physical interfaces) with external systems or internal system elements supporting interactions or exchanges. External interface requirements are important for embedded systems and outline how your product will interface with other components. There are several types of interfaces you may have requirements for, including: • Hardware: Describe the logical and physical characteristics of each interface between the software product and the hardware components of the system. • Software: Describe the connections between this product and other specific software components (name and version), including databases, operating systems, tools, libraries, and integrated commercial components. Identify data that will be shared across software components. • Communications: Describe the requirements associated with any communications functions required by this product, including e-mail, web browser, network server communications protocols, electronic forms, and so on. Identify any communication standards that will be used, such as FTP or HTTP. Specify any communication security or encryption issues, data transfer rates, and synchronization mechanisms.
Performance Requirement	**PRF**	Performance requirements can refer to individual functional requirements or features (e.g., speed of response for a certain functionality).

Security Requirement	**SEC**	Security requirements are related to both the facility that houses the system(s) and the operational security requirements of the system itself. This could include the factors that would protect the system from accidental or malicious access, use, modification, destruction, or disclosure. In safety-critical embedded systems this might incorporate a distributed log or history of data sets, the assignment of certain functions to different single systems, or the restriction of communications between some areas of the system. Examples: • Access requirements • Integrity requirements • Privacy requirements
Operational Requirement	**OPR**	These requirements define the operational conditions or properties that are required for the system to operate or exist. This type of requirement includes: • Delivery mode • Access mode • Availability • Maintainability • Reliability • Capacity • Scalability • Portability • Installation
Usability Requirement	**USB**	These requirements define the quality of system use such as: • Environment of use • Appearance and style • Ease of use • Internationalization • Accessibility
Policies & Compliance Requirement	**P&C**	These requirements identify relevant and applicable organizational policies or regulatory requirements that could affect the operation or performance of the system(s). Examples: Laws and regulations, standards, business rules.
Environmental Requirement	**ENV**	Environmental Requirements, which identify the environmental conditions to be encountered by the system in its different operational modes. This should address the natural environment (e.g., wind, rain, temperature, fauna, salt, dust, radiation, etc.), induced and/or self-induced environmental effects (e.g., motion, shock, noise, electromagnetism, thermal, etc.), and threats to societal environment (e.g., legal, political, economic, social, business, etc.).
Design Constraint	**DSG**	These requirements are mainly imposed by regulation, integration and/or evolution with existing design.
Ethical Requirement	**ETH**	To avoid confusion, “ethical requirements”, as understood here, are requirements that include intentional actions that impact negatively or positively the lives and values of others.
Other Requirements	**OTR**	Any other requirement that cannot be classified with the above categories.

Table 2 - Requirements detailed types

3.2 Requirement Identification

The COMP4DRONES Use Case requirements will be uniquely identified by an alphanumeric code consisting of:

<Demonstrator number>-*<classification>*-*<number>*, where:

<Use Case ID>	**UC1**	**Transport** (INDRA) Application of drones for optimization of transport control, operation and infrastructure management	
		DEM1	Road Transport Traffic Management & Monitoring and Incident Detection
		DEM2	Port Infrastructure Supervision and Maritime Drone Applications
		DEM3	Routine monitoring of railways infrastructure
	UC2	**Construction** (ACCIONA) Smart Application of drones for virtual design, construction and operation of transport infrastructures	
		DEM1	Digitalisation of the state of the constructive process of a civil infrastructure
		DEM2	Analysis of the status of constructive process in underground constructions
	UC3	**Logistics** (TOTAL) Logistic using heterogeneous drones fleet	
		DEM1	Deployment of an Autonomous Communication System in hard-to-access areas thanks to a Highly Automated Multi-Vehicles System
		DEM2	Logistics in 5G urban environment: Clinical Sample delivery in Hospital campus
	UC4	**Surveillance and Inspection** (THALES-NL) Drone and wheeled robotic systems for inspection, surveillance and rescue operations with enhanced navigation and autonomous abilities	
		DEM1	Inspection of offshore turbines structure with hyperspectral technology carried by drones
		DEM2	Fleet of multi robot navigating and mapping in an unknown environment
	UC5	**Agriculture** (AIT) Smart and Precision Agriculture: From drone to rover	
		DEM1	Wine production specific tasks Demonstrator
		DEM2	Drone with sensory equipment in agricultural area
<classification>	**FNC**	Functional Requirements	
	INT	Interface Requirements	
	PRF	Performance Requirements	
	SEC	Security Requirements	
	OPR	Operational Requirements	
	USB	Usability Requirements	
	P&C	Policies & Compliance Requirements	
	DSG	Design Constraints	
	ETH	Ethical Requirements	
	OTR	Other Requirements	
<number>	A progressive number that uniquely identifies the requirement within a requirement type and a Use Case particular demo.		

Table 3 - Requirement ID composition

Example:

UC1-DEM2-USB-01 → Use Case: 1, Demonstrator: DEM2, Requirement type: Usability Requirement, Requirement number: 01

3.3 Requirement Principles

The following principles apply:

Characteristics	Specific requirements should comply with the following characteristics: Unambiguous Complete Consistent Ranked for importance and/or stability Verifiable Modifiable Traceable
Cross-references	Specific requirements should be cross-referenced to earlier documents that they relate to.
Readability	Careful attention should be given to organizing the requirements to maximize readability.
IDs	All requirements should be uniquely identifiable (via ID).

Table 4 - Requirements principles

Each requirement should also be **testable**.

3.4 Requirement Attributes

Each requirement will be classified according to the following ***Priority***:

Priority	Feature	How to describe it
High	A required, must have feature	The system **shall**…
Medium	A desired feature, but may be deferred till later	The system **should**…
Low	An optional, nice-to-have feature that may never make it to implementation	The system **may**…

Table 5 - Requirements priority levels

The ***Source*** field identifies the origin of the requirement i.e., where/whom it comes from.

The ***STO (Specific Technological Objective)*** fields describe the relationship between the requirement and the WP3-WP6 work-packages (building blocks), i.e.:

- If/how the requirement will have some impact on WP3-6 modules
- If the requirement foresees the usage of a WP3-6 module

If the requirement foresees a non-COMP4DRONES module or tech to be used, that is to be specified in the ***Other*** field.

Objective	STO	Description
O1	STO1	Integrated Modular Architecture for Drones
O2	STO2	Safe Intelligent Navigation

O3	STO3	Trusted Communication
O4	STO4	Design, Performance and Verification Tools

Table 6 - Project objectives

3.5 Requirements naming uniformity

The writing of this document was started early in the project however each demonstrator had already started requirements identification. The naming convention was not ready so they adopted one that is close to the current presented above. In order to prevent any traceability issues, it was decided to keep their names. A document delivered with this deliverables lists all the requirements and also links the “usage” requirements ID with the “uniform” IDs.

Deliverable D1.2 will focus more on the traceability between high-level requirements and technical ones, but also their traceability in the validation process. The use-cases will present their methodology to assess the completion of the requirements measured thanks to the tests and demo flights. Additionally, tools dedicated to this purpose are presented in the deliverables from WP6.

3.6 Drone autonomy classification

The demonstrators showcase different level of drone autonomy. In order to demonstrate this level for each demonstrator, a common classification has been used. Figure 1 presents the different levels of autonomy, and each demonstrator mentions its level according to this classification.

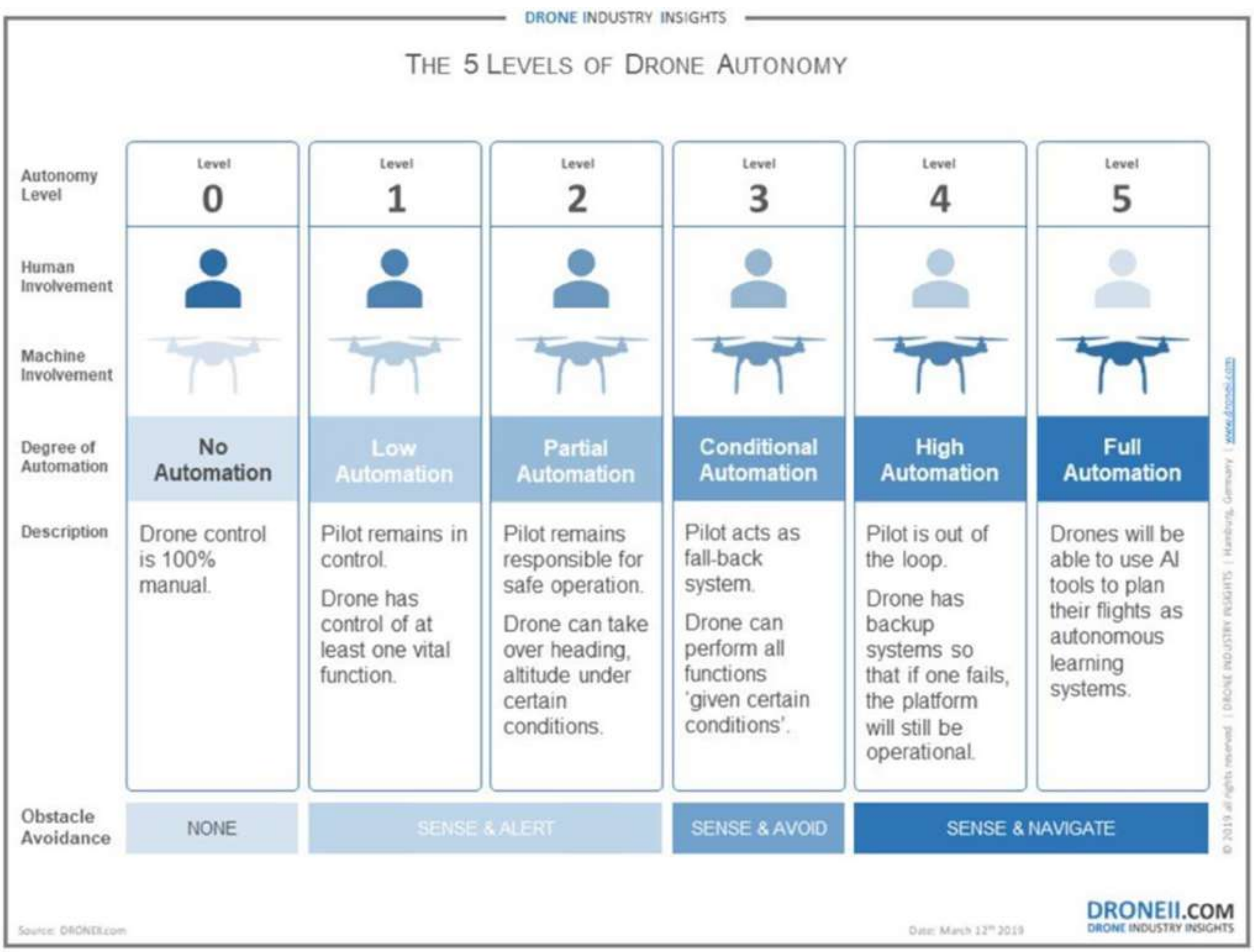


Figure 1 - Classification of drone autonomy level

4 UC1: Transport

4.1 Overall motivation and ambition of the Use Case

This use case will demonstrate the technology developed in COMP4DRONES in the Transport domain with the use of drones as sensors and monitoring devices for different transport infrastructures. The main applications will be:

- Detection and early response to traffic incidents.
- Support applications in ports.
- Railway infrastructure full-cycle: from inspection phase to maintenance.

Three demonstrators will be deployed in this use case: Traffic Management, Port Operations and Railway Infrastructure.

Figure 2 - UC1: Overview of the three demos

4.1.1 Use Case concept and challenges

When there's an incident happening on the transport infrastructure, or there's an activity scheduled to be performed, the infrastructure is equipped with cameras, sensors and other devices that transmit information to the operators and control centres, sometimes in real time so the operators can take the needed actions. However, there are incidents occurring in areas that are not being monitored by any equipment in the infrastructure and/or in areas that are hard to access. For these situations, current solutions lack of a rapid response time, clear real-time view/information of what is going on, thus limiting the capacity of response.

Drones can also become key players in the monitoring and operation of transport infrastructures, in particular, due to their flexibility to take images/video and easy access to areas that may be congested or difficult to access and even to locate accidents in an early manner.

The ambition of this use case is to optimize and enhance transport control, operation and infrastructure management activities, such as traffic management (traffic status and incidents), monitoring and maintenance of the transport infrastructure with the use of drones.

This use case will develop, deploy and test an integrated drone solution for drone operators, transport infrastructure managers and transport control centers.

The main challenges of this use case are:

- Provide broadcast of real-time HD video from hard-to-access areas in different conditions.
- Ensure safety during flight in geofenced area.
- Ensure air space availability and exclusivity to emergency services.
- Fast actuation of road and public authorities and prompt response to incidents.
- Perform BLVOS flights for long-distances and operations covering extensive transport infrastructures.

4.1.2 Use Case objectives

This use case will target the following main objectives:

- Secure deployment of drones as monitoring devices of the road traffic conditions and the detection and early response to incidents.
- Safe integration of drones into the airspace and daily transport operations.
- Automatize the usage of drones in transport infrastructure operations and incident management.

4.1.3 Contribution to project objectives

Contribution to Project Objectives.

Proposal Objective	Use Case Contribution	Measurable Outcomes
O1: Easing the integration and customization of drone embedded system	Customization of non-civil drones into civil drones for transport applications taking as a reference the **COMP4DRONES** architecture. Integration and customization of drones as "new sensors" to existing transport monitoring systems	Initial non-civil drone platform with a wide range of integrated sensors for transport applications
O2: Enabling drones to Integrate intelligent perception for safe control loops	Drones will integrate new sensors on-board to develop perception algorithms that process data from drones' surrounding remotely	Algorithms to extract information from video / image capture by drones
O3: Ensuring the deployment of trusted communications	Trustworthy communications over 4G to ensure communication between the drone and the transport control center to monitor the transport infrastructure	Secure communication channel for sending/receiving information to/from drones
O4: Optimize the design and verification effort for complex drone applications	Development of processing modules for capturing processing and analysing images and videos generated by cameras on-board in drones	Tested and validated transport application
O5: Ensuring sustainable impact and creation of an industry-driven community	Indra will bring their test facilities to validate the project developments in order to sustain the "Rozas" Aerodrome ecosystem as a key element in the Spanish drone sector	Additional partners will be involved in the Rozas environment with the project

Table 7 - UC1: Contribution to project general objectives

Contribution to COMP4DRONES Technical Objectives:

Proposal Technical Objective	Use Case Contribution
ST01: Integrated Modular Platform	Integrate new sensors and components in the following drones manufactured by Indra and other providers
ST02: Safe Intelligent Navigations	Develop the relevant database of images/video from different type of drones used to monitor the port infrastructure. Develop specific AI algorithms
ST03: Trusted Communication	Develop trustworthy communication modules over 4G to ensure encrypted communication channels around the drone applications
ST04: Design, Performance and Verification Tools	Simplified design/integration of system components

Table 8 - UC1: Contribution to project technical objectives

4.1.4 Boundary conditions

Name	Short Description

Weather conditions	According to Spanish civil regulations, flights are to be performed under VMC (Visual Meteorological Conditions) and therefore, during daylight time.
Spanish National regulations and European Regulations	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. All the flights performed in this use case will be performed under this regulatory framework and the protocols of the bodies and agencies EASA, AESA, Enaire.
Flight Time	In Demo 1 the flight time of the Mantis drone is limited to 60min.
Line of Sight	In Demo 1 the maximum distance of the Mantis drone is limited to 10km.
Height	In Demo 1 the height of the Mantis drone is limited to 100m. In Demo 2 the height of the captive drone is limited to 25m.

Table 9 - UC1: Boundary conditions

4.1.1 Traceability methodology

All of the features and subsystems in each of the demonstrators of the use case are linked to requirements, KPIs and technical components that will be developed in the technical work packages. Each requirement is also linked to a flight stage and mission application, so its verification and validation can be performed at each stage when the demonstrators are deployed.

Each demonstrator has its own test campaign plan. D1.2 will detail the verification and validation plans to be performed in each campaign, linking the requirements and KPIs that will be evaluated during the test cases. Each test and campaign result will assess the progress of the fulfilment of the requirements, and KPIs, indicating whether the requirement has been successfully addressed, failed, or hasn´t been evaluated in the test.

This progress will be assessed using a detailed excel file in which each requirement will be evaluated regarding its level of completeness (% of work completed) and results (successful, failed to achieve or not performed) Also, each KPI will provide its own verification method, which will be explained in detail in D1.2.

4.2 Demonstrator 1

4.2.1 Justification Plan

4.2.1.1 Demonstrator overview

This demonstrator will focus on the deployment of drones as monitoring devices of the road traffic conditions and the detection and early response to incidents. The drone facilities will incorporate capabilities to request a drone's flight over an area of the infrastructure identified by its operators. The objective is to apply the use of drones to improve the efficiency and automation of monitoring activities, as well as to lower their costs, upgrade the control and maintenance of transportation operations and their infrastructure, offering greater flexibility and stability in solutions and services.

Up until now, the usage of drones by Spanish transport operators and road authorities has been limited to test pilots. Current applications involving drones are not integrated into the transport control center - platform/system. With this demonstrator, the ambition is to widen the spectrum of traffic incidents and locations that could benefit from drone services (enhance safety in the operations of road management) by reducing the response time to the incident location, the risk and exposure to danger for the road agents, and the accident investigation time as accurate and detailed data is collected in less time and provide high quality images/data of the incident in real time from different angles, with the ability to cover multiple road points and large area extensions, accessing difficult areas and adding new image capabilities.

This demonstrator will use drones as sensors for current transportation monitoring systems. It will develop image and video processing tools based on graphics cards as well as artificial intelligence and deep learning technologies to analyze video and images taken by the drones, so that incidents can be automatically detected.

It will integrate Indra's transportation management solution (HORUS) with its own unmanned aircraft system traffic management (UTM) platform in low-altitude airspace and its Drone Mission and Data Processing Center (CMPD), thus creating a pioneering comprehensive solution for intermodal mobility, unprecedented in the market, which will provide infrastructure managers with an array of new and secure drone applications.

This application will be deployed at the Rozas Aerodrome in Lugo (Spain), part of the Civil UAVs Initiative, a Xunta de Galicia project that is the driving force of the unmanned aerial systems for civil applications sector in Europe, in which Indra acts as an anchor company.

In addition, this demonstrator will use Indra's Mantis fixed-wing drone, developing a civil use version for innovative transportation applications. Among other improvements, Indra will work on the detection capabilities of Mantis, in order to facilitate both the processing and the analysis of the images and videos obtained.

4.2.1.2 Description and scope

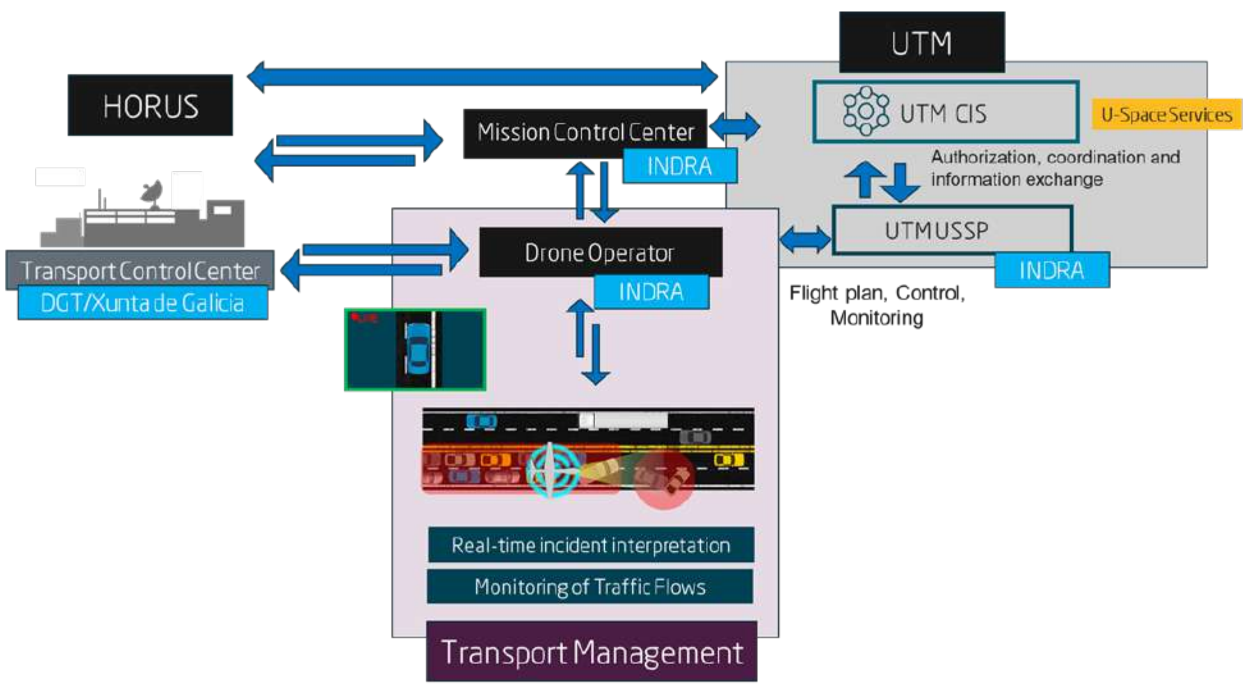


Figure 3 - UC1 D1: Demonstrator overview

In this demonstrator, the Traffic Control Center (HORUS) receives the notification of an incident detected in the road. This alarm contains the information related to the time, type of incident and location.

The HORUS operator determines that the response to this incident will require obtaining live images in HD of the incident. Due to the location of the incident and the unavailability of fixed cameras or any other infrastructure equipment in the area, the HORUS operator determines that this incident requires the use of a drone. The HORUS operator activates the request of a drone resource in HORUS of "a service of the stream of live images from the incident area" to the Drone Mission Control Center (CMPD) through a dedicated interface.

The activation of the drone resource in HORUS triggers a request of geofencing an area at the location of the incident. This request is sent to the UTM (CIS) through an interface connecting the HORUS Platform with the UTM CIS. This geofenced area will remain activated until the HORUS operator changes the status of the incident to "finalized".

The UTM (Hub) receives the geofence request from the road authority and proceeds to the activation of this area.

The CMPD manages the drone service/request by HORUS with its authorized drone operator through a dedicated interface. This request will contain the type of service (emergency), the location of the incident, date and time when it is needed (immediate), type of services needed (broadcast of HD video in real time of the location of the incident).

The drone operator creates a flight plan based on the service requested and submits it to the UTM (USSP) for its validation through an interface connecting the Drone operator, and UTM USSP.

The UTM USSP receives the flight plan and request. Since the drone operator and its drones have been previously authorized to access the emergency geofenced area created by the road authority, the UTM USSP authorizes the flight plan and notifies the drone operator through the interface connecting them.

The drone operator sets the drone and ground control station on site and launches the drone autonomously, following the flight plan created and authorized. The ground control monitors the whole flight and shares the drone telemetry with the UTM USSP. The drone telemetry is also shared with HORUS (through the dedicated interface), and the HORUS HMI displays the drone position in real time.

Near the incident location, the drone operator starts broadcasting the HD video captured by the drone through the interface connecting the ground control with the CMPD, which will be streamed to the HORUS platform. The HORUS platform displays these images in real time through a widget/element of the platform HMI.

Once the mission has been completed, the drone returns and lands according to the flight plan, the flight finishes and the drone operator stops sharing the telemetry and live images from the drone. The HORUS operator changes the status of the incident to "finalized", which automatically triggers the deactivation of the drone resource and the deactivation of the geofenced area in the UTM CIS.

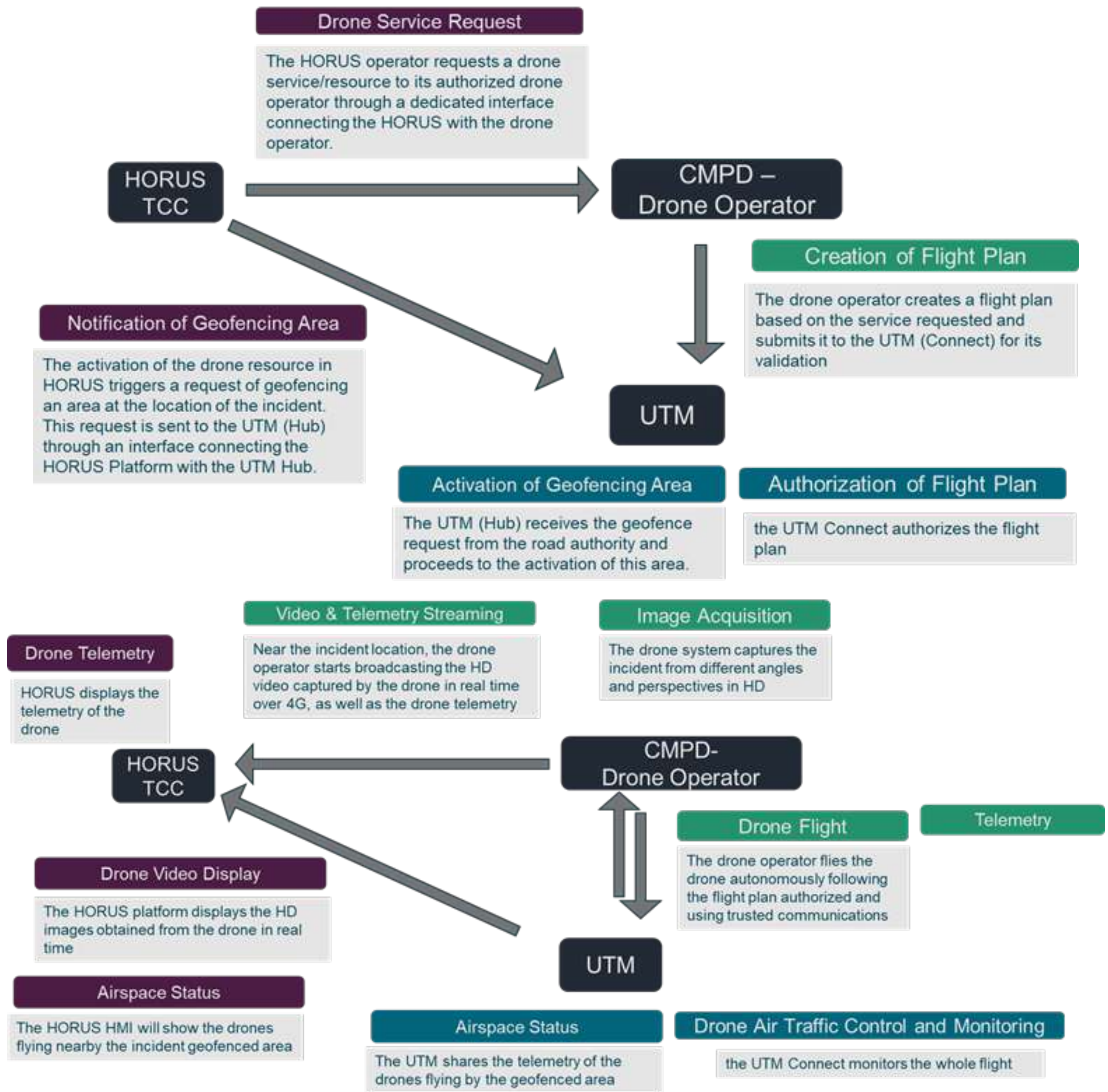


Figure 4 - UC1 D1: Data exchanges in the system

4.2.1.3 Objectives

This demonstrator has the following objectives:

- Development of drones processing tools based on graphic cards for the capture, processing and analysis of images/video generated by aerial and maritime drones.
- Development of secure communication modules to ensure communication between the Control Center, different infrastructure elements and the drone for monitoring and inspection of the infrastructure.
- Integration of Artificial intelligence technologies/DEEP Learning/Machine Learning to analyse the images received by the drones to perform operational and maintenance activities.
- The drones will be integrated with other transport monitoring devices (DAS/DAI) that launch incidents in order to verify these incidents without the need to mobilize human resources.

4.2.1.4 Key concepts and technologies

This demonstrator will involve and integrate three main platforms that will enable the applications:

HORUS: This platform controls and manages any type and number of mobility infrastructures, systems and operation and any type of city incident related to transport and emergencies. This module will collect city incidents with their location as well as other information needed by operators to manage the incident such as status, allocation of resources, response time, etc. Smart transport management: It enables the integration of multiple smart units and systems to control and monitor mobility. It will be integrated with UTM and drone service providers in order to safely deploy drones as resources to perform the different operations and applications.

UTM: Unmanned Traffic Management or UTM is the set of services, delivered concertedly by one or more entities, that allow the efficient, sustainable, safe and secure access and usage of the airspace in which all kind of drones will perform different kind of operations, in a safe way both for airspace users and people and assets in the ground. The UTM services 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). Emerging technologies will be explored to enhance the security of the U-Space services during the project.

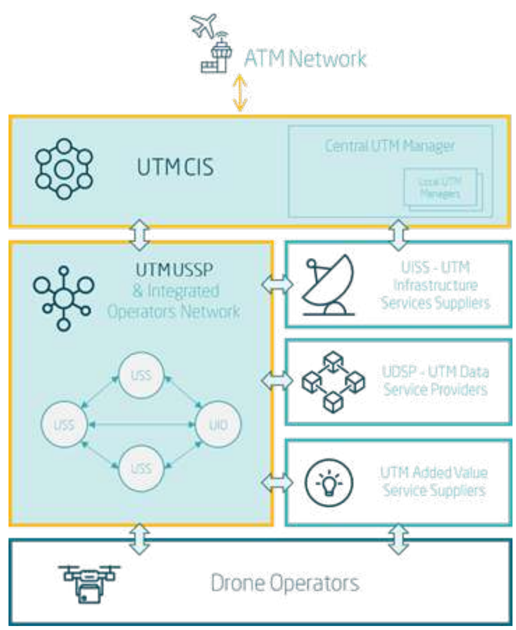


Figure 5 - UC1 D1: Components for the UTM integration

UTM CIS (Common Information Service) is the core of the system and it is responsible for the communications between the regional ATM network and the local UTM Manager, providing connectivity services to all UTM actors and a set of core services to coordinate UTM environments guaranteeing safety. It is a public service regulated by airspace authorities at national and international levels.

UTM USSP (U-Space Service Provider) enables the connection of UTM users within the UTM environment, enabling the provision of UTM services to the end users (drones, pilots and operators, local authorities and local airspace managers) while providing interfaces to mobile apps, web services and other application program interfaces (API). It is an open UTM market solution.

Full U-Space services are detailed in D2.1 section 2.2.

Mission and Data Processing Center – CMPD: is a Data Processing and Mission Center that is responsible for receiving, processing, archiving, distributing and monitoring sensor data on unmanned platforms. It consists of the following sub-systems:

- Mission center: Track the performance of a data capture mission, scheduled or contingent, and interact in real time with unmanned system operators.
- Operations center: Modules that contain the business logic and the main services of management and planning of missions, as well as the management and recovery of information from the UxV.
- Data processing center: It consists of a series of components and software tools whose main objective is to format, index and catalog the data received from the platforms involved in the missions, to be made available to subscribers.

Artificial Vision: To analyze the images captured by the drones, different algorithms will be developed based on image analysis that allow monitoring of road traffic in the area covered by flight of the drone.

Applications and algorithms are grouped into three large blocks:

Vehicle detection-based applications: From the images distributed by the drone or by the fixed-wing drone, it will be possible to detect the vehicles at the scene. This detection will be performed using deep learning techniques to detect objects according to the state of the art. This will make it possible to carry out different traffic analyses such as:

- Vehicle counting on the scene: Know the number of vehicles on the track (in the area covered by the drone) at that time.
- Traffic density analysis: It will be possible to analyze the density of traffic in a given area. This can enable high-level analytics such as density analysis by lane, time slot, etc.
- Detection of jams and queues: Early detection of possible jams or holds.

Vehicle classification-based applications: After carrying out the detection (or in the same detection architecture) it will be possible to classify the detected vehicle within the possible categories that will be defined. The applications that can be carried out thanks to the classification of vehicles are, among others, the following:

- Heavy traffic density analysis: Analysis of heavy traffic of a certain track.
- Heavy traffic vs light traffic: Analysis of the percentage of heavy traffic versus light traffic in a given track/zone.
- Heavy traffic on prohibited roads: Detection of heavy vehicles in those roads or areas where they cannot drive.

Applications based on trajectory analysis: Tracking algorithms allow you to obtain the trajectories of the detected objects. In addition, by knowing navigation data from the drone, it will be possible to make an estimation of the speed of the vehicles. Possible applications that can be developed from trajectory analysis are as follows:

- Detection of prohibited trajectories and/or kamikazes: It will be possible to identify when a vehicle is following a prohibited trajectory. For example, when traveling in a lane in the opposite direction (kamikaze). This may require prior knowledge of the pathway.
- More repeated trajectory heat maps: By analysing in time all the trajectories of vehicles in a given area, it would be possible to obtain a visual map of the most repeated trajectories.
- Stopped vehicles: Vehicles that are stopped on the track may be identified.
- Average track speed: Calculation of the average speed of a given track. It could be useful in identifying traffic problems at an early stage.

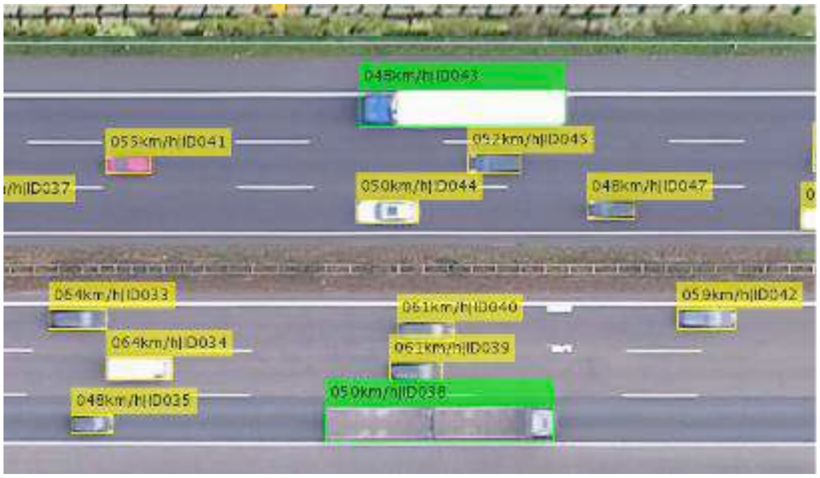


Figure 6 - UC1 D1: Example of artificial vision algorithms output

4.2.1.5 Infrastructure and drones

4.2.1.5.1 Drone: Mantis

Figure 7 - UC1 D1: Drone Mantis

MANTIS is a multirole fixed-wing UAV system based on low weight and very low acoustic trace designed for a wide range of operations for civilian and military applications. It provides real-time accurate information to support operations and has been designed to operate autonomously during all phases of flight, allowing operators to obtain real time recognition data over different weather conditions, day or night. The system has been developed to be managed by a single operator, assisted for deployment and take-off by another support person.

The system has been designed in a modular basis to facilitate transport and maintenance tasks, also to facilitate upgrades as may be needed in the future. MANTIS system aircrafts take off automatically with the help of a rubber cords system. Bungee launcher is light, fast deployment and collection, compatible with all types of airstrips (paved airstrips and flat dirt airstrip) and even it is operational in the absence of track, with the only need of a cleared land of vegetation (20 meters). It has a payload that transmits color or infrared images in real time with three-axis gyro-stabilization, offering autonomous control and target tracking.

D2.1 section 3.1.3.1 describes with more detail the system architecture.

4.2.1.5.2 Commercial / 3rd Party drone

In addition to Indra's Mantis drone, the system integrations and artificial vision functionalities and algorithms will also be tested using of-the-shelf commercial drones (3rd party from DJI), in order to validate all the developments. The possibility to adapt one of these 3rd party DJI drones to perform BVLOS flights will also be considered.

4.2.1.5.3 Stakeholder & Rozas Aerodrome (Civil UAVs Initiative)

Part of the Civil UAV Initiative and coordinated by Xunta de Galicia (GAIN), with a 40M€ investment, this aerodrome is located in Castro de Rey (Galicia, Spain). Its contract is managed by Babcock and Indra. Indra has moved all its development activities of unmanned aircrafts to this location, which allows the deployment of pilots and experiments, as its airspace is not affected by general restrictions and regulations. This demonstrator will be deployed in this aerodrome, where final demonstrations and scenarios will be tested.

The Galician government launched the Civil UAVs Initiative for the use of unmanned aerial systems (UAVs) in the civil field and in improving the provision of public services in the framework of the impetus for the development of a European reference aeronautical pole in Galicia. GAIN is also part of the Experts group of COMP4DRONES and will provide overall technical support to the project. GAIN will review and provide input on the technical designs and solutions that will be developed during the project and offer technical support and review and discuss the selected recommendations with the project managers.

Algodor Aerodrome (Toledo) will also be considered as an alternative aerodrome to perform tests an integrations during the project.

Figure 8 - UC1 D1: Rozas Aerodrome (Galicia, Spain

Figure 9 - UC1 D1: Algodor Aerodrome (Toleda, Spain)

4.2.1.6 Implementation

4.2.1.6.1 Stage 1: Technology Validation

This demonstrator will focus on validating key **technologies** based on initial data collection and exchange by drones and all the systems involved. Data acquisition campaigns will be carried out in lab or real environments to collected video and images to be processed and analysed during this phase.

In this first stage, we will carry out the first drone campaigns to proceed with the first Data and Images Acquisition. During these campaigns we will also perform the first integration tests between the main systems of the use case: HORUS – CMPD – MANTIS – UTM.

4.2.1.6.2 Stage 2: Technology Experimentation

Second phase integration test between the main systems of the use case: HORUS –CMPD – MANTIS – UTM. Tests will be carried out in lab, aerodrome environments and Las Rozas, a test facility located in Galicia where Indra is developing and testing their drone platforms.

We will integrate the first component prototypes developed in technical WPs to perform lab tests and data/images acquisition with new campaigns.

4.2.1.6.3 Stage 3: Technology Implementation

With the support of the local transport operator (Xunta), in-situ trials will be carried out in this phase where drones will validate the integration of the main systems of the use case: HORUS –CMPD-MANTIS – UTM, the AI algorithms, the trusted communications and the integrated guidance systems in a real environment collecting real-time images/ and processing them at the control center, deploying the scenarios of the use case.

We will integrate and validate the final components developed in technical WPs and deploy the UC with all the interfaces and functionalities in the test site under real conditions.

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

Campaign	Stage	Period	Description	Milestone
Campaign 1	Stage 1	M1-M3	Image and data acquisition with Mantis. Definition of scenarios.	**MS2.1 UC specification MS2.2 Initial Data Collection**
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.	**M4.1 UC ready to be deployed on site**
Campaign 4	Stage 2	M16-M20		
Campaign 5	Stage 3	M23-M24		
Campaign 6	Stage 3	M27-M32	Validation of final components. Deployment of the UC in real site with all the components, interfaces and integrations. BVLOS flights	**MS6.1 Lessons Learned from UC**
Campaign 7	Stage 3	M34		

4.2.2 KPIs

During the development of the Project, it is intended to demonstrate:

- Usability of drone Technology for traffic management and incident response.
- Optimization of Costs/Times of Transport Monitoring and Maintenance/Operations.
- Improvement of algorithms to identify vehicles, traffic, etc.

4.2.2.1 Business KPIs

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	5-10%

UC1-D1-KPI-2	Optimization of costs in traffic management and incident monitoring activities	% Reduction of operational costs in traffic monitoring activities	5-10%

Table 10 - UC1 D1: Business KPIs

4.2.2.2 Technical KPIs

ID	KPI	Definition and measurement of Indicator	Target Value
UC1-D1-KPI-3	Improvement of automatic tracking system of objects and persons	The indicator for this KPI will be the number of times it is necessary to locate the object/person being tracked by the automatic tracking system. The video tracking system uses contrast algorithms between the object/person to follow and the background in which it is located. All this is framed within a small area (red box).	Between 0-2 (currently it is between 2-4)
		The indicator will be calculated by the number of times the tracked object/person needs to be re-located. When contrast decreases, sometimes the automatic tracking system may not be able to identify the movement followed by the target and this way loses the automatic tracking.	
		Improving the resolution of the video (from SD to HD) increases the number of contrasting pixels available in the tracking area so the tracking algorithm should increase its reliability.	
UC1-D1-KPI-4	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-5	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-6	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-7	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-8	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%

4.2.3 Specification Plan

Figure 10 shows the data flows and information exchange of all the systems involved in the demonstrator and explained above, indicating all the interactions and interfaces required for deploying the demonstrator:

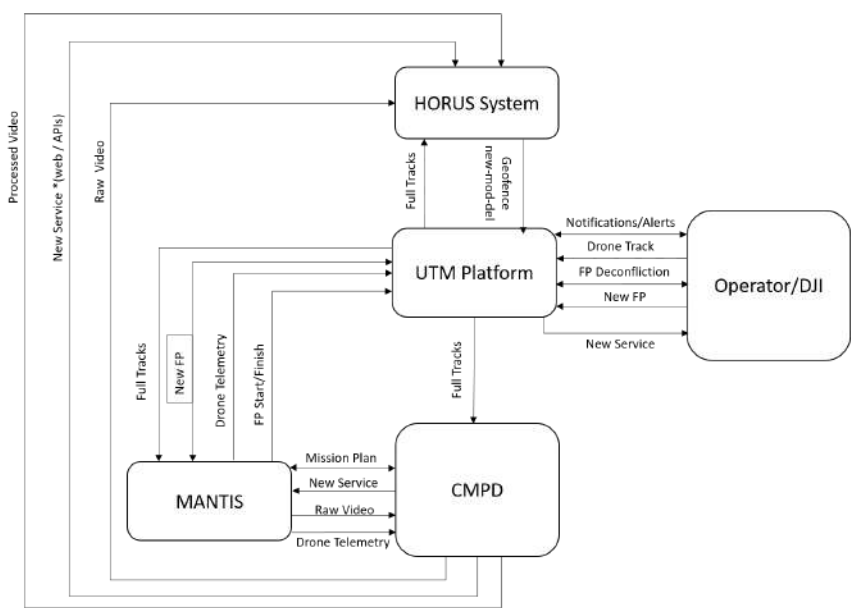


Figure 10 - UC1 D1: Components and their interconnection

Pre-flight:

Id	Origin	Destination	Name
1	HORUS	UTM	Geofence Request

2	UTM	HORUS	ACK Geofence Request
3	HORUS	CMPD	Mission request
4	CMPD	Horus	ACK Mission request
5	CMPD	CMPD	Activity Flow Launch of Contingent Mission Request
6	CMPD	MANTIS	Request for contingent mission
7	MANTIS	MANTIS	Assessment of contingent mission request
8	MANTIS	CMPD	Mission acceptance communication
9	CMPD	HORUS	Mission acceptance communication
10	HORUS	UTM	Geofence modification request to include operator and drone IDs
12	MANTIS	MANTIS	Creation of flight plan
13	MANTIS	UTM	Communication and request for approval of the flight plan
14	UTM	MANTIS	Flight plan validation confirmation
15	MANTIS	CMPD	Communication to CMPD of approved flight plan
16	CMPD	HORUS	Communication to HORUS of approved flight plan
17	HORUS	CMPD	Access to CMPD resources for contingent mission monitoring
18	MANTIS	MANTIS	Pre-fight
19	MANTIS	CMPD	Mission-ready communication
20	CMPD/HORUS	UTM	UTM Connection
21	CMPD	HORUS	Mission-ready communication
22	HORUS	CMPD	Confirmation to start mission
23	CMPD	MANTIS	Confirmation to start mission
24	MANTIS	CMPD	ACK start mission
25	CMPD	HORUS	ACK start mission
26	MANTIS	UTM	MANTIS-UTM connection for telemetry transmission
27	MANTIS	UTM	Start-of-flight communication
28	MANTIS	CMPD	MANTIS-CMPD connection for telemetry and video transmission
29	MANTIS	CMPD	Start of telemetry sharing
30	MANTIS	CMPD	Start-of-flight communication

Mission:

Id	Origin	Destination	Name
M-1	HORUS	CMPD	Mission monitoring and control
M-2	UTM	MANTIS	Flight tracking and control
M-3	MANTIS	UTM	Traffic Management tracking orders
M-4	HORUS	MANTIS	End-of-mission order

Mission return and completion:

Id	Origin	Destination	Name
R-1	MANTIS	HORUS	ACK End-of-mission
R-2	HORUS	CMPD	Disconnection from HORUS
R-3	MANTIS	CMPD	End-of-flight communication
R-4	MANTIS	UTM	End-of-flight communication
	HORUS	UTM	Geofence deleted request
R-5	MANTIS	CMPD	Loading data offline

Debrieffing:

Id	Origin	Destination	Name
D-1	HORUS	CMPD	Loading data offline

HORUS will request a drone service to the CMPD. The CMPD will notify a flight service request to the MANTIS. The MANTIS operator will complete the mission plan and send mission plan authorization request to the UTM system. The UTM response will be notified to the MANTIS system.

In the event that the flight is approved, at the time the mission starts, the MANTIS system will notify the CMPD and UTM, starting to send them telemetry and video data. During the execution of the mission, the MANTIS system will be subscribed to the topic “tracks” published by UTM to have information about other flights that are being carried out in the area of operation. In addition, it will have continuous communication with the CMPD flight coordinator. When the mission is terminated, the MANTIS system shall notify the CMPD and UTM of the status.

Demonstrator drones (MANTIS and 3rd party drones) will send to the UTM platform a new Flight Plan request for every new Flight Plan that will be scheduled. Once sent, this new Flight Plan is evaluated internally for the UTM system. Flight rules, airspace structure and strategic deconfliction services (among others) are evaluated, and deconflicted Flight Plans will be sent to operator when the new FP is in conflict with another existent FP (planned or in flight). Airspace rules and structure (Geofences, etc…) are evaluated as well. Then, when deconflicted FP is validated for the Operator, the FP is stored in the UTM platform (and ready to fly when scheduled). Priority Flight Plans are going to be managed different due to its inherit condition of priority.

MANTIS and/or DJI pilots (through their GSC’s) will have access to query or cancel all their Flight Plans and its status. REST requests will be prepared in the UTM system for the project. Once started, flew and finished the scheduled Flight Plans, their status (and its internal updates) are automatically handled and managed for the UTM system.

Project drones can send **either drone tracks or telemetry** to the UTM Platform. Then, all these UTM tracks or telemetry will be integrated to the UTM system, whom will manage internally all drone tracks with the others (other UTM tracks & manned traffic tracks when/if available) normally. UTM tracking service has been developed to receive and manage both track and/or telemetry files coming from the agreed drone GCS’s.

Output for all drone tracks to be consumed for 3rd parties (CMPD and HORUS in this specific case) can be accessed and consumed. MQTT server connection and REST requests to connect to the UTM Traffic Monitoring service will be provided to project team in order to be able to gather and integrate all the UTM Tracks into the CMPD or HORUS Operational Platform.

In order to define a no-flight area (Geofence) in the UTM system, the geographical area of application and the time (ms since Unix epoch) and altitudes intervals (in m) must be indicated. Besides, it is also possible to add certain drones to a whitelist to override geofences effects (invasion alerts among others) to those drones.

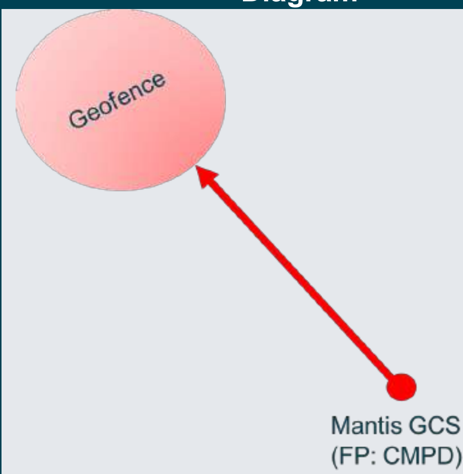
Two geofence types are considered:

- Manual geofences that can be overridden with previous authorization, and
- Non-manual geofences that cannot be overridden.

All geographical information is stored following GeoJSON standard as a Feature containing a Polygon geometry. Other primitive features (corridors and circles) must be converted to a polygon before storing them.

4.2.3.1 Scenarios

Two scenarios will be deployed: a "simple" scenario will test all the integrations and information flows presented, which will be enhanced and extended in a "complex" scenario with added functionalities to demonstrate the system capabilities in a real scenario.

Scenario	Description	Diagram
Simple	1- HORUS is notified of a traffic accident 2- HORUS generates a Geofence in UTM in the indicated area 3- Geofence is shown on UTM 4- HORUS sends service request to CMPD 5- CMPD launches priority FP new request to UTM and UTM is approved 6- Mantis carries out his operation 6.1- HORUS and CMPD receive the composite tracks generated by UTM 7- Mantis completes his mission and reports accordingly 8- HORUS requests geofence erasure from UTM 9- UTM erases Geofence **Level of Autonomy**: Partial Automation (Level 2, Sense and Alert)	

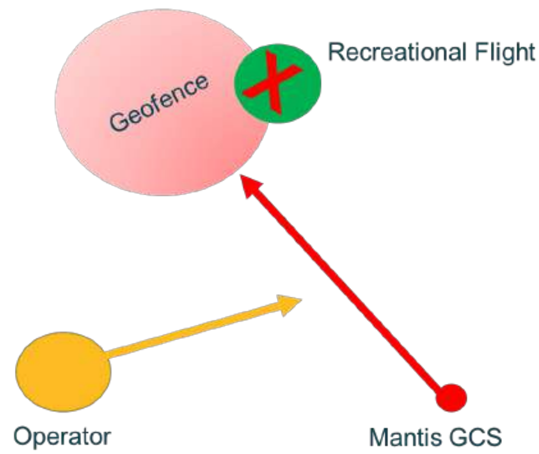
Complex	1- HORUS is notified of a traffic accident 2- HORUS generates a Geofence in UTM in the indicated area 3- Part of the new Geofence collides with an area where a Recreational Flight is located. This is revoked and the pilot notified. 4- Geofence is shown on UTM 5- HORUS sends service request to CMPD 6- CMPD launches priority FP new request to UTM and UTM is approved 7- Mantis carries out his operation 7.1- HORUS and CMPD receive composite tracks, generated by UTM 8- 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. 9- The operator begins his mission 10- Mantis completes its mission and reports accordingly 11- HORUS requests Geofence erasure from UTM 12- UTM erases Geofence 13- The operator finishes his mission **Level of Autonomy**: Partial Automation (Level 2, Sense and Alert)	

Table 11 - UC1 D1: Scenarios overview

Features for each scenario:

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
DEM1-Scenario-1	Simple	UTM Geoawareness & Geofence Management UAV Registration & Flight Plan Management Flight Plan Assesment Air Traffic Monitoring Road Area Mapping Communications Control station Image Acquisition Robust multi-radio communications Navigation Traffic management application	H	DEM1

DEM1-Scenario-2	Complex	UTM Geoawareness & Geofence Management UAV Registration & Flight Plan Management Flight Plan Assesment Air Traffic Monitoring Strategic Deconfliction Road Area Mapping Communications Control station Image Acquisition Robust multi-radio communications Navigation Traffic management application	H	DEM1

Table 12 - UC1 D1: Scenarios description

4.2.3.2 Features and/or subsystems

Feature/Subsystem	Description	Requirements	U-Space
UTM Geoawareness & Geofence Management	Service for managing geofenced areas. Activation/deactivation of geofences (Temporary flight restrictions) as an authority.	DEM1-FNC-2 DEM1-FNC-3 DEM1-FNC-1 DEM1-FNC-9 DEM1-FNC-10 DEM1-FNC-12 DEM1-FNC-14 DEM1-P&C-2	Geo-fence provision (U2)
UAV Registration & Flight Plan Management	Pre-tactical service to identify and register the drones in the UTM platform (for Mantis). Reception of flight plan from Mantis GCS over UTM Connect API	DEM1-INT-3 DEM1-FNC-18 DEM1-FNC-19 DEM1-FNC-20 DEM1-FNC-21 DEM1-P&C-1 DEM1-SEC-2 DEM1-FNC-14 DEM1-FNC-15 DEM1-FNC-1 DEM1-FNC-2	Registration (U1)
Flight Plan Assesment	Alerts notification from UTM Hub (flight plan conformity, telemetry, violation of geofences) to Mantis GCS over UTM Hub/Connect API. Authorisation workflows.	DEM1-FNC-28 DEM1-FNC-29 DEM1-FNC-30 DEM1-FNC-1 DEM-SEC-1 DEM1-FNC-2 DEM1-PRF-1 DEM1-P&C-1 DEM1-SEC-2	Traffic information (U2) Operation plan preparation (U2)

Air Traffic Monitoring	Tracking, conformance monitoring, traffic information, ATC interface,	DEM1-FNC-24 DEM1-FNC-25 DEM1-P&C-1 DEM1-FNC-10 DEM1-FNC-12 DEM1-FNC-16	Monitoring (U2) Tracking (U2)
Strategic Deconfliction	Proximity conflict detections & Deconfliction workflows	DEM1-FNC-28 DEM1-FNC-29 DEM1-FNC-30 DEM1-FNC-15 DEM1-SEC-2	Strategic conflict resolution (U2)
Road Area Mapping	Mapping of the area of operation for UTM pre-tactical and tactical services.	DEM1-FNC-27 DEM1-DSG-2 DEM1-P&C-2	Geospatial information service (U3)
Drone Connections and Communications	Compression of sensor data (HD video) Payload and physical connection avionics and interconnection systems of the drone	DEM1-P&C-1 DEM1-SEC-2 DEM1-SEC-3 DEM1-INT-1 DEM1-SEC-4 DEM1-FNC-3 DEM1-FNC-5	Datalink and spectrum
Control station	communication between the frontend and the backend of the control station	DEM1-SEC-3	Datalink and spectrum
Image Acquisition	HD video capture with HD single electronic optical payload, infrared payload and dual payload (gyro-stabilized)	DEM1-PRF-2 DEM1-PRF-3 DEM1-FNC-3 DEM1-DSG-1 DEM1-OPR-1 DEM1-FNC-5 DEM1-USB-1 DEM1-USB-2	Sensing
Systems communications	Communication between the use case systems: Mantis ground control station - CMPD - HORUS - UTM	DEM1-FNC-5 DEM1-FNC-2 DEM1-SEC-2 DEM1-SEC-3 DEM1-FNC-8 DEM1-FNC-7 DEM1-FNC-11 DEM1-FNC-13 DEM1-INT-2	Datalink and spectrum
Navigation	Autonomous navigation providing automatic tracking of objects and persons	DEM1-FNC-4 DEM1-FNC-6	Navigation coverage information (U3)

Traffic management application	Reception and display of video stream received from drone and the airspace traffic of the drones utilized for the area operation, including tracking and conformity alerts. Notification of invasion of the geofences activated by an incident in HORUS and reception of information of these external drones violating the geofences (temporary flight restrictions). AI and DL technologies for analysing the images obtained and providing operational data to the end user	DEM1-FNC-1 DEM1-FNC-2 DEM1-PRF-1 DEM1-FNC-5 DEM1-PRF-2 DEM1-INT-1 DEM1-FNC-7 DEM1-FNC-9 DEM1-FNC-10 DEM1-FNC-11 DEM1-FNC-13 DEM1-INT-2 DEM1-USB-2 DEM1-FNC-32	Traffic information (U2) Geo-fence provision (U2)

Table 13 - UC1 D1: Features/Subsystems

4.2.3.2.1 Components

WP	Component ID	Component	Feature/Subsystem
3	WP3-IND-1	Payload (Single Visible HD)	Image Acquisition
3	WP3-IND-2	Payload (Infrared HD)	Image Acquisition
3	WP3-IND-3	Payload (Dual HD)	Image Acquisition
3	WP3-IND-4	GCS - HMI	Control Station
5	WP5-IND-1	Avionics – Communications/Radio Links	Drone Connections and Communications
4	WP4-IND-1	Avionics - Encoder	Drone Connections and Communications
4	WP4-IND-2	Autopilot - Navigation	Navigation
5	WP5-IND-2	Communications - Ports	Drone Connections and Communications
5	WP5-IND-3	Communications – GCS - Autopilot	Drone Connections and Communications
5	WP5-IND-4	Communications – GCS - CMPD	Systems communications
5	WP5-IND-5	Communications – UAV – GCS – CMPD - UTM	Systems communications
4	WP4-IND-3	UTM Ground Service	Road Area Mapping
4	WP4-IND-4	UTM Airspace Structure	UTM Geoawareness & Geofence Management
4	WP4-IND-5	UTM Flight Plan Management	UAV Registration & Flight Plan Management Flight Plan Assessment
4	WP4-IND-6	UTM Trajectory algorithms	Air Traffic Monitoring Strategic Deconfliction
4	WP4-IND-7	UTM Flight Plan Authorization	Air Traffic Monitoring Strategic Deconfliction Flight Plan Assessment

Table 14 - UC1 D1: Component list

4.2.3.3 Requirements

Requirement Type	Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI
Functional Requirement	DEM1-FNC-1	Activation of incident geofence	The activation of the incident resource in HORUS shall trigger the activation of a geofenced area at the location of the incident. This area shall remain activated during the whole lifetime of the incident.	H	HORUS	UC1-D1-KPI-B1
Functional Requirement	DEM1-FNC-2	Flight plan	The drone operator shall create a flight plan based on the incident communicated by HORUS.	H	Drone Operator /CMPD	UC1-D1-KPI-B1
Functional Requirement	DEM1-FNC-3	HD video	OEM Camera shall provide HD video (min 720p).	H	Drone Payload	UC1-D1-KPI-T1
Functional Requirement	DEM1-FNC-4	Tracking	The drone shall be able to perform automatic tracking of objects and persons.	H	Drone Navigation	UC1-D1-KPI-T2
Functional Requirement	DEM1-FNC-5	Real time video streaming	The drone shall provide HD video in real time to the Mission Center over 4G.	H	Drone Communications	UC1-D1-KPI-B1
Functional Requirement	DEM1-FNC-6	Drone navigation	The drone must autonomously navigate with high position accuracy during landing.	H	Drone Navigation	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-7	Video transmission	Video may be transmitted through HTTP (HTML5).	L	Drone Communications	UC1-D1-KPI-B1
Functional Requirement	DEM1-FNC-8	Drone GCS communication	The drone must communicate with the GCS and inform about its landing position.	H	Drone Communications	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-9	Geofence communication	HORUS should send the incident area geometries and required characteristics over UTM Hub API.	H	HORUS	UC1-D1-KPI-B1
Functional Requirement	DEM1-FNC-10	Display of airspace	The HORUS HMI shall show the drones flying nearby the incident geofenced area.	M	HORUS	UC1-D1-KPI-B1
Functional Requirement	DEM1-FNC-11	Drone position	The HORUS HMI shall show the drone position of the drone operator.	H	HORUS	UC1-D1-KPI-B1

Functional Requirement	DEM1-FNC-12	Airspace status	The UTM system shall provide/be provided with the airspace status (official) in real time - public API drones.enaire.es	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-13	Drone service request	HORUS shall communicate the request a drone service/resource to its authorized drone operator through a dedicated interface connecting the HORUS with the drone operator.	H	HORUS	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-14	Airspace allocation	The UTM shall modify airspace allocation when a Flight Manager or Operation Manager becomes unavailable.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-15	Trajectory conflicts	The UTM shall detect trajectory conflicts between different agents.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-16	Unauthorized behaviour	The UTM shall detect unauthorized behaviour by any of the handled agents.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-17	Compliance with U-Space	The UTM shall allow Flight Managers to check that the agents or systems of agents' usage of the airspace is compliant with U-Space and their declared mission.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-18	Flight Plan Validation	UTM system shall evaluate the validity of the flight plans requested by CMPD. The possible outputs shall be planned, manual or denied status.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-19	Flight plan alternatives	UTM system shall provide alternative flight plans when possible if the original flight plan requested by CMPD was denied.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-20	Alternative authorization request	UTM system shall be able to receive the authorization request for an alternative flight plan proposed to the CMPD. The complete authorization process shall be performed.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2

Functional Requirement	DEM1-FNC-21	Manual authorization	UTM shall provide the state/authority with each manual flight plan for its manual authorization.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-22	Planned flight plans	Flight plans in PLANNED status are authorized and ready to flight once its start time is reached.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-23	Authorization notification	UTM shall send to CMPD a notification message with the complete output of the authorization process.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-24	Telemetry reception	UTM shall support the reception of the drone telemetry from CMPD in the UTM format.	H	UTM/CMPD	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-27	Drone conformance calculation	UTM system shall calculate the conformance of the drone and rise an alert in case of horizontal, vertical, or longitudinal non-conformance.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-28	Geofence violation alarm	UTM system shall rise an alarm when a drone track violates an active geofence.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-29	Tactical conflict alarm	UTM system shall rise an alarm when there is a tactical conflict between two or more drones.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-30	Tracking and alert information to linked systems	UTM shall send the tracking and alert information to the CMPD and HORUS systems.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-31	Geofence reception and creation in UTM	UTM shall be able to receive new or modified geofences in the UTM format from HORUS system and create them in the airspace.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2
Functional Requirement	DEM1-FNC-32	Delete geofence in UTM	UTM shall be able to receive the delete input from HORUS system of a geofence within its jurisdiction.	H	UTM	UC1-D1-KPI-B1; UC1-D1-KPI-B2

Table 15 - UC1 D1: Main requirements

4.3 Demonstrator 2

4.3.1 Justification Plan

4.3.1.1 Demonstrator overview

This demonstrator will focus on the deployment of a captive drone as a mobile system for security and aerial surveillance in real time, in the port environment.

The usage of this system will improve the current port surveillance infrastructure, saving deployment

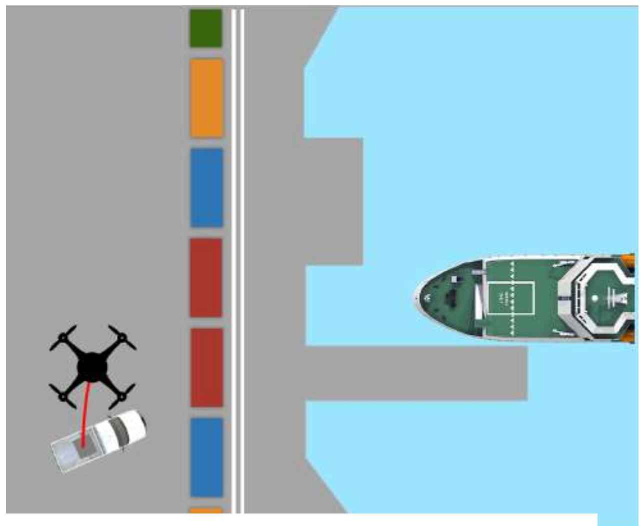


Figure 11 - UC1 D2: Demonstrator overview

costs of a new network of fixed cameras and providing a surveillance system of higher quality and accessible from any point, thereby increasing security.

The fact that the drone is captivated, provides a clear added value compared to a normal operation with drones, since in addition to limiting the range of action of possible damage and guaranteeing the privacy of the data, provides 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.

The system will be integrated into a surface vehicle to take advantage of both a mobile system and unlimited autonomy.

In addition, the captive drone has 4G data link, making it possible to connect from any Wi-Fi point, in order to validate its operation or obtain data in real time.

There are multiple possible applications in which the use of the captive drone in the port environment can be of great interest. Among them, the application selected for this demonstrator is night surveillance rounds in areas not covered by the currently available systems.

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 night 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.

4.3.1.2 Description and Scope

In this demonstrator, a vehicle equipped with the "Captive UAV System" will follow the vehicle that is in charge of the night surveillance work of the Port of Vigo, going through all the port facilities of interest, providing high-quality thermal images in real time and covering all the blind spots or specific areas that are required. This will lean on a camera that can be controlled at about 25 meters above the ground which provides a very wide range of vision.

4.3.1.3 Objectives

This demonstrator will target the following objectives:

- High-quality real-time image transmission from the drone to the operations center.
- Increased efficiency in surveillance tasks:
    - Shorter surveillance rounds.
    - Increase of controlled areas in the same space of time.
    - Increase of visible areas and elimination of blind spots.
    - Greater ability to detect movements in low visibility conditions.

4.3.1.4 Key concepts and technologies

Micro-tether: lightweight and very flexible, it is designed to supply continuous power to the drone with a minimum weight ratio. The micro-tether is composed of the following parts: power and data transmission conductors, aramid reinforcement and a black protection sheath. Its aramid reinforcement guarantees a full mastering of the drone's evolution and makes it compliant to most civil aviation "tethered drone" regulations. The end connector is composed of a mechanical fastener, a power connector and a data connector.

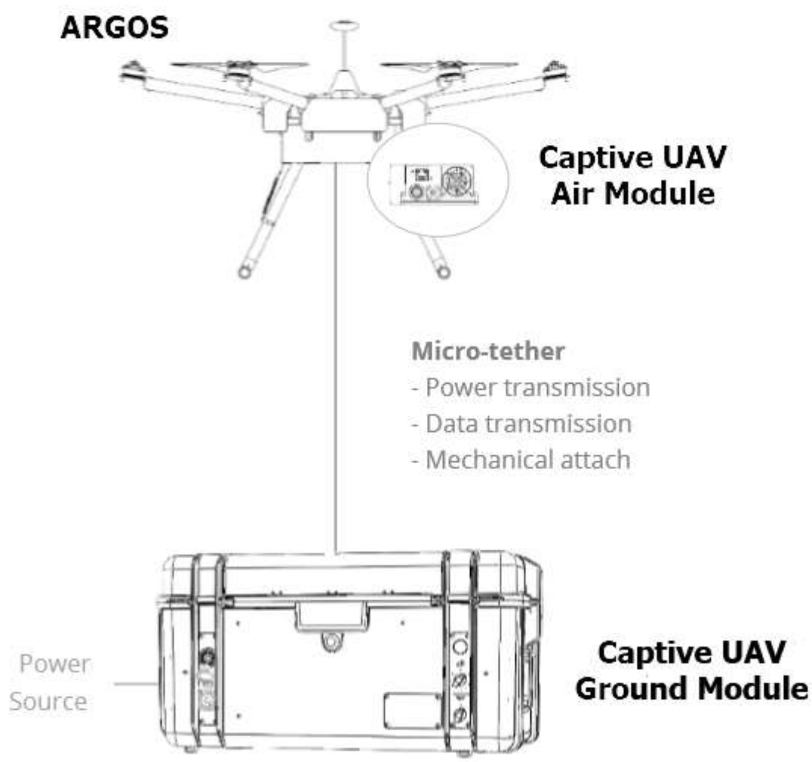


Figure 12 - UC1 D2: Micro-tether UAV

Camera/Gimbal: it is a high precision 3-axis gimbal with 10X optical zoom camera and thermal camera, based on FOC technology, features high stability, small volume and low power consumption. It also has a target tracking function, which ensures that you will never lose the object.

Its high performance makes it ideal for application in many fields like power line inspection, searching, emergency monitoring and rescue.

Figure 13 - UC1 D2: Gimbal and camera

4.3.1.5 Infrastructure and drones

4.3.1.5.1 Captive UAV system

ARGOS is a multirole quadcopter captive UAV based on low weight and wingspan, designed for a wide range of operations for civilian and military applications.

Figure 14 - UC1 D2: Argos tethered UAV

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 a 4G cellular communications link, which acts as a command/ control link for the captive UAV and can act as a communications repeater for the ground vehicle, using the ethernet connection between the "Captive UAV Ground Module" and the "Captive UAV Air Module".

The system is controlled from a "Captive UAV Control Center", consisting of a PC and a 4G communications module, which serves as a communication link with the UAV.

The Captive UAV has a payload that transmits color or infrared images in real time with three-axis gyro-stabilization, remotely monitored from the "Captive UAV Control Center".

The UAV is operated through the SW application of the "Captive UAV Air Module", in charge of managing the UAV control systems following the orders sent from the "Captive UAV Control Center", and the GPS position controlled by the "Captive UAV Air Module".

The system has been developed to be managed by a single operator responsible for executing and supervising the mission from the "Captive UAV Control Center", in which there will be a "UAV manual remote Control" always accessible to the UAV pilot so they can take the control of it if the situation requires it (in normal operation, the use of the "UAV manual remote control" or the intervention of a pilot will not be necessary).

The Captive UAV has an on-board processing system in order to follow the path of the surface vehicle in which the system is integrated and control the camera according to the commands received from the "Captive UAV Control Center".

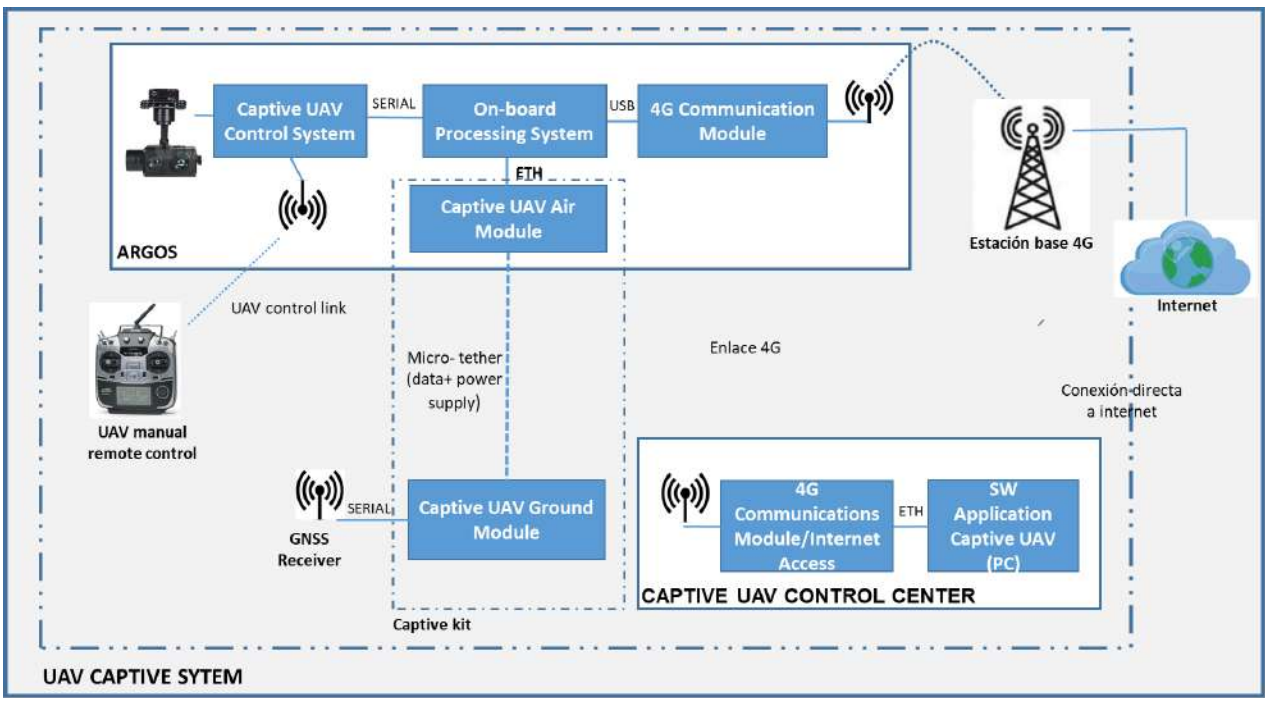


Figure 15 - UC1 D2: Description of the system

4.3.1.5.2 Stakeholder: Port of Vigo

This demonstrator will be deployed at Port of Vigo (Galicia, Spain). Autoridad Portuaria de Vigo is an institution in charge of managing the Port of Vigo's infrastructure, covering a Land Service Area (SA) of 2,572,577 m2 over five municipalities. Port of Vigo is ranked as the 1st port of fresh fishing in Spain and the 1st port of frozen fishing in Europe. Autoridad Portuaria de Vigo will support and facilitate the deployment of this demonstrator (see Annex for Xunta letter of support) provide the necessary permissions and infrastructure and authorize INDRA to complete the activities planned in COMP4DRONES.

Figure 16 - UC1 D2: Port of Vigo

4.3.1.6 Implementation

4.3.1.6.1 Stage 1: Technology Validation

In this first stage, the requirements, analysis and manufacturing and/or necessary developments will be carried out in order to implement the monitoring of the captive drone, its feeding (taking as source direct current) and the fixing system of the "Captive kit" to the mobile vehicle.

In addition, the first tests of the Captive drone on a moving platform will be carried out.

4.3.1.6.2 Stage 2: Technology Experimentation

During this second stage, the PIDs of the tracking algorithm will be adjusted until the target is achieved. Additionally, the tests integrated with the feeding and anchoring system of the "Captive Kit" defined in the previous stage will be carried out.

4.3.1.6.3 Stage 3: Technology Implementation

In this last stage, the fine adjustments to the system will be completed, validating its complete operation through a real use case in the facilities provided by the Port of Vigo.

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).

4.3.2 KPIs

During the development of the Project, it is intended to demonstrate:

- Usability of the captive drone for surveillance and security tasks in real time.
- Improvement of the image quality currently obtained by the port systems, covering possible blind spots.

There KPIs will be calculated and measured due to:

- Possibility of deployment of the system at any point, being able to be operational for very long periods, limited by the system maintainability.
- Possibility of connecting from any WiFi point to validate its operation or obtain real-time data.
- Possibility of knowing the position of the drone and the vehicle at any time during the mission.
- Possibility of registering and analysing the LOGs obtained during a mission.

The verification method for the KPIs will be based on:

- Conduct a surveillance round and check times.
- Analyze the LOGs obtained during a mission and verify that the maximum angle of the drone with respect to the horizontal plane of the vehicle is as expected.

4.3.2.1 Business KPIs

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.

Table 16 - UC1 D2: Business KPIs

4.3.3 Specification Plan

The following action protocol is defined:

- 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” starts the “Captive UAV system” and deploys the drone.
- 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.

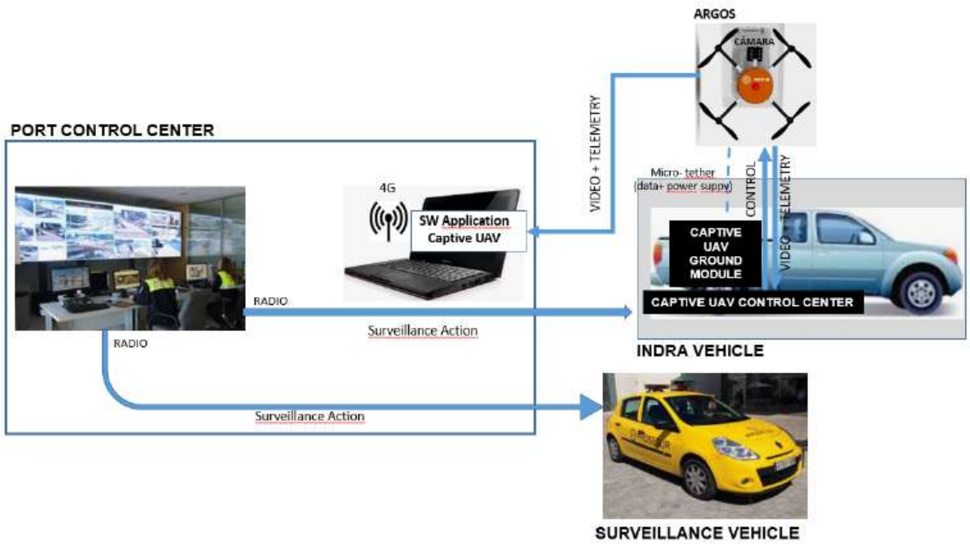


Figure 17 - UC1 D2: Demonstrator system description

4.3.3.1 Scenarios

Two scenarios will be deployed:

- A "first" scenario will demonstrate the system capabilities in order to reduce the operation time and increase the size of the controlled areas.
- A "second" scenario will demonstrate the system capabilities to view people or objects in low visibility conditions.

Scenario	Description	Diagram
First Scenario	1. "Captive UAV Control Center" is notified of a surveillance mission. 2. "Captive UAV Control Center" operator starts the "Captive UAV system" and deploys the drone. 3. INDRA vehicle performs a specific surveillance round and checks times and the volume of the controlled surface. 4. From the "Captive UAV Control Center" the camera is remotely operated in order to take the required images/video recordings in real time. 5. Video and telemetry are transmitted both to the "Captive UAV Control Center". 6. The operator finishes the mission. **Level of autonomy**: Partial Automation (Level 2, Sense and Alert)	

Second Scenario	1. "Captive UAV Control Center" is notified of a surveillance mission. 2. "Captive UAV Control Center" operator starts the "Captive UAV system" and deploys the drone. 3. INDRA vehicle performs a reconnaissance/surveillance round focusing on identifying low visibility areas and possible blind spots. 4. 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. 5. Video and telemetry are transmitted both to the "Captive UAV Control Center". 6. The operator finishes the mission. **Level of autonomy**: Partial Automation (Level 2, Sense and Alert)	

Table 17 - UC1 D2: Scenarios

4.3.3.2 Features and/or subsystems

Feature/Subsystem	Description	U-Space / KET	Requirements
Camera/gymbal (payload)	Described in 4.3.1.4.		DEM2-10
Micro-tether	Described in 4.3.1.4.	Take-off (KET 2.2.1)	DEM2-4 DEM2-5
Power Supply-Captive Kit	The generator provides the necessary power for the operation of the "Captive Kit". Analysis of requirements and market research, in search of solutions that provide us with the necessary power requirements. Once the most optimal solution has been selected, the equipment will be purchased and validated. Next, the anchoring/fixing system will be defined and manufactured. Finally, the equipment will be installed in the vehicle and validated.	Take-off (KET 2.2.1)	DEM2-4 DEM2-5

Captive UAV System	All the "Captive Kit" ground components, are assembled in a single block except the generator. The drone will rest on or next to this assembly. The fixing will be carried out according to the characteristics of the surface vehicle, always based on a system that damps vibrations, absorbs stress, and ensures a rigid and stable connection, provided with the necessary anchorages. Design, manufacture, and installation of the optimal fastening for anchoring the "Captive UAV System" to the vehicle.	Take-off (KET 2.2.1)	DEM2-5
GNSS Receiver	The "GNSS Receiver" is located on top of the "Captive UAV Ground Module". This module is responsible for sending the vehicle's GPS position to the captive UAV so that the system can operate in tracking mode. The most suitable GPS antenna with the desired coverage, precision and quality will be searched for the subsequent treatment of the data and its integration into the Captive UAV System.	Tracking (U2)	DEM2-8
Captive UAV/Surface Vehicle - Navigation	The objective of the algorithm is to provide positioning information of the UAV with respect to the vehicle at all times.	Monitoring (U2)	DEM2-1 DEM2-2 DEM2-3 DEM2-5 DEM2-6
Captive UAV Control Center	All the operations of the captive UAV are controlled from the "Captive UAV Control Center", centralizing all the information received from the "UAV Captive System". It is a dedicated interface to display telemetry and video and to be able to interact in real time (integrated into the network of any Control Center). The information is sent with a high data rate, handling a small latency and low delay in packet refresh.	Tracking (U2)	DEM2-7 DEM2-9

Table 18 - UC1 D2: Features/Subsystems

4.3.3.2.1 Components

WP	Component ID	Component	Feature/Subsystem
1	WP1-IND-1	Power Supply- Captive Kit	Drone Platform
1	WP1-IND-2	Installation - Captive UAV System	Drone Platform
3	WP1-IND-3	GNSS Receiver	Drone Connections and Communications

4	WP4-IND-9	Tracking algorithm Captive UAV/Surface Vehicle - Navigation	Drone Navigation
5	WP1-IND-4	Real-time display in “Captive UAV Control Center”	Drone Connections and Communications

Table 19 - UC1 D2: Component list

4.3.3.3 Requirements

Requirement Type	Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI
Functional Requirement	DEM2 -1	Speed of the surface vehicle	The maximum speed of the surface vehicle (in which the Captive UAV System is integrated) is 50km/h.	H	Drone platform	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -2	Wind conditions	Maximum operating wind conditions for the drone are 12 m/s.	H	Drone platform	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -3	Drone speed	The maximum speed of the drone is 15m/s.	H	Drone platform	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -4	System power	The “Captive kit” has power requirements of 220-250 VAC and 3KW minimum.	H	Drone platform	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -5	Installation	The “Captive UAV System” must be installed in a surface vehicle.	H	Drone platform	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -6	Route tracking	The Captive UAV must have the ability to follow the surface vehicle route.	H	Drone Navigation	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -7	Connection encryption	The client-server connection must be encrypted.	H	Drone Communications	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -8	Geodetic Reference System	The drone must be provided with a WGS84 Geodetic Reference System.	H	Drone Navigation	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3

Functional Requirement	DEM2 -9	Real time images	The system must be able to provide images in real time over 4G.	H	Drone Communications	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3
Functional Requirement	DEM2 -10	Low visibility conditions	The system must be able to provide images in low visibility conditions.	H	Payload	UC1-D2-KPI-B1; UC1-D2-KPI-B2, UC1-D2-KPI-B3; UC1-D2-KPI-B4

Table 20 - UC1 D2: Main requirements

4.4 Demonstrator 3

4.4.1 Justification Plan

4.4.1.1 Demonstrator overview

Rail Baltica demonstrator will **focus on** deployment of autonomous **drone flight command and controlled exclusively through cellular network**. A drone as a service concept will be elaborated and demonstrated to be further incorporated in routine monitoring of Pan European railway infrastructure construction and exploitation stages.

4.4.1.2 Description and scope

PAN EUROPEAN RAIL NETWORK - Rail Baltica

The Rail Baltica project is one of European Union transport priority by building currently missing cross-border connections and promoting modal integration and interoperability of North East Europe with Central Europe. According to project timeline within year 2020 and 2021 the pre-construction and construction phase are foreseen to be implemented.

Figure 18 - UC1 D3: Rail Baltica as Part of the North Sea-Baltic Core Transport Network Corridor

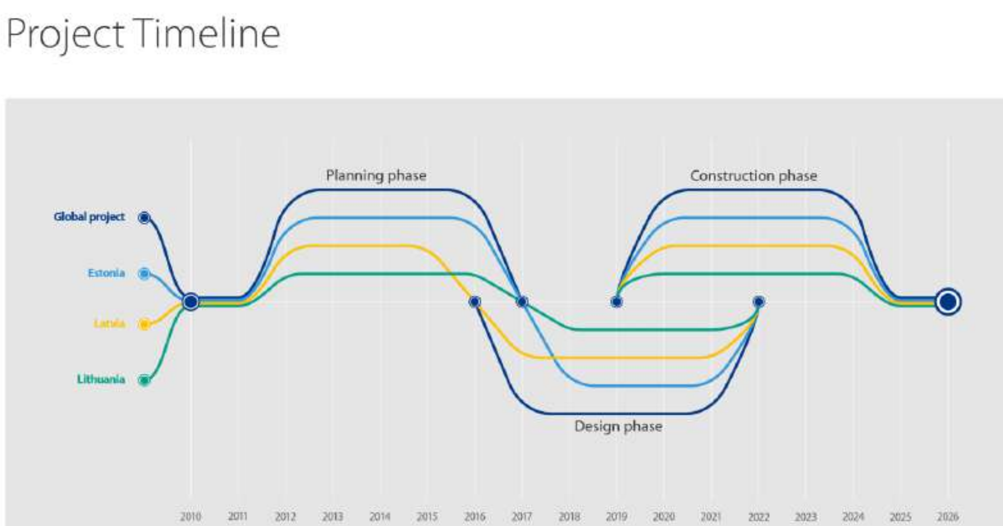


Figure 19 - UC1 D3: Rail Baltica project timeline. (2020-2021 design and construction phase within Latvia territory)

Eventual drone as a service for the Rail Baltica project will focus on several use case scenario modelling:

1. Pre-construction phase: surveying of land before the construction (possibly only for a small number of key areas)
2. Construction phase: surveys, progress reporting, potential for volumetric asset tracking and accounting.
3. Commissioning: design vs as-built validation, detailed monitoring during testing.
4. Operational: routine surveys, including vegetation growth, track/ wayside condition monitoring, alignment of overhead lines, etc.

A service on demand would be an option to consider for incident response, which would apply almost to any of previously identified scenarios. In case of incident where video streaming would be required on ASAP basis. Example would include an incident occurred during construction, which our inconsistencies identified during commissioning. Once the infrastructure would become operational this type of response would address inquiries like accidents, our "intruder on track" alerts, inspection following severe weather, and so on. This would save the downtime for employees and reduce the human resources required for 24/7 monitoring of the critical infrastructure.

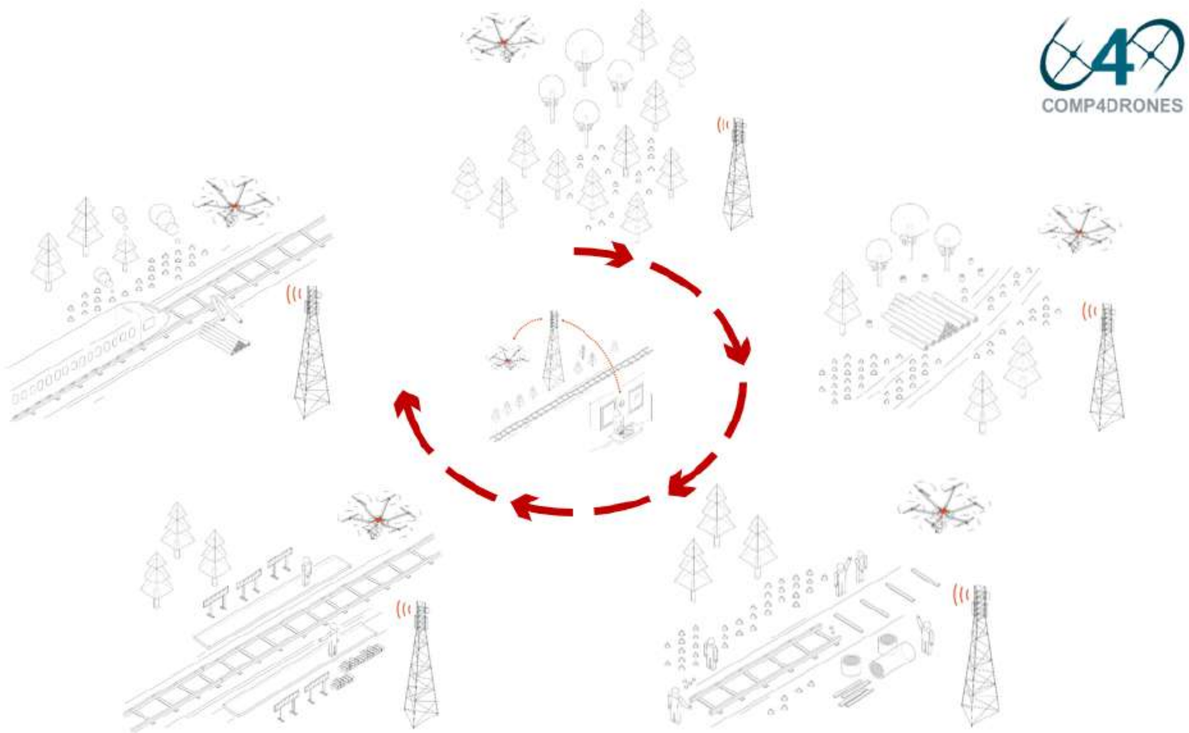


Figure 20 - UC1 D3: Eventual Rail Baltica scenarios for autonomous drone flight by C2 link of LMT cellular network.

As service will evolve within the stages of the Rail Baltic project, it is hard to predict most accurate system configurations and end user requirements to be addressed by drone autonomous flight. Besides quadcopters this may include elaborated fleet of VTOL and fixed wing drone capacities.

4.4.1.3 Objectives

Objective of use case is to demonstrate the reliability and national, trans-national wise connectivity of command-and-control link of autonomous drone by Wireless broadband cellular network.

The demonstration architecture is designed for 3rd level of drone autonomy:

- degree of automation – conditional automation;
- pilot acts as fall-back system;
- drone can perform all functions 'given certain conditions;

- obstacle avoidance – sense&avoid.

4.4.1.4 Key concepts and technologies

The key concept for LMT as an unmanned aerial system service supplier (USS) is to integrate several enabling technologies on top of existing cellular network capacity to provide a safe, reliable with high data fusing capacity cellular connection. Long Term Evolution (LTE) telecommunications network usage will be explored in full capacity from 2G to 5G connections assessing frequency bands and associated bandwidths availability securing drone service on top of existing cellular network business model.

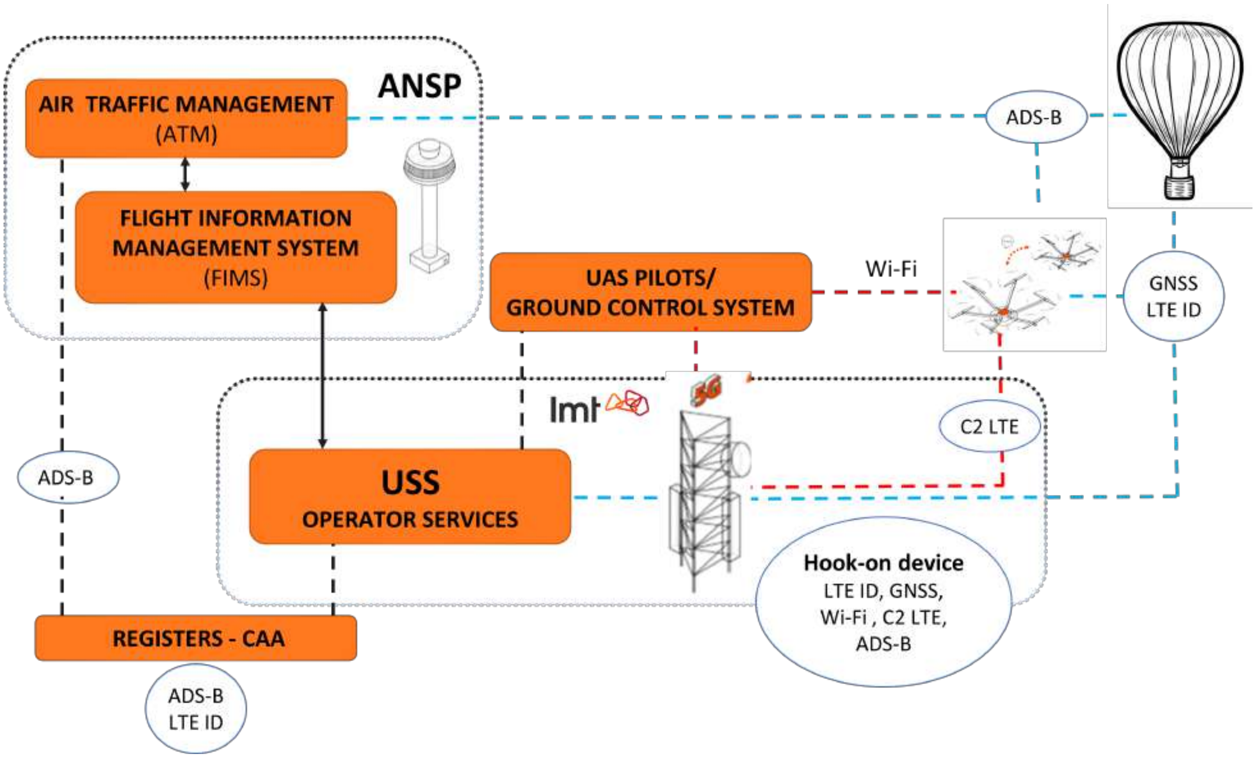


Figure 21 - UC1 D3: Key concept of LMT as USS drone service.

Both software and hardware are integral part of drone services, like a hook-on devices in order to provide an e-identify, alternative command control link our situation awareness (redundancy in case of GNSS signal loss) are not required currently however will enable such a service deployment and further standardisation. As existing legislation in EU is changing a common understanding of UAS service supplier is evolving too. According to Global UTM Association (GUTMA) only interoperability of systems will ensure proper management of UAS traffic. Therefore, a key concept involves a direct link with National Aviation Authorities which organise air traffic above currently available drone flight zones. Besides drone flights the balloons, light aircrafts and gliders or powered parachutes share common airspace and controlled by visual rather than radio navigation systems. Integrated Unmanned Aircraft System Traffic Management with LTE identification and collision avoidance system are technology to build and to extend the LMT service system.

4.4.1.5 Infrastructure and drones

LMT has the most extensive communications and data network in Latvia boasting more than 1,200 base stations equipped with backup electricity and wideband data connections (optical cables and/or radio relay lines). A national wide 4G and rapidly growing 5G network in Latvia, which will be gradually upgraded to support 3GPP Releases R.16 and the R.17 for facilitating the large-scale field trials along major transport paths (road and rail) in Latvia.

Two data centres and deployable (on wheels) 4G cellular network base station with communication bands: 811,0MHz/ 842,0 852,0MHz; 890,0-903,2 MHz / 935,0948,2 MHz; 1710,0-1734,8 MHz / 1805,0-1829,8 MHz; 1915-1920 MHz; 1920-1940 MHz / 2110-2130 MHz; 2300-2330MHz; 2500-2520 MHz / 2620-2640 MHz; 2570 MHz 2620 MHz (TDD); 3400 3450 MHz; 3650 3700 MHz.

Within the demonstrator LMT should develop a capacity to assess the optimal coverage bandwidth and its signal to noise ratio as well as latency properties for autonomous drone flights within restrictive 120m above ground level flight zone.

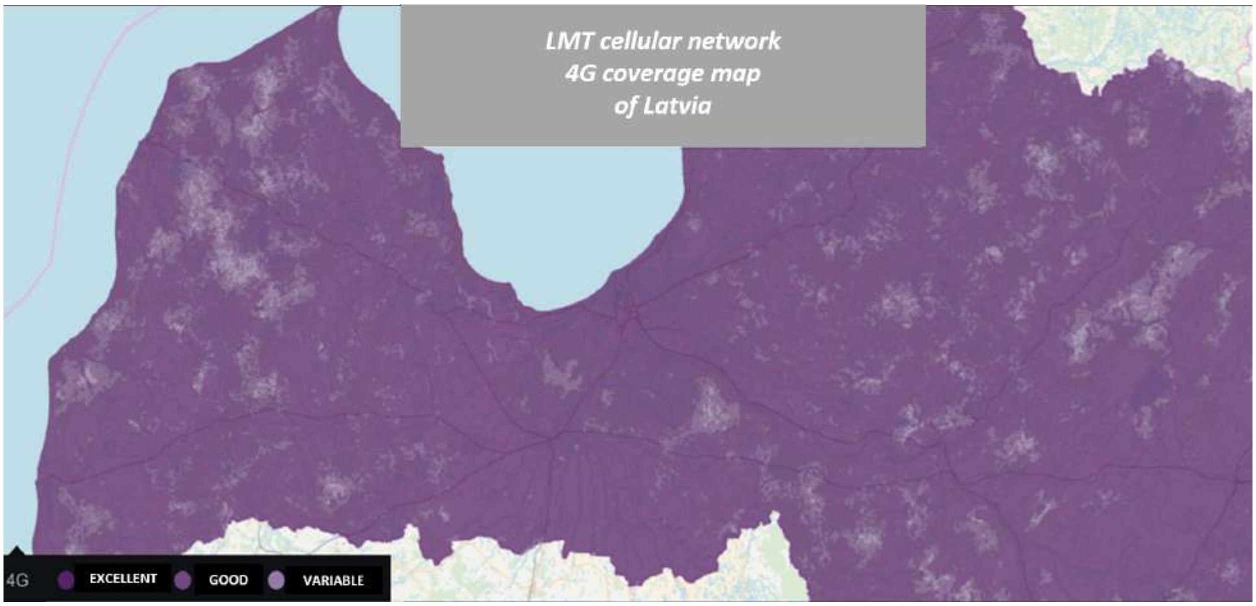


Figure 22 - UC1 D3: LMT cellular network 4G coverage map of Latvia (violet – excellent data rate and connectivity).

An assessment of flight path connectivity issues has been delivered focusing on Reference Signal Receive Power (RSRP) from closest mobile network cell and a cell interference at 60m altitude. Even though an excellent RSRP is present for most of the 30km distance flight path two particular zone`s it was identified a fairly good signal strength indications. Those sections of interest will be scrutinised for autonomous flight connectivity and uplink/downlink speed. Meanwhile one of major concerns is interference from several mobile operators at the same area and vicinity of sea border. A radio signal traveling distance is remarkable and interference in coastal region is meddled by multinational operators. From LMT point interference could be assessed from LMT owned cellular network only, however there could be a major gap on the spots which need to be exploited afterwards.

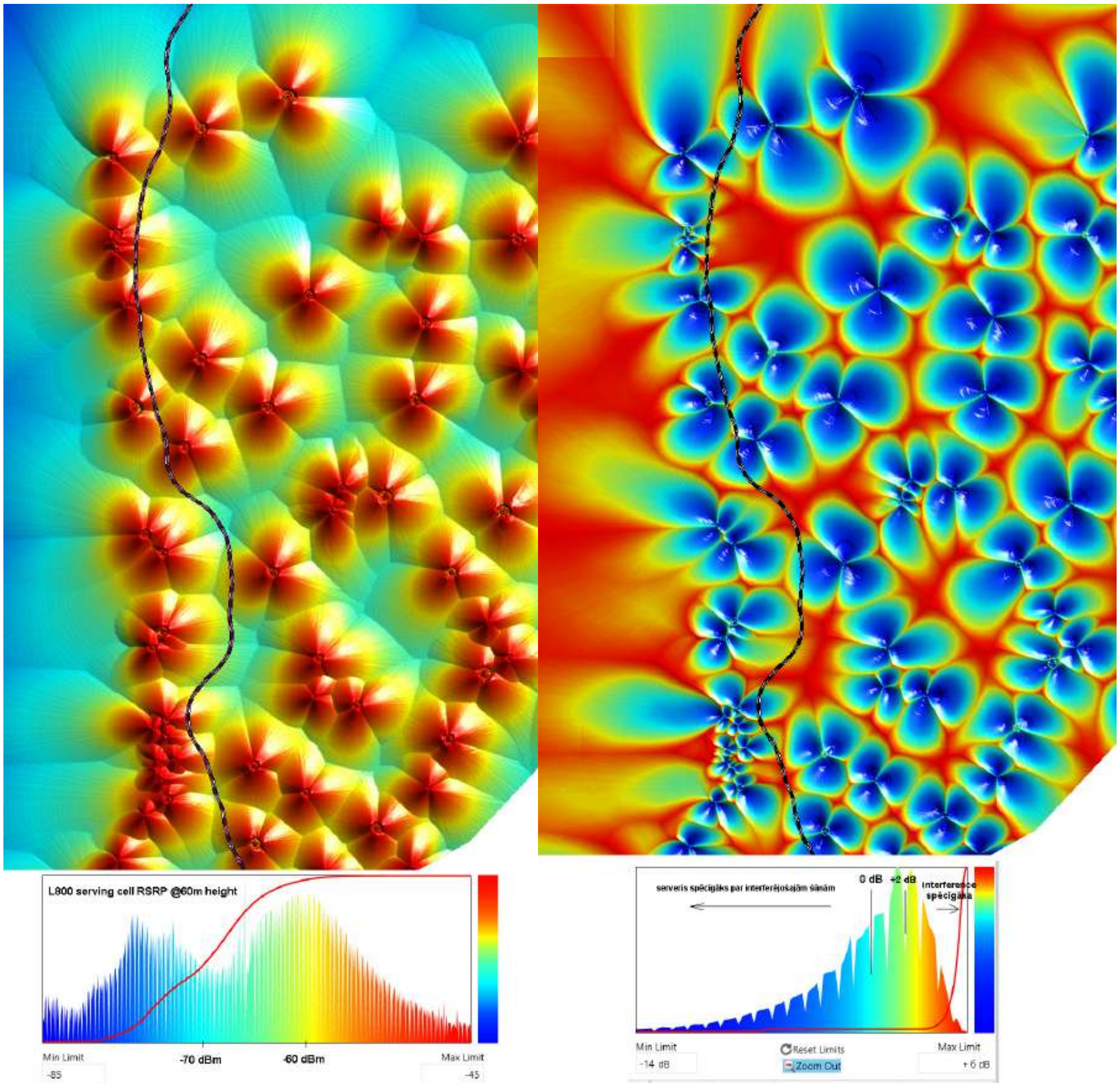


Figure 23 - UC1 D3: Rail Baltica C4D demonstration section RSRP and Interference analysis at 60m autonomous flight altitude

4.4.1.5.1 Drone requirements

An essential requirement for drone is the ability to communicate using LTE bandwidth. It could be fully integrated system our Hook-on device either way the primary command and control link should be cellular network.

It should be noted that drone must have capacities for demonstration purpose to autonomously monitor Rail Baltica building progress in current stage and to perform a service maintenance in later stages of service implementation. Estimated Phase1 flight range is up to 50 km, while for Phase2 range should be extended up to 100 km.

The drone may have alternative technologies enabled by extended technology readiness level maturity:

- The drone would be required to navigate and sense with high position accuracy during take-off, landing and docking in order to autonomously guarantee the absence of humans, animals or objects nearby, aborting the operation if needed.

- The drone is required to dynamically detect and consider other UAS in the area (including light aircrafts, balloons, propelled parachutes etc).
- The drone must integrate intelligent perception for safe control loops, providing increased awareness to vehicles and humans.
- The drone must respect geofencing even in the almost or complete absence of GPS/Galileo satellite signals.
- The drone must have an embedded interface module for communication that is generic and that guarantees its secure and resilient control.
- The drone must be allowed to fly in several countries of Europe (cross border flights' possibilities is required).
- The drone must be adaptable for payload with different kind of AI/ IOT solutions.

4.4.1.5.2 AI/IOP requirements

- GIS based infrastructure assessment tool for supervising authority.
- Tailored made mission planning system for on-demand inspection or for controlling inconsistences

4.4.1.5.3 Autonomous Drone flight assessment software requirements

Design software shall be capable to demonstrate cellular network coverage and reliability capabilities for beyond visual line of sight flight applications. The autonomous drone flight design software must make an effort to assess the ground and airspace risks according to SORA methodology including population density. Integration of UTM is required for further drone as a service deployment.

4.4.1.6 Implementation

4.4.1.6.1 Stage 1: Technology Validation - research on the possibilities to conduct a drone flight in a mobile network and validation of identified technologies

- Technology test flights in Ādaži (Latvia) – November of 2019 Verification of: network coverage, remote ID 1Gen, BVLOS, real time video streaming https://www.youtube.com/watch?v=EpEOOKXEi5E https://www.youtube.com/watch?v=MfFc2cfYxlk https://www.lmt.lv/en/press-releases?pid=915
- Technology cross border Latvia-Estonia test flights – February of 2020 Verification of: cross border flight, BVLOS, interconnectivity – switch from one operator to another, remote ID second generation, mobile network coverage, GNSS tracking, cellular network simulation for safe autonomous mission planning

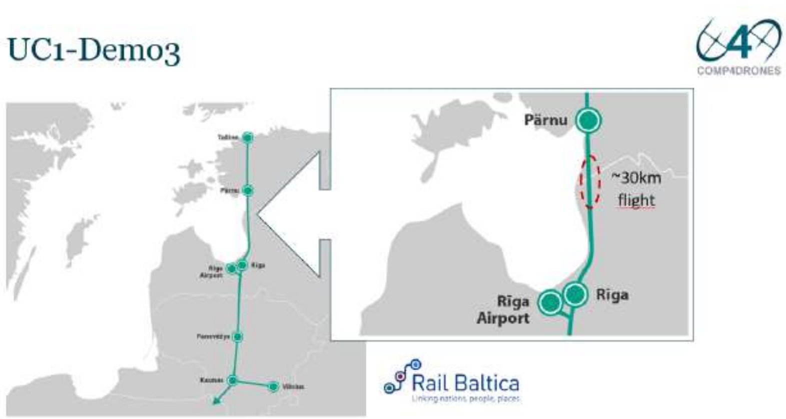


Figure 24 - UC1 D3: Eventual autonomous flight route Latvia/Estonia cross border connectivity

https://innovations.lmt.lv/en/news/LMT-successfully-conducts-first-cross-border-drone-flight-on-the-mobile-network

https://www.youtube.com/watch?v=n3-op7tDLPw

https://www.youtube.com/watch?v=3WprYCqgChE

4.4.1.6.2 Stage 2: Technology Experimentation

Technology experimentation will take place on eventual Rail Baltica tracks including cross border region of Latvia and Estonia in accordance with the developed methodology.

The demonstrator system to be developed is comprised of four critical subsystems:

1. GSM base stations and cellular network coverage assessment software. The communication network must be high performance 4G our 5G cellular network in bandwidth:
    - 800 MHz;
    - 1800 MHz;
    - 2.4 GHz;
    - 4.2 GHz.

    While communication infrastructure between these subsystems must be:
    - Redundant
    - Secure
    - Robust
    - Dissimilar
    - Deterministic
    - Permanent
    - Multimodal
2. The prior drone mission simulations.
3. Solution for notification of other airspace users (according to NAA requirements), where national and EU legal framework requirements and guidelines must be followed.
4. The flying drones (Phase1 – quadcopter or VTOL, Phase2 – fixed wing drone).

Voluntary technology requirements include:

- The system must be built making use of interoperable components from different third parties.
- The communication between the subsystems must demonstrate a fail-safe capacity and a resistance to cyber-attacks.

Following the network research methodology mentioned above, the identified mobile network KPIs are validated or hypotheses are tested by obtaining, analysing and interpreting extensive network measurement data.

A measurement data repository is created, where data on measurements performed in the identified area of the use case at four different altitudes up to 120 m (VLL airspace) are stored.

The measurement data is converted into several formats and analysed from different aspects: from a network perspective and from an unmanned aircraft perspective. In order to identify possible measurement errors, control measurements with several measuring devices in the same place are also performed and compared.

Interpretation of the analysed data will allow to confirm the assumption of network KPIs or it will be possible to specify KPI values.

The new KPI values will be tested by performing a certain number of repeated drone flights on the mobile network to ensure their reliability.

The entire validation process is documented and traceable. Before the implementation stage, the information will be summarized with conclusions and recommendations, including the preparation of an article to share the knowledge gained.

Trusted cellular network information enabling connectivity options with aviation systems in future.

4.4.1.6.3 Stage 3: Technology Implementation

As the most critical aspect within the autonomous drone flight, the LTE communication network must be benchmarked and validated against predesigned signal coverage estimate. The estimate should be multidimensional including all available cellular network bandwidth.

A secondary target should have a demonstration system composed of 55% of COMP4DRONES components available from the project partners' repositories.

4.4.2 KPIs

Each demonstration stage and iteration will provide more clear definitions and measurement of indicators.

4.4.2.1 Business KPIs

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

ID	KPI	Description	Target value/ Goal
UC1-D3-KPI-01	GSM connectivity complex KPI.	Reconfiguration costs for drone flight above ground level are foreseen as current service thus require substantial connectivity antenna reconfiguration which affect`s existing network and client services.	Set up cost of new business case
UC1-D3-KPI-02	GSM C2 link strength complex KPI.	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
UC1-D3-KPI-03		Roaming costs and it`s optimisation based on uplink/downlink mission requirements.	Set up cost of new business case

Table 21 - UC1 D3: Business KPIs

4.4.2.2 Technical KPIs

Technical KPIs related to reliable connectivity of autonomous drone command to control by cellular network.

ID	KPI	Description	Target value/ Goal
UC1-D3-KPI-04	GSM C2 link power KPI	Mission reconfiguration before and during the flight	> -110 dB reference in simulated network
UC1-D3-KPI-05	GSM C2 link quality KPI		> -12 dB

UC1-D3-KPI-06	GSM C2 link interference KPI		> 5 dB
UC1-D3-KPI-07	GSM C2 link channel quality KPI		5
UC1-D3-KPI-08	GSM C2 link strength complex KPI		< 50 ms
UC1-D3-KPI-09	GSM C2 link reliability KPI		at least 60-100 kbps
UC1-D3-KPI-10	4G/5G data transfer rate		at least 3 mbit
UC1-D3-KPI-11	Reliability of second GSM C2 data link		Down time less than 1 sec

Table 22 - UC1 D3: Technical KPIs

4.4.3 Specification Plan

4.4.3.1 Scenarios

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
1.3.1	GSM downlink signal strength analysis tool for autonomous drone flight C2 through cellular network	Reliable C2 data downlink	H	UC1-DEM3-Rail Baltic
1.3.2	GSM uplink signal strength analysis tool for data streaming from drone sensors	Reliable 4G/5G data uplink	M	UC1-DEM3-Rail Baltic

Table 23 - UC1 D3: Scenarios description

4.4.3.2 Boundary conditions

The focus of railway inspection use-case will be to test, analyze, demonstrate and provide the network requirements as recommendations for safe drone flights related to the 3rd drone autonomy level.

As the main boundaries are marked:

Name	Short Description
Weather conditions	According to Latvian regulations flights are to be performed under VMC (Visual Meteorological Conditions) and appropriately to the drone exploitation instructions from the drone manufacturer's manual.
Latvian National regulations and European Regulations	All flights that take place within the territory of Latvia are to comply with Latvian RPAS regulation and European regulation framework that includes Regulation (EU) 2018/1139, Delegated Regulation (EU) 2019/945, and Implementing Regulation (EU) 2019/947. All the flights performed in this use case will be performed under this regulatory framework and the protocols of the bodies and agencies EASA, CAA and LGS.
Flight Time	In Demo 3 the flight time of the drone is limited to 60min.
Line of Sight	In Demo 3 the maximum distance of the drone flight is limited to 10km and one of the scenarios include BVLOS flight.
Height	In Demo 3 the height of the drone flight is limited to 120m.

Table 24 - UC1 D3: Boundary conditions

4.4.3.3 Features and/or subsystems

Correlation with the concept of U-Space services – the level of drone autonomy and drone connectivity will be provided in the context of U2 when the U-space initial services support the management of drone operations and may include flight planning, flight approval, tracking, airspace dynamic information, and procedural interfaces with air traffic control.

Feature/ Subsystem	Description	Requirements	U-Space or KET
Intelligent Mission Management	Unmanned Aircraft System Traffic Management system for authorization coordination and information exchange between drone service provider (LMT) and national authorities (EE/LV/LT/PL).	DEM3	Tracking and position reporting (U2) Surveillance data exchange (U2)
Contingency Management	Drone flight with 4G/5G support by native/roaming SIM cards - a path manager to monitor connection availability and quality (native/roaming SIM card) of the 4G/5G communication channels for drone autonomous flight. Downtime less than 5 sec.	DEM3	Communication infrastructure monitoring (U2) Communication coverage information (U3)
Planning and Scheduling	GSM downlink and uplink 4G/5G signal strength analysis tool for flight path planning	DEM3	Operation plan preparation/ optimisation (U2) Operation plan processing (U2)

Table 25 - UC1 D3: Features/Subsystems

4.4.3.4 Requirements

Requirement Type	Requirement ID	Short Description	Description	Priority (H/M/L)	Link to KPI
Functional Requirement	DEM3-FNC-1	Communication channel	The drone must communicate using 4G and 5G network. LTE-M based mobile network connectivity for autonomous flight C2C.	H	UC1-D3-KPI-01 UC1-D3-KPI-11
Functional Requirement	DEM3-FNC-2	Alternative communication channel	There must be the capability of deploying secondary (alternative) communications channel.	H	UC1-D3-KPI-01 UC1-D3-KPI-11
Functional Requirement	DEM3-FNC-3	Flight planning framework	The EU and national level legal framework requirements and guidelines must be followed.	H	UC1-D3-KPI-01
Functional Requirement	DEM3-FNC-4	Flight plan	The drone operator shall create a flight plan based on the daily basis inspection plan or incident communicated by railway technical surveillance/ safety system.	H	UC1-D3-KPI-01
Functional Requirement	DEM3-FNC-5	Tracking	The Command Centre shall be able to track drone throughout the mission.	H	UC1-D3-KPI-01
Functional Requirement	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	UC1-D3-KPI-01
Functional Requirement	DEM3-FNC-7	Drone navigation	The drone must autonomously navigate with high position accuracy during take-off, flight and landing	H	UC1-D3-KPI-01
Functional Requirement	DEM3-FNC-8	Authorisation of flight plan	The Control Centre shall be able to send/receive the authorization request for a flight plan proposed to the national civil aviation authorities. The complete authorization process shall be performed.	M	UC1-D3-KPI-01

Table 26 - UC1 D3: Main requirements

5 UC2: Construction

5.1 Overall motivation and ambition of the Use Case

5.1.1 Use Case concept and challenges

During the construction phase of a civil infrastructure, it is very important to keep a good track of its progress in order to have an adequate control of costs, times and qualities, as well as to be able to certify the state in which the construction process is at a certain moment. Nowadays, the construction process of an infrastructure is monitored through traditional processes, processes that have changed little in recent decades.

New technologies allow a great digitalization of the state of construction. In addition, these data must allow greater control in all phases of the construction process. (Measurements, advance control, digitalization, certifications.) So, the main challenge of the use case will be to develop the technology required to carry out any type of operation that allows the digitalization of the state of the constructive process of a transport infrastructure.

Moreover, this use case is aligned with the ECSEL Multi-Annual Strategic Plan (MASP) addressing the following key challenges and essential applications:

- Ensuring secure connected, cooperative, and automated mobility and transportation (Challenge 6.3.3).
- Infrastructure and services for smart personal mobility and logistics (Challenge 6.3.5).

5.1.2 Use Case objectives

The objective of the use case is to use the current drone technology and to develop the integration of sensors (Lidar/RGB) that allow the digitization of the state of the construction process and make all data capture without causing any interference in the development of activities undertaken in the work.

In addition, the use of the aforementioned technology allows to reduce the costs and times of Acquisition of Data in relation to traditional technologies; either by traditional surveying or terrestrial methods. The use case will validate this reduction and try to prove that the data obtained from the UAV platforms allows generating useful and applicable information for the construction and the management of the infrastructure.

The digitization of the state of the construction process will allow generating products that allow approximating the development of construction in a BIM Model, a work methodology that will be of mandatory use by 2020 in the European Union for the construction of civil infrastructures.

During the development of the Project, it is intended to demonstrate:

- Usability of drone technology for the digitization of constructive processes.
  - BVLOS technology.
  - Cyber-security test.
  - Does not interfere with the work.
  - Operational ease.
  - Risks evaluation.
- Improved system design productivity provided by the COMP4DRONES system engineering framework.
- Optimization of costs/times in constructive monitoring and maintenance/operations.
- Automatic data processing for the generation of basic products (MDT, ORTO, Curved).
- Development of algorithms to automate the point cloud classification and to identify vehicles, traffic, etc.

- Generation of BIM and exploitation of results.
- Detection of features and their location in video feeds: persons, construction vehicles, etc.

The **main stakeholders** will be all the construction companies that normally perform these types of operations in their works. Moreover, technology developers will be interested in the development of features that can bring significant advantages. In the case of the C4D, the main stakeholder will be Acciona, which takes the role of end-user, and the joint ventures and works of the Spanish government for which they work. At the technology level, all the partners involved in the development of the UC demonstrators will be also taken into account as major stakeholders.

5.1.3 Contribution to project objectives

The use case is aligned with the different general objectives of the project in order to obtain measurable outcomes. The main contributions to each objective are listed below:

Proposal Objective	Use Case Contribution	Measurable Outcomes
O1: Easing the integration and customization of drone embedded system	Application of the system modelling methodology ensuring component reusability, interoperability and adaptability. Analysis and selection of the best heterogeneous multicore platforms for each subsystem component.	Reference architecture, Integration, certification and customization efforts reduction
O2: Enabling drones to Integrate intelligent perception for safe control loops	Plug-and-play integration of composable GNSS+INS navigation systems. Use of the virtual model generation to analyse the extra-functional properties of the SW&HW for intelligent perception. Use computer vision to increase context awareness of the drone in-flight.	Obstacle avoidance, local pre-processing and post-processing techniques AI algorithms
O3: Ensuring the deployment of trusted communications	Use of the virtual model generation to analyse the trust of the communication network.	QoS, cybersecurity
O4: Optimize the design and verification effort for complex drone applications	Use of the COMP4DRONES design and verification framework to reduce the design time and effort for complex drone applications.	Design and verification effort
O5: Ensuring sustainable impact and creation of an industry-driven community	Preparation of training material based on the use case experience.	Courses, seminars

Table 27 - UC2: Contribution to project general objectives

Moreover, the use case is focused on contributing to achieve the technical objectives defined in the project. Next table summarizes the main objectives:

Proposal Technical Objective	Use Case Contribution
ST01: Integrated Modular Platform	Definition and implementation of a safety hybrid architecture that can combine better both approaches (modular architecture and heterogeneous multicore architecture). Integrate new sensors, safety elements and components.

ST02: Safe Intelligent Navigations	Composable GNSS+INS navigation systems. Advanced AI techniques. Deep learning for video. Safety monitoring.
ST03: Trusted Communication	Anomaly detection. Security measures. Vulnerability detection.
ST04: Design, Performance and Verification Tools	Model-driven approach. Compositional approach. Separation of Concerns. Tool interoperability.

Table 28 - UC2: Contribution to project technical objectives

5.1.4 Boundary conditions

Name	Short description
Regulation	the new European regulatory framework develop (Regulation (EU) 2018/1139, Delegated Regulation (EU) 2019/945 and Implementing Regulation (EU) 2019/947), and which is under integration in Spain, the regulatory framework for the use of RPAS is governed by Royal Decree 1036/2017, of December 15, which modifies Royal Decree 552/2014, of June 27.Once The protocols for coordinating flights in controlled airspace with the different service companies, such as Enaire, Ferronat or Saerco, are established.
EASA	The body in charge of regulating the use of drones in Spain is the State Aviation Safety Agency (EASA) , it must have the acceptance by EASA of all the established protocols, since you must request the authorization from EASA every time you want to carry out a flight in any of the following situations: • The cases in which the regulations themselves require the completion of a safety study. This requirement is essential every time you fly in populated areas and also at events where there are people meetings. • On flights beyond visual range or BVLOS. • In operations you carry out in areas of controlled airspace. • In operations with drones of more than 25 kilos. • Every time you want to make night flights.
Service provider applications	Some of the service providers have their own applications available to all citizens, so that any RPAS pilot or operator, professional or hobbyist, can plan the flight of their RPAS safely. Moreover, tools for consulting NOTAM (NOtice To AirMen) and for accessing aeronautical information in digital and integrated Insignia format are also made available to drone pilots and operators.
NOTAM´s in the work area	A NOTAM (Notice To Airmen), it is a notice presented to the aviation authorities to alert the pilots of the aircraft of possible dangers along a flight route or in a place that may affect the safety of the flight. When you plan to do a drone flight you should take into account all the events in your area.
Weather conditions	Following the Spanish normative all flights must comply with the established meteorological conditions to be able to perform the flight

Worksite conditions	

Table 3 - UC2: Boundary conditions

5.1.5 Traceability methodology

At the user-level and at each demo, It will check that the drone platform and the integrated components are able to do the missions established and if they fulfill the requirements. Moreover, the KPI´s progress will be check by evaluating the % of progress in each data acquisition campaign done. The evaluation could be done with tests at the laboratory level or in a relevant environment. This result of the tests displays the following information for each demo and subsystem that it lists:

- Work Progress
  - **% Work Completed**: A numeric value and visual representation that shows the percentage of completed work (KPIs) based on completed work for all tasks that are linked to the requirement.
  - **Work Remaining**: A numeric value for the rollup of all remaining work for all tasks that are linked to the requirement.
- Test Status
  - **Tests**: A numeric value that represents the number of test cases (laboratory tests or data acquisition campaigns) that are linked to the requirement or KPI.
  - **Test Results**: A numeric value and visual representation that shows the percentage of test cases where the options are Passed (green), Failed (red), or Not Run (black).

The validation tests and the combination with the progress check of the components will be more deeply explained in the D1.2 where the technological requirements are summarized

5.2 Demonstrator 1

5.2.1 Justification Plan

5.2.1.1 Demonstrator overview

The present demonstrator aims to develop the technology required to carry out any type of operation that allows the Digitalization of the State of the Constructive Process of a Civil Infrastructure. For the use case, a section of a road under construction will be analysed.

5.2.1.2 Description and scope

To achieve the digitalization of a civil infrastructure, the definition and study of the data will be required, to make the best use of them and try to achieve the challenge of creating a procedure to accelerate the extraction of the elements, from a cloud of points to a geometric definition.

The study of the data and the creation of different tools will allow identifying elements related to the geometry and characteristics of the terrain of the construction site, flat surfaces of structures, recognition of fix elements and alignments. The main objective is the automated creation of a database of objects of predefined types, directly out of the captured cloud points, where those objects are automatically recognized, detected and added to the database.

5.2.1.3 Objectives

On one side, the demonstrator will allow to assess operational risks due to loss of integrity in the navigation data, related to the operation of the drone in scenarios close to magnetic interference (GNSS outage zones, and malicious attacks). On the other side, this will also show how the improved navigation system contributes to the resilience of the navigation data, and by extension to the reduction of the operational risks.

Additionally, the demonstrator will enable the assessment of the design, performance analysis and verification methods and tools, which constitute the COMP4DRONES system-engineering framework.

These tools will allow the modelling of the BIM, the creation of a virtual model of the drone's application, the analysis of performance (delays, execution times, energy consumption, data traffic, etc.), application optimization and code generation.

5.2.1.4 Key concepts and technologies

WP	Task	Contribution
3	T3.1 & T3.2 & T3.3	Drone Pre-certified MPSoC based module.
3	T3.3	Computer Vision components for analysis of drone-captured data.
3	T3.2 & T3.3	Improved HW/SW platform for navigation solutions.
3	T3.2	Design and development of reusable, platform-independent, HW and SW components of the AFCS.
4	T4.1 & T4.2	Novel version of the navigation SW outperforming previous one and serving for the digitisation purposes. It will include positively assessed AI-based enhancements.
4	T4.2	Simulated data aggregator supporting intelligent decision in computer vision components
5	T5.3	Security Management Toolchain for the monitoring and control of drone vulnerabilities.
5	T5.2 & T5.4	Navigation system with anti-jamming and anti-spoofing features.
6	T6.3	Optimized version of HW platform for the navigation system. Optimized version of HW platform for GNSS compass.
6	T6.2	IoT Environment extra-functional validation methodology and toolchain.
6	T6.1 & T6.2 & T6.3	S3D: Mixed-Criticality system modelling, design & verification framework. SoSSim: Architectural exploration and design tool with extra-functional analysis (energy consumption, execution times & security) Tool.
6	T6.1 & T6.2 & T6.3	ESDE: ACORDE ESL eSW Design Framework (system-level modelling, eSW generation, performance estimation)

Table 29 - UC2 D1: Key contributions to each workpackage and task

5.2.1.5 Infrastructure and drones

For the development of the tools, the first testing and training flights will be done in the Villanueva de la Cañada airfield, located near to Madrid. It is an extensive private airfield that allows the training of pilots and experiments, as its airspace is not affected by general restrictions and regulations. It has two main landing areas: 03-21 280m compacted earth and 12-30 170m compacted earth airstrips.

Figure 25 - UC2 D1: Villanueva de la Cañada airfield

Another option for the testing and training flights is the Flight Test Centre called ATLAS. ATLAS is located in Villacarrillo, Jaen, Spain (see below Figures). It is specially designed for light and small UAS operations. It counts with 1.000 Km2 of segregated airspace until 5.000 ft. available jointly with a main runaway of 600 m and auxiliary one of 400 m which allows performing long-range flights even with the current Spanish UAS regulation. Telemetry and primary surveillance radar facilities are also available, along with a suited orography and climatology enabling more than 300 days per year for operations. Furthermore, offices, meeting rooms, hangars, workshops are ready for customers, including full support to operations: management of flight permits for the coordination of flight operations, and interactions with Civil Aviation Authorities in Spain. Then, this is an ideal location for outdoor technology integration and validation, before pilot experiments, and it is planned to be used in this project.

Figure 26 - UC2 D1: ATLAS flight test center, Villacarrillo

Finally, flights in a real construction environment will be done in Acciona’s facilities or works.

For this demonstrator, one drone has been initially selected. The drone is based on the Matrice600 platform from DJI (see below Figure). This is an off-the-shelf multi-rotor platform with 5Kg payload, around 20 minutes of endurance and a very versatile configuration since it has enough space to integrate the different sensors and equipment developed during COMP4DRONES project. Moreover, DJI offers an SDK that allows the integration of the multicopter autopilot with ROS (Robot Operating System), facilitating the use of advanced positioning functionalities based on GNSS.

Figure 27 - UC2 D1: DJI Matrice600 UAV platform

Demonstrator 1 is Level 3 in terms of **Drone Autonomy classification** as the operational tests will always involve 1 pilot per drone, but this pilot's function is only for safety back-up matter and is not supposed to act if there is no safety event during flight. When reaching an industrial stage, the overall system is designed to be capable to operate without pilot.

5.2.1.6 Implementation

5.2.1.6.1 Stage 1: Technology Validation

The first stage will be divided into two campaigns according to the project schedule. The first one, before month M4, will consist of the definition of the requirements of the demonstrator and in the identification of the civil construction site and testing fields where the first trials will be done.

In the second campaign, M4-M10, the technical requirements will be defined into more detail, the first GPS-drone integration tests and the initial test for the AI developments will be done. To test the developments and to obtain the necessary data first data and images acquisition will be performed.

5.2.1.6.2 Stage 2: Technology Experimentation

During the second stage and continuing with the development of the technologies required integration works on the first drone prototypes will be done. Data and image acquisition campaigns on testing fields will continue to test the developments and the debugging of the SW and HW solutions.

5.2.1.6.3 Stage 3: Technology Implementation

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

5.2.2 KPIs

5.2.2.1 Business KPIs

ID	Measured to be evaluated	KPI/Metric	Target Value
UC2-D1-KPI-05	Optimization of times in constructive monitoring	% reduction in the response time of monitoring of the status of an infrastructure.	20%
UC2-D1-KPI-06	Optimization of costs in constructive monitoring	% reduction of costs of monitoring the status of an infrastructure.	10%

UC2-D1-KPI-07	Optimization of the efforts in constructive monitoring	Reduction in % of the specialized workers and managers efforts.	10%

Table 30 - UC2 D1: Business KPIs

5.2.2.2 Technical KPIs

ID	KPI	Definition and measurement of indicator	Target value
UC2-D1-KPI-01	Recognition of work elements through AI.	Detection of main work elements position in the road through point cloud	Accuracy less than 20cm
UC2-D1-KPI-02		Detection of the total number of elements	At least 90% of the elements
UC2-D1-KPI-03	Improved performance of navigation solution.	Accuracy, Continuity and Integrity of position and attitude estimates are improved for practical usability for digitisation in open sky conditions.	10cm CEP error in position
			Bounded position and attitude error for any valid output with&without fix (integrity).
			<1deg RMSE error for all attitude components
			Valid data 90% of flight (continuity)
UC2-D1-KPI-04	Navigation following waypoints and capturing data.	The drone is able to fly autonomously covering the area of interest and capturing data along the whole flight.	90% of flight mission of the drone is done autonomously (all phases of data capturing). The rest of phases corresponds to take-off, landing and approach procedures, which could be done manually by the safety pilot.

Table 31 - UC2 D1: Technical KPIs

SMART					
KPI ID	Specific	Measurable	Actionable	Relevant	Timely
UC2-D1-KPI-01	KPI refers to the detection of the position in the road for main work elements to be detected.	The metric is measurable as we know the real position and the detected position by the computer vision system so we can calculate the precision.	The results obtained during project execution will provide feedback to improve the AI algorithms in terms of accuracy.	The detection of the work elements position in the road from the set of images captured from the drone is a relevant input for the BIM model definition.	These KPI metrics are obtained once the images of the road are captured and processed.
UC2-D1-KPI-02	KPI refers to the number of correct detected the work elements placed in the road	The metric is measurable as we know in advance the total number of the work elements placed in the road and then we know how many of them are detected by the computer vision component.	The results obtained during project execution will provide feedback to improve the AI algorithms in terms of accuracy.	The identification of the signals placed in the road is a key relevant functionality in the UC2 in order to improve the civil infrastructure construction.	These KPI metrics are obtained once the images of the road are captured and processed.

UC2-D1-KPI-03	KPI refers to specific geo-referencing parameters (position, attitude) and metrics (accuracy, continuity, integrity), Moreover, specific details (CEP, RMSE, open-sky) are provided for ensuring clear conditions and fair evaluation.	All these metrics are measurable, as ACORDE did in the past, and will do in UC2-demo1, in collaboration with the drone integrator (CATEC). Position and attitude error estimation will be done via post-processing, using the same raw captured data and RINEX files from base station, e.g., SEV12 (https://www.juntadeandalucia.es/institutodeestadisticaycartografia/rap/descarga-rinex), in the vicinity of a former capture flight.	Output results will let ACORDE evaluate the results and decide modifications and improvements, at least on the GLAD algorithms and configuration. Moreover, captures will be done so that also raw data, which will provide further evaluation of improvements taking the KPI metrics as a reference.	Position and Attitude accuracy is definitely relevant for the speeding up of the digitisation task. Poor accuracy demands the digitation tool widening the correlation windows and exponential increase of the computational effort.	These KPI metrics are obtained right after the flight. It can be a matter of days after the flights with only raw data capture (only scheduled for the former flight in Jan 2021)
UC2-D1-KPI-04	KPI refers to the capability to perform the flight according to the mission and the flight plan.	The metrics is measurable as we are able to know the numbers of flight that perform correctly the objective of the demonstrator.	The results obtained will let know the viability of the components, integrations and drone system.	The performance of the flights will give relevant information regarding the technologies and demonstrate the viability of the drones as tools for the construction works	The KPIs metric will be obtained when the results of the study of the test are done.

5.2.3 Specification Plan

5.2.3.1 Scenarios

The demonstrator 1 could be divided into two scenarios depending on the activities to be performed. First scenario will be related with the UVA platform and the data acquisition requirements in the construction site environment and the second scenario with the components develop and features related with the post-processing work that allows the digitalization of the status of the constructive process.

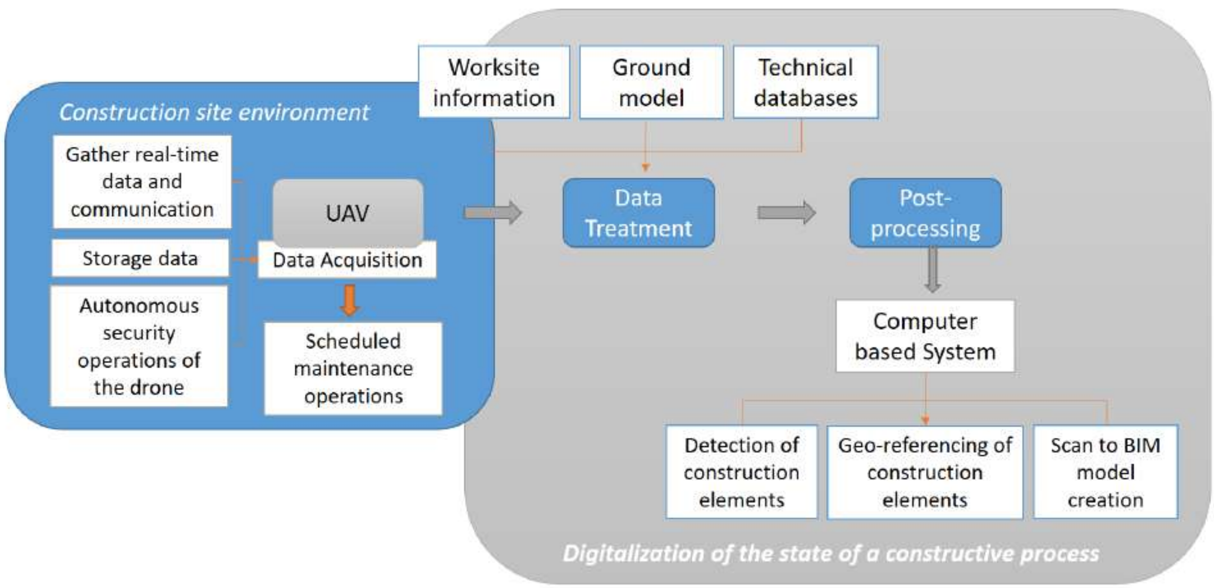


Figure 28 - UC2 D1: Main modules

Scenario ID	Scenario	Features	Priority (H/M/L)
Scenario 1	Data acquisition of the construction site environment	Gather real-time data and communication with the land station. Storage data Capacity Outdoor positioning and attitude estimation. Georeferencing system in-field autonomous security operations of the drone. Scheduled maintenance operations.	H
Scenario 2	Data treatment and post-processing	Detection of construction elements. Geo-referencing of construction elements. Digitalization of the state of a constructive process. Scan to BIM model creation.	H

Table 32 - UC2 D1: Scenarios description

5.2.3.2 Features and/or subsystems

Nº	Subsystem	Description	KPI
DEM1 – S1	Georeferencing system in-field	Outdoor positioning and attitude estimation. Multi-GNSS antenna system with sensor fusion capable to provide in real-time accurate estimation of position and attitude, synchronized with the GPS time base.	UC2-D1-KPI-03
DEM1 – S2	Post-processing computer vision system	Development of required software and algorithms in order to be able to detect construction elements and digitalize the status of a construction site.	UC2-D1-KPI-01 UC2-D1-KPI-02
DEM1 -S3	Security simulation systems	Analysis of security tools for remote vulnerability discovery and management.	UC2-D1-KPI-04
DEM1-S4	Remote sensing and drone platform	Monitoring and control of drone vulnerabilities and operations.	UC2-D1-KPI-01 UC2-D1-KPI-02 UC2-D1-KPI-04

Table 33 - UC2 D1: Subsystem description

Feature	Description	Subsystem	Requirements
Provide in real-time accurate estimation of position and attitude	The navigation and positioning systems developed and that later they will be shipped on the drone, they will be designed and implemented algorithms capable of performing the following operations: • Synchronized with the GPS time base (RTK-Real Time Kinematic). With a data link connection, such as GSM or Wi-Fi, the RTK system will connect to a base station or virtual reference station (VRS) through the laptop that controls the flight. Camera positions will be calculated in real time, referring to the ground base whose location is accurately measured over a long period. This type of calculations is essential to correct the camera positions until the models with errors around 2-3cm of precision are left, in the horizontal and vertical component. This information will be indexed in the metadata of the captured images to improve in time and precision the post-processing tasks in the composition of the photogrammetric models. • This real-time positioning system should allow decisions to be made regarding the drone's access to restricted flight zones and geofences enabled by the operator during use.	DEM1– S1	UC2-FUN-03 UC2-INT-01 UC2-PRF-01 UC2-PRF-02
Outdoor positioning and attitude estimation	As part of the payload of the onboard system, an enhanced version of GLAD [1], a GNSS/INS-based low-cost geolocation and attitude estimation system provided by ACORDE, is boarded. The system is capable to provide in real-time this information (and thus serving as either main or redundant position & location source to the navigation system). Thought, the main role of this system in the demonstrator is to serve as a helping trace for the speeding up of the digitisation process. Accurate position and attitude traces synchronized with the image data captured with the drone can save a main computational load to the digitisation process. However, achieving them via high grade inertial sensors and expensive multi-frequency receivers are an important barrier for 3D mapping and digitisation from UAVs [2].	DEM1– S1	UC2-FUN-03 UC2-FUN-04 UC2-INT-01 UC2-PRF-01 UC2-PRF-02

Detection of construction elements	To achieve the digitalization of civil infrastructure, the definition and study of the data will be required creating a procedure to accelerate the extraction of the elements, from a cloud of points to a geometric definition. The study of the data and the creation of different tools will allow identifying elements related to the geometry and characteristics of the terrain of the construction site, flat surfaces of structures, recognition of roads fix elements and road marks. The main objective is the automated creation of a database of objects of predefined types, directly out of the captured cloud points, where those objects are automatically recognized, detected and added to the database.	DEM1– S2	UC2-FUN-01 UC2-FUN-02 UC2-FUN-08
Geo-referencing of construction elements	In addition to the detection, it is also needed to georeferenced the construction elements. The geo-referencing of these elements it´s useful to know the spatial positioning of them into the BIM model.	DEM1– S1 DEM1– S2	UC2-FUN-01 UC2-FUN-02 UC2-FUN-03
Scan to BIM model creation	A unified point cloud file is typically data-heavy and must be broken down into manageable chunks. Algorithm-based modelling tools that operate within BIM authoring software help simplify the process by carrying out automated feature extraction, identifying items such as structures, bridges, road signs, and road markings and transforming them into 3D objects. 3D components in BIM effectively “know” what they are and where they are in the model and have survey data and attributes tagged to them. They provide designers with much more detailed information to work with than static 2D floor plans, sections, and elevations	DEM1– S2	UC2-FUN-02
Digitalization of the state of a constructive process	The drone in UC2 D1 has the mission of capturing data from the affected flight area (areas under construction, civil works assets, motorways and highways, ...) This capture will be carried out using mass data capture technologies and positioning systems in space. The post-processing in office of the entire set of data collected, through the use of new artificial intelligence technologies developed within the C4D, must provide the necessary data to carry out the Scan to BIM step, prior to the generation of a georeferenced model of assets construction and civil works.	DEM1– S2	UC2-FUN-05 UC2-FUN-06

Security Module	This is in charge of the data collection and information delivery to the monitoring services. The communication uses the OSSEC message protocol and is sent compressed over a cyphered channel. This module also applies the required software updates.	DEM1- S3	UC2-FUN-07
Security Services	This services outside the drone infrastructure process the received data and detect any vulnerability or anomalous behaviour. • **Monitor:** The monitor services are connected to the security modules through their OSSEC message protocol. • **Update:** The update services check if the security requirements regarding software components are up to date or need to be updated. If needed the updates are exchanged with the protocols used for each one of them.	DEM1- S3	UC2-FUN-07
Gather real-time data and communication with the land station	In addition to the images and videos, in order to complete the georeferenced models, it is necessary to collect the information in real-time and all the communications between the drone and the ground station.	DEM1-S4	UC2-FUN-05 UC2-FUN-06
Storage data Capacity:	During the missions, a large amount of data is generated that needs to be stored in the drone. Relevant information will be shared with the ground station, but in case of missing communication issues and bugs; the drone shall store all the information.	DEM1-S4	UC2-FUN05
Autonomous security operations of the drone:	The drone team must incorporate the main security operations for the execution of the missions in safe conditions. Depending on the use case, operations such as they return home in case of loss of communication or risk alarms (low battery, wind speed alert, geofencing, etc.) and the options for detection and avoidance of obstacles should be incorporated with the equipment.	DEM1-S4	UC2-FUN-07
Scheduled maintenance operations:	To ensure the correct operation of the equipment, it is necessary to incorporate on-site maintenance operations that can solve the problems without having to cancel the mission.	DEM1-S4	UC2-FUN-04

Table 34 - UC2 D1: Features description

5.2.3.2.1 Components

Component ID	Category	Subsystem	Name	Owner	TRL	WP
WP3-15_2	System (Positioning)	DEM1 – S1	Multi-antenna GNSS/INS based navigation	ACORDE	5	3
WP4-16	System (Positioning)	DEM1 – S1	Enhanced navigation SW	ACORDE	5	4
WP5-11-ACO	System (Positioning)	DEM1 – S1	Navigation system with anti-jamming and anti-spoofing features	ACORDE	4	5
WP6-21	Tool (HW/SW System Development Cycle)	DEM1 - S4	ACORDE ESL eSW Design Framework	ACORDE	5	6
WP3-04	System	DEM1 – S2	Computer Vision components for drones	HIB	7	3
WP3-01	System	DEM1 - S3	Pre-Certified SOM	IKERLAN	6	3
WP5-02	U-Space	DEM1 -S3	Security Management Toolchain for Drone Monitoring and Control	IKERLAN	5	5
WP6-22	Tool	DEM1-S4	IoT Environment Extra-functional validation methodology and toolchain	IKERLAN	5	6
WP6-23	Tool	DEM1-S4	Event based IoT Environment validation methodology and toolchain	IKERLAN	5	6
WP6-25	Tool	DEM1-S4	S3D Framework	UNICAN	6	6
WP6-26	Tool	DEM1-S4	VIPPE simulation & performance analysis	UNICAN	6	6

Table 35 - UC2 D1: Features/Subsystems

5.2.3.3 Requirements

Requirement Type	Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI	U-Space Service
Functional Requirement	UC2-FUN-01	Detection of construction elements	The computer vision system shall recognise and position typical construction elements such as Jersey barriers, guardrails and others from the point cloud.	H	Computer vision system / DEM1 – S2	UC2-D1-KPI-01 UC2-D1-KPI-02	Tracking (U2)
Functional Requirement	UC2-FUN-02	Export to BIM model	The computer vision system shall export the recognised elements to a BIM model.	H	Computer vision system / DEM1 – S2	UC2-D1-KPI-01 UC2-D1-KPI-02	Not related WITH U-SPACE. Post-processing service.
Functional Requirement	UC2-FUN-03	Position, Attitude estimation system	The GNSS/INS navigation system shall provide an accurate attitude & position trace that can be synchronized vs an absolute time reference for digitisation purposes.	H	Geo-referencing system / DEM1 – S1	UC2-D1-KPI-03	Tracking (U2)
Functional Requirement	UC2-FUN-04	Drone operation	The drone system shall fly following a predefined flight plan.	H	Drone system / DEM1-S4	UC2-D1-KPI-04	Operation plan preparation/ optimisation (U2)
Functional Requirement	UC2-FUN-05	Data captured	The drone system shall capture all the data and save it on-board for latter processing.	H	Drone system / DEM1-S4	UC2-D1-KPI-04	Not related WITH U-SPACE. Cost/performance requirement
Functional Requirement	UC2-FUN-06	Operation monitoring	The drone system shall communicate with a ground control station in order to be able to monitor the mission operation.	H	Drone system / DEM1-S3 / DEM1-S4	UC2-D1-KPI-04	Monitoring (U2)
Functional Requirement	UC2-FUN-07	Basic safety considerations	The drone shall consider a basic set of safety considerations to mitigate possible hazard risks.	H	Drone system / DEM1-S3	UC2-D1-KPI-04	Monitoring (U2)

Interface Requirement	UC2-INT-01	Geo-referencing system output trace formats	It may support the extraction of the attitude/position output trace in a format directly accepted by digitisation software.	M	Geo-referencing system / DEM1 – S1	UC2-D1-KPI-03	Tracking (U2)
Performance Requirement	UC2-PRF-01	Geo-referencing system estimation performance	Improved Position, Attitude estimation performance	H	Geo-referencing system / DEM1 – S1	UC2-D1-KPI-03	Tracking (U2)
Performance Requirement	UC2-PRF-02	Geo-referencing system cost performance	A low-cost solution for the accurate attitude-position output trace for digitisation (below FOG-based solutions <3K€ the cheapest).	H	Geo-referencing system / DEM1 – S1	UC2-D1-KPI-03	Tracking (U2)

Table 36 - UC2 D1: Main requirement

5.3 Demonstrator 2

5.3.1 Justification Plan

5.3.1.1 Demonstrator overview

This demonstrator will focus on the deployment of drones as new tools for the analysis of the status of the constructive process in underground constructions such as tunnels. The drone platform will be able to obtain data in real-time, keeping the distance to the wall sides and detecting any interfering obstacle inside the tunnel. During the flights, the drone platform will acquire data and, as a result, the system should give high accuracy models.

The information produced will improve the efficiency of the activities of planning, exploration, measurements of the underground environment, mapping of tunnels, generation of complete high-precision models, and production of base models for implementation in BIM. In short, it will be a helpful tool for decision making in hostile environments.

5.3.1.2 Description and scope

The main drawback in an underground environment when we make a flight with RPAs is the deactivation of the all the navigation elements based on GNSS positioning system. Currently, the main applications of RPAs are carried out in open spaces where aircraft perform precise positioning thanks to the GNSS signal received from different satellites. The RPAs use this signal as the main indicator of the horizontal position of the aircraft in the algorithms used for control, navigation, and stabilization in the air. However, in an underground environment, we will not have available this type of signal, which makes it difficult to use this type of vehicle indoors.

The use of RPAs in underground environments offers the same advantages and benefits as in open spaces. However, the vast majority of commercial vehicles are not designed to fly on enclosed spaces and those that offer some possibility, do it in a very limited way because their positioning system depends on the existing light indoors. To position themselves in the environment, these vehicles are equipped with sensors based on optical flow control systems, so they depend directly on the origin and quality of the light source. Due to these circumstances, its use may not offer good performance in many underground and mining works where the amount of light is usually poor and intermittent in nature.

In addition, indoor flights are faced with the inconvenience of space restrictions, which does not occur outdoors, where a deviation of meters may not be significant. In a closed environment, the vehicle must include embedded sensors that allow recognizing the stage, this way it will be able to avoid collisions with present objects and maintain a safe distance from the physical limits of the vehicle.

The resulting information of the autonomous underground explorations will be a point-cloud from which is expected to obtain a high-density 3D models in standard file format. Point-clouds will be combined with geolocation information to provide geoformation of the models, useful for underground survey works.

5.3.1.3 Objectives

The demonstrator will be focused on the development of the necessary embedded technologies and in demonstrating the capability of integrating them in a vehicle that will be able to fly in an underground environment. To solve some of the problems mentioned above, a different positioning/navigation system from the GNSS system will be integrated. Finally, all the post-processing of the data obtained will be also implemented in order to obtain high-quality 3D models that will help in the daily jobs of underground construction.

5.3.1.4 Key concepts and technologies

WP	Task	Contribution
3	T3.1 & T3.2 & T3.3	Drone Pre-certified MPSoC based module.
3	T3.3	Computer Vision components for drones.
3	T3.2 & T3.3	Improved HW/SW platforms for navigation solutions.
3	T3.2 & T3.3	Customized platform solution for georeferenced real-time indoor positioning.
3	T3.2	Design and development of reusable, platform-independent, HW and SW components of the AFCS.
4	T4.1 & T4.2	Anchor tag firmware of customized real-time georeferenced indoor positioning solution.
4	T4.3	Computer vision for drone's navigation based on Deep Learning with in-device and in-server profiles. Will focus on tracking of obstacles and send detection alerts and situational awareness data to control center.
5	T5.3	Security Management Toolchain for Drone Monitoring and Control.
5	T5.2 & T5.4	Robust and enriched communication among beacons, and among beacons and drone, enabling an improved indoor positioning.
6	T6.3	Optimized version of HW platform for the navigation system. Optimized version of HW platform for GNSS compass.
6	T6.2	IoT Environment Extra-functional validation methodology and toolchain.
6	T6.1 & T6.2 & T6.3	S3D: Mixed-Criticality system modelling, design & verification framework. SoSSim: Architectural exploration and design tool with extra-functional analysis (energy consumption, execution times & security) Tool.
6	T6.1 & T6.3	Modelling and Analysis Framework for Indoor Positioning Systems (IPS-MAF)

Table 37 - UC2 D2: Key contributions to each workpackage and task

5.3.1.5 Infrastructure and drones

First testing and training flights will be done in an indoor testbed at FADA-CATEC facilities. This indoor testbed has 15x15x5 volume with the VICON positioning system that can be used as a ground truth to validate the indoor navigation system. This testbed (see below Figure) will be used in the project as part of the integration and validation activities to further validate the technologies before the outdoor and pilot experiments.

Figure 29 - UC2 D2: FADA-CATEC Facilities

For this demonstrator, the drone will be based on a small aerostructure (like F550 from DJI) due to the specific requirements of the underground infrastructure. A special drone configuration will be used in order to integrate the advanced indoor navigation functionalities and the sensors required for 3D reconstruction (like for example Lidar). The autopilot will be based on PixHawk opensource autopilot and an external computer that will integrate the advanced GNSS-free navigation algorithms.

Demonstrator 2 is Level 3 in terms of **Drone Autonomy classification** as the operational tests will always involve 1 pilot per drone, but this pilot's function is only for safety back-up matter and is not supposed to act if there is no safety event during flight. When reaching an industrial stage, the overall system is designed to be capable to operate without pilot.

5.3.1.6 Implementation

5.3.1.6.1 Stage 1: Technology Validation

The first stage will be divided into two campaigns according to the project schedule. The first one, before month M4, will consist of the definition of the requirements of the demonstrator and in the identification of the civil construction site and testing fields where the first trials will be done.

In the second campaign, M4-M10, the technical requirements will be defined into more detail, the first GPS-drone integration tests and the initial test for the AI developments will be done. To test the developments and to obtain the necessary data first data and images acquisition will be performed.

5.3.1.6.2 Stage 2: Technology Experimentation

During the second stage and continuing with the development of the technologies required integration works on the first drone prototypes will be assessed. Data and image acquisition campaigns on testing fields will continue to test the developments and the debugging of the SW and HW solutions will be done.

5.3.1.6.3 Stage 3: Technology Implementation

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

5.3.2 KPIs

5.3.2.1 Business KPIs

ID	Measured to be evaluated	KPI/Metric	Target Value
UC2-D2-KPI-05	Optimization of times in constructive monitoring	% reduction in the response time of monitoring of the status of an infrastructure.	20%
UC2-D2-KPI-06	Optimization of costs in constructive monitoring	% reduction of costs of monitoring the status of an infrastructure.	10%
UC2-D2-KPI-07	Optimization of the efforts in constructive monitoring	Reduction in % of the specialized workers and managers efforts.	10%

Table 38 - UC2 D2: Business KPIs

5.3.2.2 Technical KPIs

ID	KPI	Definition and measurement of indicator	Target value
UC2-D2-KPI-01	Project construction using Virtual Construction Technology (BIM)	Monitoring of the work progress in real time,	Measurement deviations < 10%
UC2-D2-KPI-02	Self-Recognition of work elements through AI	Auto-detection of main work elements through point cloud.	Accuracy less than 20cm
UC2-D2-KPI-03	Position available at the tunnel to enable autonomous, way point based fly of the drone.	Position integrity for all the flight areas of the drone defined for the indoor facilities, with enough accuracy for safe flight.	Position error (CEP) <30cm in significant drone trajectories, <50cm in all the indoor infrastructure.
UC2-D2-KPI-04	Autonomous navigation inside the tunnel.	The drone is able to fly autonomously along a tunnel capturing data and avoiding collisions with the obstacles.	90% of flight mission of the drone is done autonomously (all phases of data capturing). The rest of phases corresponds to take-off, landing and approach procedures, which could be done manually by the safety pilot.

Table 39 - UC2 D2: Technical KPIs

SMART					
KPI ID	Specific	Measurable	Accionable	Relevant	Timely
UC2-D2-KPI-01	KPI refers to the capability to measure the work progress with the drones in an underground infrastructure.	The metric is measurable as we know the work schedule and we can calculate the real works regarding the expected ones.	The results obtained during project execution will provide feedback to calculate deviations in the tunnel surface and check the work progress.	The measurement of the work surface in the tunnel from the set of images captured from the drone is a relevant input for the calculation of the work progress and the quality measurements needed for other operations.	These KPI metrics are obtained once the images of the tunnel are captured and processed.
UC2-D2-KPI-02	KPI refers to the detection of the main work elements.	The metric is measurable as we know the real position and the detected position by the computer vision system so we can calculate the precision.	The results obtained during project execution will provide feedback to improve the AI algorithms in terms of accuracy.	The detection of the work elements position in the tunnel from the set of images captured from the drone is a relevant input for the BIM model definition.	These KPI metrics are obtained once the images of the tunnel are captured and processed.

UC2-D2-KPI-03	KPI refers to a specific geo-referencing parameters, position accuracy and integrity, with specific details (type of error: CEP, conditions of the CEP error) for ensuring clear conditions and fair evaluation	All these metrics are measurable. ACORDE has experience in setting up log systems and is supporting CATEC (drone integrator in UC2-demo1), for the system integration and suitable interfaces for enabling this data also on their telemetry. Specific la based in-lab experiments are being settled by ACORDE for ensuring a trustable position reference.	Output results will let ACORDE evaluate the results and decide modifications and improvements, at least on the anchor and tag algorithms and their configuration. Also, on the optimum anchor deployment.	A minimally accurate position along all the tunnel is relevant to keep the drone back to the desired digitisation trajectory (e.g., tunnel axis), and avoid dangerous closeness to a wall or an obstacle which risks the digitisation mission. Ensuring an even better accuracy on the planned trajectory is important for a stable positioning with minimum affectation on the digitisation instruments.	The metric will be obtained right after the flight
UC2-D2-KPI-04	KPI refers to the capability to perform the flight in an autonomous way	The metrics is measurable as we are able to know the numbers of flight that perform correctly the objective of the demonstrator.	The results obtained will let know the viability of the components, integrations and drone system.	The performance of the flights will give relevant information regarding the technologies and demonstrate the viability of the drones as tools for the construction works	The KPIs metric will be obtain when the results of the study of the test done are done.

5.3.3 Specification Plan

5.3.3.1 Scenarios

The demonstrator 2 could be divided into two scenarios depending on the activities to be performed. First scenario will be related with the UAV platform and the data acquisition requirements in the construction site environment and the second scenario with the components develop and features related with the post-processing work that allows the digitalization of the status of the constructive process.

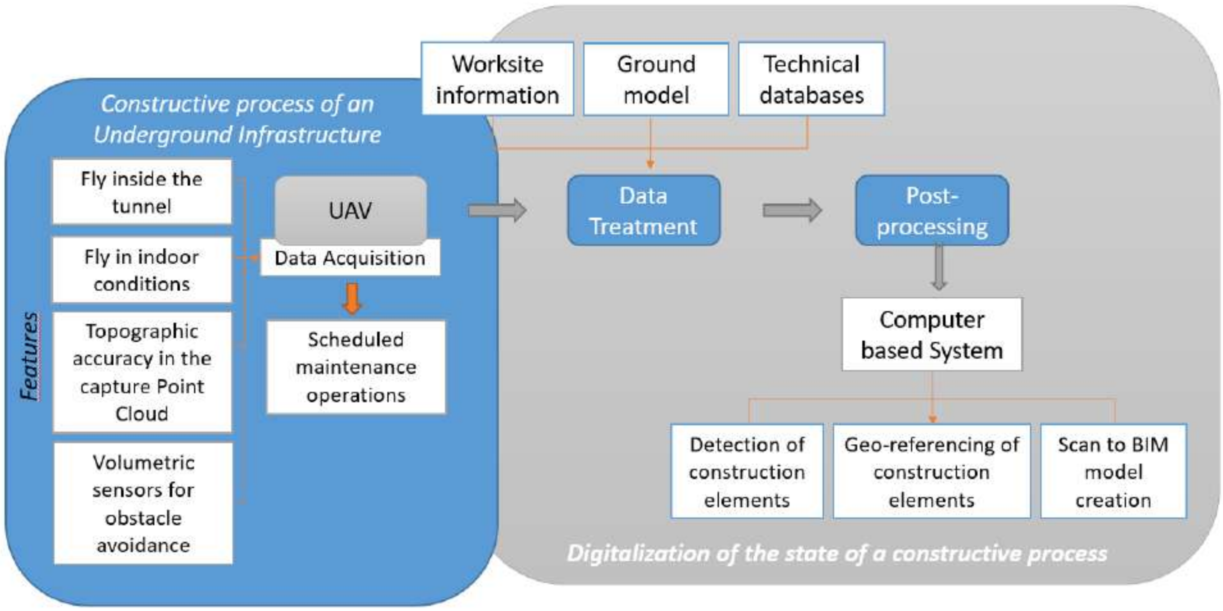


Figure 30 - UC2 D2: Main modules

Scenario ID	Scenario	Features	Priority (H/M/L)
Scenario 1	Data acquisition of the construction site environment	Autonomous tunnel navigation inside without direct GNSS positioning. Topographic accuracy in the capture of the point cloud. Fly inside the tunnel. Fly in indoor conditions. Storage data Capacity. Autonomous security operations of the drone. Scheduled maintenance operations.	H
Scenario 2	Data treatment and Post processing	Geo-referencing of construction elements. Digitalization of the state of a constructive process. Scan to BIM model creation.	H

Table 40 - UC2 D2: Scenarios description

5.3.3.3 Features and/or subsystems

Nº	Subsystem	Description	KPI
DEM2 – S1	Autonomous tunnel navigation inside without direct GNSS positioning	Indoor Navigation system. System able to provide location information for drone navigation and to perform the necessary autonomous operations.	UC2-D2-KPI-03 UC2-D2-KPI-04
DEM2 – S2	Computer vision system	Detection of construction elements and digitalize the status of a construction site in post-processing	UC2-D2-KPI-02 UC2-D2-KPI-01
DEM2 -S3	Communication system	Avoid interferences and communication losses with the drone prototype.	UC2-D2-KPI-02 UC2-D2-KPI-04
DEM2-S4	Drone system	Drone platform prototype development for indoor works.	UC2-D2-KPI-04 UC2-D2-KPI-01

Table 41 - UC2 D2: Features description

Feature	Description	Subsystem	Requirements
Fly inside the tunnel	The drone must be able to navigate autonomously within the tunnel following a pre-established path without GPS signal. The path should be defined previous to go inside the tunnel and once inside the drone must have a detect-and-avoid system in order to prevent collisions with the site equipment	DEM2-S1 DEM2-S4	UC2- FUN- 05 UC2- FUN- 02 UC2- FUN- 01
Fly in indoor conditions	The drone must be able to navigate within the tunnel with extremely conditions dust, humidity, and low lighting conditions. These conditions should not affect the quality of the data obtained by the drone	DEM2-S4	UC2- FUN- 06 UC2- FUN- 07
Development of a georeference d model	From the data obtained from the equipment, a georeferenced model (point cloud) must be created. The information obtained from the models will improve the efficiency of the activities of planning, exploration, measurements of the underground environment, mapping of tunnels, generation of complete high-precision models, and production of base models for implementation in BIM. In short, in any environment, it will be a helpful tool for decision making in hostile environments.	DEM2-S2	UC2- FUN- 11 UC2- FUN- 04
Indoor Positioning system	Indoor positioning concepts and technologies are crucial in this demonstrator. Their main application in this demonstrator is to enable real-time positioning of the drone platform. This is crucial for ensuring a sufficiently accurate and predefined (way-point based) flight of the drone platform within the tunnel. First, it enables safety, as it is possible to schedule routes indoor avoiding forbidden regions, or regions of the infrastructure occupied by machinery, fans, etc. It also enables the application of "indoors geofencing" (as a first measure, complementary to obstacle-detection systems).	DEM2 – S1	UC2- PRF- 01 UC2- PRF- 02 UC2- USA- 01 UC2- FUN- 05 UC2- FUN- 10
Geo-referencing of construction elements	In addition to the detection, it is also needed to georeferenced the construction elements. The geo-referencing of these elements it´s useful to know the spacial positioning of them into the BIM model.	DEM2-S2	UC2- FUN- 11 UC2- FUN- 04

Scan to BIM model creation	A unified point cloud file is typically data-heavy and must be broken down into manageable chunks. Algorithm-based modelling tools that operate within BIM authoring software help simplify the process by carrying out automated feature extraction, identifying items such as structures, bridges, road signs, and road markings and transforming them into 3D objects. 3D components in BIM effectively "know" what they are and where they are in the model and have survey data and attributes tagged to them. They provide designers with much more detailed information to work with than static 2D floor plans, sections, and elevations	DEM2-S2	UC2- FUN- 11 UC2- FUN- 02
Analysis of underground constructions status	The drone at UC2 D2 has the mission of capturing a georeferenced scanner of the progress in the construction of a tunnel developed by conventional means (explosives, gravel, hammers ...). This capture is carried out using drones inside the tunnel, capturing the data set using Lidar technologies and using positioning / navigation systems developed in the C4D project for autonomous navigation inside the tunnel. In the post-processing in the office, the entire set of collected data will be positioned in the space using software with automatic beacon / sphere recognition systems to subsequently carry out the Scan to BIM step prior to the generation of a georeferenced advance model of tunnel under construction.	DEM2-S2	UC2- FUN- 11 UC2- PRF- 01 UC2- PRF- 02
Storage data Capacity	During the missions, a large amount of data is generated that needs to be stored in the drone. Relevant information will be shared with the ground station, but in case of missing communication issues and bugs; the drone shall store all the information.	DEM2-S4	UC2- FUN- 02
Autonomous security operations of the drone	The drone team must incorporate the main security operations for the execution of the missions in safe conditions. Depending on the use case, operations such as they return home in case of loss of communication or risk alarms (low battery, wind speed alert, geofencing ...) and the options for detection and avoidance of obstacles should be incorporated with the equipment.	DEM2-S4	UC2- FUN- 01 UC2- FUN- 08 UC2- FUN- 09 UC2- FUN- 03
Drone system design	The equipment must be designed with systems that allow flight in the presence of obstacle (volumetric sensors) and must be able to follow a predefined trace in areas without satellite location. Furthermore, the final design must guarantee that the equipment is capable of flying more than 10 minutes before changing batteries with a high data storage capacity.	DEM2-S4	UC2- FUN- 02 UC2- FUN- 03 UC2- FUN- 04 UC2- FUN- 06 UC2- FUN- 07 UC2- FUN- 08 UC2- FUN- 09

Gather real-time data and communication with the land station	In addition to the images and videos, in order to complete the georeferenced models, it is necessary to collect the information in real-time and all the communications between the drone and the ground station.	DEM2-S4 DEM2-S3	UC2- FUN- 02 UC2- FUN- 04

5.3.3.3.1 Components

In the project different components have been defined in order to fulfill UC features and requirements, next table summarize the components related with the UC2-DEMO2.

Component ID	Category	Subsystem	Name	Owner	TRL	WP
WP3-15_1	System (Positioning)	DEM2-S1	UWB based indoor positioning	ACORDE	5	3
WP4-17	System (Positioning)	DEM2-S1	Anchor&Tag firmware of the Indoor Positioning System	ACORDE	5	4
WP5-19-ACO	System (Positioning)	DEM2-S1	Robust and enriched communication among beacons, and among beacons and drone, enabling an improved indoor positioning	ACORDE	5	5
WP6-21	Tool (HW/SW System Development Cycle)	DEM2-S4	Indoor Positioning System Modelling&Analysis Framework (IPS MAF)	ACORDE	4	6
WP3-30	Indoor System	DEM2-S1	Indoor positioning module	CATEC	5	3
WP3-01	SYSTEM	DEM2-S4	Pre-Certified SOM	IKERLAN	6	3
WP5-02	U-Space	DEM2-S4	Security Management Toolchain for Drone Monitoring and Control	IKERLAN	5	5
WP6-22	Tool	DEM2-S4	IoT Environment Extra-functional validation methodology and toolchain	IKERLAN	5	6
WP6-23	Tool	DEM2-S4	Event based IoT Environment validation methodology and toolchain	IKERLAN	5	6
WP6-25	Tool	DEM2-S4	S3D modelling Framework	UNICAN	6	6
WP6-26	Tool	DEM2-S4	VIPPE simulation & performance analysis	UNICAN	6	6

Table 42 - UC2 D2: Features/Subsystems

5.3.3.4 Requirements

Requirement Type	Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI	U-Space Service
Functional Requirement	UC2-FUN-01	Autonomous drone operation	The drone system shall fly autonomously along the tunnel.	H	Drone system	UC2-D2-KPI-04	Operation plan preparation/ optimisation (U2) Navigation structure monitoring (U2)
Functional Requirement	UC2-FUN-02	Data captured	The drone system shall capture all the data and save it on-board for later processing.	H	Drone system	UC2-D2-KPI-04 UC2-D2-KPI-01	Operation plan preparation/ optimisation (U2)
Functional Requirement	UC2-FUN-03	Operation monitoring	The drone system shall communicate with a ground control station in order to be able to monitor the mission operation.	H	Drone system	UC2-D2-KPI-04	Monitoring (U2)
Functional Requirement	UC2-FUN-04	Point cloud	The drone system shall save all the raw Lidar data.	H	Drone system	UC2-D2-KPI-02	Monitoring (U2)
Functional Requirement	UC2-FUN-05	GNSS unavailability	The drone system shall navigate without using GNSS localization.	H	Drone system	UC2-D2-KPI-03 UC2-D2-KPI-04	Tracking (U2)
Functional Requirement	UC2-FUN-06	Low visibility	The drone system and sensors shall work in very low light conditions.	H	Drone system	UC2-D2-KPI-04	Tracking (U2)
Functional Requirement	UC2-FUN-07	Humidity and dust	The drone system and sensors shall work under indoor construction conditions of humidity and dust.	H	Drone system	UC2-D2-KPI-04	Tracking (U2)
Functional Requirement	UC2-FUN-08	Obstacle detection	The drone system should be able to detect an obstacle on its flying route.	M	Drone system	UC2-D2-KPI-04 UC2-D2-KPI-03	Tracking (U2)
Functional Requirement	UC2-FUN-09	Obstacle avoidance	The drone system should be able to automatically avoid flying against obstacles.	M	Drone system	UC2-D2-KPI-04 UC2-D2-KPI-03	Tracking (U2)

Functional Requirement	UC2-FUN-10	Indoor positioning	An indoor positioning system shall provide geo-references position to drone for enable autonomous, waypoint-based flight.	H	Indoor System	UC2-D2-KPI-04	Tracking (U2)
Functional Requirement	UC2-FUN-11	Detection of construction elements	The computer vision system shall recognise and position typical construction elements	H	Computer vision system	UC2-D2-KPI-02	Tracking (U2)
Performance Requirement	UC2-PRF-01	Indoor positioning system accuracy	The system shall provide real - time navigation data with submetric accuracy in all the infrastructure.	H	Indoor System	UC2-D2-KPI-03	Monitoring (U2)
Performance Requirement	UC2-PRF-02	Indoor positioning system cost	The system shall imply an affordable and scalable cost for the infrastructure	H	Indoor System	UC2-D2-KPI-03	Not related WITH U-SPACE. Cost/performance requirement
Usability Requirement	UC2-USA-01	Indoor positioning system usability	Easy deployment of the system for workers.	M	Indoor System	UC2-D2-KPI-03	Operation plan processing (U2)

Table 43 - UC2 D2: Main requirements

6 UC3: Logistics

6.1 Overall motivation and ambition of the Use Case

6.1.1 Use Case concept and challenges

The logistics domain could benefit from a UAV system because it can provide features conventional solutions cannot offer: simultaneous delivery at several location for a reduced price, accessibility to remote areas or areas without infrastructures, overall speed of the delivery.

In order to demonstrate those capabilities, the use case develops two demos: the first one aims at delivering geophysical sensors using an autonomous fleet of UAVs, the second aims at delivering a parcel in a hospital using ground vehicles to carry it inside buildings and a UAV when outside to achieve fast deliveries.

However, these features require to tackle some challenges addressed in the UC. Mainly:

- Integration in the airspace.
- Ensuring clearance on take-off, landing and dropping.
- Carrying out logistics with a coherent fleet.
- Allowing the robots (UAVs and/or UGVs) to communicate and share their mission status.
- Monitoring a system and its operations in an efficient way.
- And achieving precise rendezvous between aircraft and ground droid.

6.1.2 Use Case objectives

The use case will focus on 6 main challenges that are related to several MASP Major Challenges:

- Selecting and Managing a heterogeneous fleet of autonomous vehicles.
- Using a communication infrastructure with redundant, secure, robust, dissimilar and deterministic abilities.
- Navigating and sensing at the landing or dropping zone with a high positioning accuracy and a guarantee of absence of objects, people or animals.
- Detecting and considering dynamically of aircrafts in the mission area and integrating vehicles of the system in air traffic management.
- Reducing risks and complexity on interactions between system operators and autonomous vehicles.
- Exploring some automated situations of logistics requiring multiple automated vehicles to cover the last mile delivery (i.e., UAV and rover collaboration for providing a service impossible by only one of them and reducing risks for people around them).

6.1.3 Contribution to project objectives

Proposal Objective	Use Case Contribution	Outcomes

O1: Easing the integration and customization of drone embedded system	Providing an architecture for a heterogeneous fleet able to adapt its size and content depending on the mission objective and various events during the operations.	Creation of a fleet architecture that can accommodate any number vehicles:
		• Remotely piloted ones that are fully controlled and monitored:
		  ○ Drones of different type
		  ○ Rovers
		• Manually piloted ones that communicate with the fleet (automatic avoidance, increased pilot awareness):
		  ○ Airships
		  ○ Helicopters
		  ○ Cars

O2: Enabling drones to Integrate intelligent perception for safe control loops	Providing increased awareness of the environment to each vehicle of the fleet and to the humans involved with it to facilitate decision making.	Creation of a comprehensive database that is exchanged between the different stakeholders of the fleet (the vehicles automated or not, the pilots and other humans that need to be informed of the fleet behaviour) allowing its safe control and monitoring. Creation of different control or monitoring interfaces adapted to the following use: • Fleet control • Manned aircraft pilot awareness • Operation management (performance follow-up) • Communication with ATC
O3: Ensuring the deployment of trusted communications	Providing a mobile communication network that can be deployed on any operational field with high level of availability and security.	Creation of a communication network that is able to: • Adapt its bandwidth, power and frequencies depending on the regulations of the country where it will be deployed • Be deployed in less than a day
O4: Optimize the design and verification effort for complex drone applications	Providing a comprehensive set of methodologies and tools to reduce the risk of failure to receive permits to fly for drone operations.	Creation of a methodology allowing the deduction from a drone mission description of all the safety related specifications that would guarantee the gain of a permit to fly for such missions. Creation of verification tools (including automatic code generation, simulation, SITL and HITL test benches) to speed up and reduce the cost of drone verification effort.
	Fast assessment of drone design and capabilities using digital twins	Virtual execution of operation profiles with virtual METIS UAV

Table 44 - UC3: Contribution to project general objectives

Proposal Objective	Use Case Contribution
ST01: Integrated Modular Platform	Developing a generic mission controller interfacing with most of autopilots and other standard modules in a robotic vehicle. The generic mission controller is compatible with COMP4DRONES architecture and has instantiated as a flight or road mission controller. At least 2 different types of drone and 1 other automated vehicle would use the same module.
	Integrating a distributed intelligent fleet management component in a safe & trusted architecture. Fleet management component will run in the mission controller as a safe function.
	Showing that a drone system can be built simply with components made by different third parties and proving by design, safely operations when running. Dynamic fleet or swarm management (Drone type addition, removal, modification).
	Demonstrating through a global system example that the control and the management of the fleet is possible with a minimum number of crew members. One man can command the complete fleet (more may be needed to prepare and maintain it).
ST02: Safe Intelligent Navigations	Designing a Ground Station for mission planning & supervision of heterogeneous vehicles, which is able to reduce complexity decision for the human authority. A single pilot is enough for operating the mission and handling every vehicle while being able to manage external and unpredictable events.
	Developing Algorithms for collaborative navigation and dynamic avoidance taking into account geofencing zones. Ability to continue the mission and to preserve the level of safety. No collision nor entry in protected zones (except for a limited time, the time to go out in the event of being in a dynamically allocated geofenced zones). Continue geofencing even in areas with very low GPS/Galileo coverage (between buildings, narrow streets).
	Increasing the automation and the safety of take-off and landing phases. Smooth and smart navigation above a terrestrial point taking account of several conditions (weather, safety zones, movement, etc.). Ability to land on a fixed or moving zone.
	Ensuring the clearance of a dropping or landing zone and positioning payload with situation awareness. Ability to detect predefined objects and to learn new situations. Ability to abort the dropping in case of presence of people and animals. Ability of a drone and a rover to complete a common task. Accuracy of the flying or driving position and of a meeting or dropped point.
	Detecting animals and other non-cooperative intruders in air or on ground. Ability to see and identify intruders on the Ground Station. Coordinates transmission to every vehicle in order that they are able to take appropriate decisions.
ST03: Trusted Communication	

	Development of an embedded module having generic communication interfaces for secure and resilient control / command links (C2Link) with vehicles during missions. Demonstrate fail safe capacity of communication network. Demonstrate resistance to cyberattacks. Tools chain to adapt to the low flow rate (rising) of the future 5G to remotely control the droids and drones, including relay switching areas or low 5G coverage.
	Building and validating by design a movable communication infrastructure for a complex and multi-layer system. Deployment of the communication network for a least one demonstration.
	Option: Ensuring dynamic navigation of flying communication relays to cover a targeted zone or to warrant good data links. Show that the vehicles composing the fleet can serve as relays in case of loss of communication.
ST04: Design, Performance and verification Tools	Simulation of failure situations and impacts on safety. Supervision of the overall communication link states and the associated level of risk. Measuring and challenging the safety level of a system including communication links.
	Methodology for the overall system safety analysis and for the propagation of the safety requirements in the design.
	Developing tools allowing to deduce the necessary and sufficient requirements from the concept of operations (CONOPS) in order that the system is intrinsically allowed to fly.
	Guidelines for development of drone (merging and adaptation for drones of ARP4754, DO178 and DO254 documents, with SORA guideline instead of ARP4761 document).
	Guidelines for development of droid / rover based on ISO 26262.
	Development of test benches: Fully simulated, allowing SITL, and allowing HITL. Test bench allowing the test of a fully assembled multirotor drone with force and momentum feedbacks with 3D simulation and visualization of its evolution.
	Developing tool to synchronize landing position between drone and rover using a target zone and sensors autonomously. Measuring and challenging the precision of parcel transfer between drone and rover.
	Modelling, virtual integration and dynamic simulation of METIS UAV (Digital Twin) in its environment. Drone virtual testing methods and framework proof of concept.

Table 45 - UC3: Contribution to project technical objectives

6.1.4 Boundary conditions

C4D has the ambition to be distribute components and drone solutions all over the European Union and its partner countries. To be allowed to do that each of them has to comply with the following requirements:

- European regulation regarding drones:
  - The latest regulations EU 2019/947 and EU 2019/945.
  - The regulations that will be produced between this document diffusion and C4D end (a first batch is expected in July 2020).

    - U-Space services compatibility.
- National regulation regarding drones: today, each EU country airworthiness authority is allowed to add their own rules to the EU regulations (they constitute the minimum to be respected).
- General Data Protection Regulation (GDPR): Drone relies heavily on data to operate and during their use, they may be in position to collect data from private individuals. This data management must comply with GDPR (this contributes in turn to the acceptability of C4D solutions).

With regards to the operational aspects, specific boundary conditions apply considering environment in which UAVs will operate. More specifically, for Demo-1:

- A segregated air space is required which allow flight altitude up to 150m and a radius of action of 3km corresponding to the communications network extension
- UAV's shall accommodate external temperatures up to 55°C and wind speed up to 10m/s

For the Use case 3 demo 2, the targeted weight of the drone is under 5kg. That means we will need some documents listed under to prepare the mission.

- European regulation regarding drones:
    - The latest regulations EU 2019/947 and EU 2019/945.
    - The next regulation of the EU planned for 2021
- National regulation regarding drones
- And a lot of documents authorizing the drone for a particular flight:
    - User Manual
    - Flight plan – ground plan
    - Manex
    - Operation Manual
    - Maintenance Manual
    - Risk assessment
    - MAP (manual of particular activity) + insurance
    - Emergency management plan

The specific boundaries applied on demo 2 are:

- A mission limited in range (2 to 3 km) and altitude under 150m
- A UAV weight under 5kg
- A delimited landing zone for each landing event in the demo
- Temperature between 5 and 50 °C and wind speed under 10m/s.

6.2 Demonstrator 1

6.2.1 Justification Plan

6.2.1.1 Demonstrator overview

Total kicked off its METIS® R&D project (EP TOTAL[3], 2018) in late 2014 to "unlock" hard-to-image in hard-to-access location. The project has developed an innovative 3D high-density (HD) geophysics solution that enhances the quality of subsurface images, lowers costs and HSE exposure while reducing the environmental footprint.

[3] METIS R&D Project: https://www.ep.total.com/fr/innovations/recherche-developpement/metis-un-systeme-integre-dacquisition-geophysique-pour-imager

6.2.1.2 Description, scope and stakeholders

In December 2017, a proof of concept (B. Pagliccia, K. Dalton, C. Walker, K. Elder, R. Jenneskens[4], 2018) with 1 drone delivering around 60 sensors in the tropical forest of "Papua New Guinea" was executed. At the industrial stage, the ultimate system will operate a fleet of 50 drones flying together to deliver up to 100 000 sensors in a foothills/deep forest environment with a minimal impact on the environment. The lesson learnt of Papua New Guinea is that the concept works but that the Authorities does not easily grant the permit-to-fly. Another proof of concept, with several drones operated by one pilot, is necessary to demonstrate that a quick deployment is possible with the agreement of the Authorities.

Based on this experience, TOTAL launched a project with the aim of designing and manufacturing a system operating a fleet of 6 drones in a context of seismic acquisition. Altran and Scalian combined their skills to conduct this project. Altran for the system (GCS) design as well as flight regulatory aspects, Scalian for the UAV design and fleet management aspects.

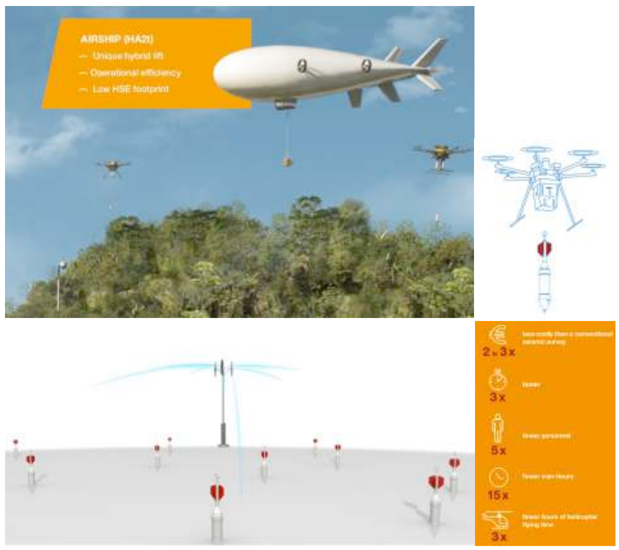


Figure 31 - UC3 D1: METIS concept of operations

6.2.1.3 Objectives

The ultimate aim of METIS® is to operate onshore geophysics operations faster (and cheaper) than the conventional way and with fewer personnel (also leading to HSE risk reduction).

Nevertheless, the METIS® concept is not restricted to oil prospecting and may be enlarged for **many other scientific or civil protection applications**:

- Research and rescue of people after natural disasters as floods, avalanches or earthquakes.
- Characterization of soil integrity for landfill sites.
- Research and control of water resources.
- Research and prevention of sinkholes.

[4] B. Pagliccia, K. Dalton, C. Walker, K. Elder, R. Jenneskens, *METIS Hits The Ground in Papua New Guinea, a Field-Proof Innovative Method to Revolutionize Onshore Seismic Acquisition*, EAGE 2018

6.2.1.4 Key concepts and technologies

By limiting human intervention on the ground, METIS® curbs the risks and environmental impacts through the implementation of key technologies:

- Maximizing the logistics from the air with a unique hybrid airship to replace the helicopter operations.
- Flying swarms of drones to efficiently cover huge surfaces with a state-of-the-art wireless real-time autonomous communication network which could be tied to any type of sensors.
- Re-engineering today's components to make the full communication network system eco-friendly with bioplastic, printed electronics and harmless batteries.

6.2.1.5 Infrastructure and drones

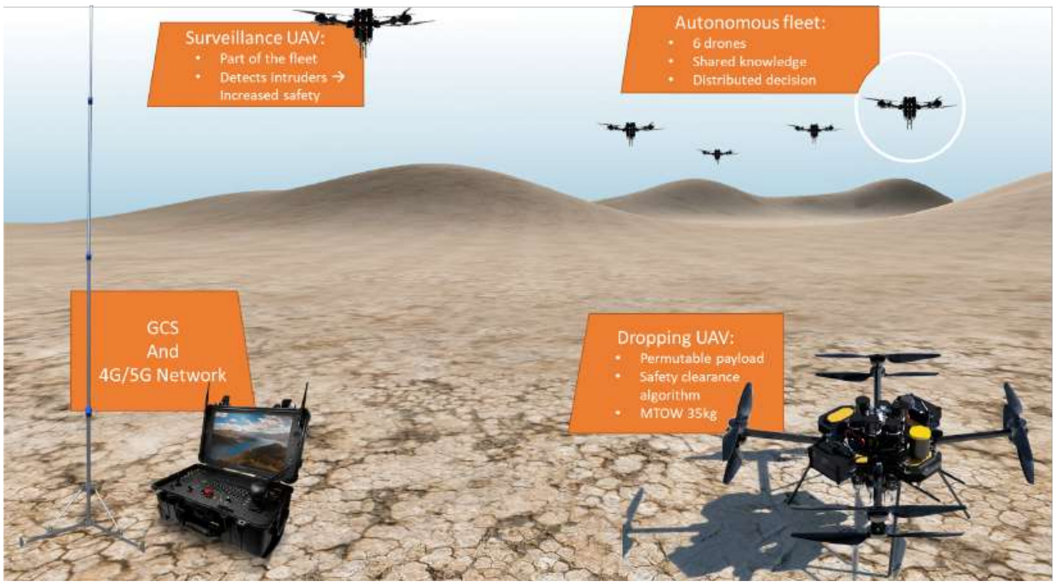


Figure 32 - UC3 D1: Composition of the METIS system

UAS: The system used in the demonstrator 1 is composed of a fleet of 6 autonomous drones. There will be several dropping UAVs that carry and drop the DART sensors. They will be helped by a surveillance UAV that will offer extra safety by detecting any intruders.

The system relies on an LTE network to allow all the agents to communicate and plan their actions. Finally, a GCS will be used by the operators to give high-level orders to the system (e.g., urgent return-to-home) and to provide mission information (e.g., operators entering the field of operations).

Autonomy level: Demonstrator 1 is Level 3 in terms of Drone Autonomy classification as the operational tests will always involve 1 pilot per drone, but this pilot's function is only for safety back-up matter and is not supposed to act if there is no safety event during flight. When reaching an industrial stage, the overall system is designed to be capable to operate without pilot.

6.2.1.6 Implementation

6.2.1.6.1 Stage 1: Technology Validation

- Validation of the concept with a small fleet of small heterogeneousness with drone pilots supporting the fleet manager.
- Vehicle modelling and virtual testing of foreseen operations in order to preliminary evaluate system integration and capacities. Analysis of flight measurements to improve the representativeness of the models.

- Preliminary assessment of specifications and concepts using modelling and simulation techniques.

6.2.1.6.2 Stage 2: Technology Experimentation

- Validation of the concept on dedicated bench with hardware in the loop, showing capability of the system to handle seismic-operation like missions
- Validation of the concept in flight with part of the fleet in heterogeneous configuration with drone pilots to support the fleet manager.

6.2.1.6.3 Stage 3: Technology Implementation

- Validation of the concept in flight with the whole fleet in heterogeneous mode with drone pilots restricted to safety related activities: (i) dart drops final authorization, (ii) emergency situation in case drone cannot go back safely to its pad.

6.2.2 KPIs

The expected uplifts of the drone technologies for seismic acquisition are dependent on the type of field it operates. For areas where, taking into account field constraints, sensor locations are easy accessible by humans (e.g., desert areas), the relevant performance expectations is mostly on productivity. For other areas where sensors locations are hardly accessible to human (e.g., rainy forest), conventional acquisition methods are environmentally intrusive, and the relevant performance expectation is on environmental footprint.

Following these considerations, 2 KPIs are proposed in relation with productivity and 1 with environmental footprint. Given the wideness of possible operation missions, the corresponding values for these KPIs will be evaluated by simulation, for a given operation scenario, using values obtained during the tests.

Another KPI is evaluating system safety, which is more related to system design, and is trivially a key aspect to obtain permit to fly in such type of operations.

Note that by using the word “operations”, we mean the deployment of <u>at least</u> 4000 sensors other a surface of <u>at least</u> 10km^2.

6.2.2.1 Business KPIs

KPI ID	Description	Goal
UC3-D1-KPI-1	Reduce the durations of operations in dense forests.	3 times faster 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.
UC3-D1-KPI-3	Be competitive for operations in accessible locations.	Equivalent duration and/or workload and/or cost than human based solutions.

Table 46 - UC3 D1: Business KPIs

6.2.2.2 Technical KPIs

KPI ID	Description	Goal
UC3-D1-KPI-4	Reduction of lost-time injuries, impact with infrastructures and airspace disturbances per hour of operations.	Less than 10^{-6}.

Table 47 - UC3 D1: Technical KPIs

6.2.3 Specification Plan

6.2.3.1 Scenarios

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
UC3-D1-SCN-01	Seismic Acquisition	Multiple UAVs Autonomous navigation Safe navigation Safe sensor droppings Autonomous flight plan decision	H	1
UC3-D1-SCN-02	Air & Ground intrusion detection	Multiple UAVs Autonomous navigation Safe navigation Object detection air&ground Object identification air&ground	H	1

Table 48 - UC3 D1: Scenarios description

6.2.3.2 Features and/or subsystems

The main features used in the Metis project are the following:

Feature/Subsystem	Description	Requirements	U-Space service
GCS	The GCS is the system that allow the operator to control and manage the fleet and its safe operations. It displays relevant information, offer orders that can be sent to the fleet.	UC3-OPR-005 UC3-OPR-006 UC3-INT-013 UC3-P&C-001 UC3-FNC-026 UC3-P&C-002 UC3-FNC-029 UC3-OPR-007 UC3-FNC-030	Geo-awareness (U1) Drone aeronautical information management (U1) Geo-fence provision (includes dynamic geo-fencing) (U2) Emergency Management (U2) Incident/accident reporting (U2) Monitoring (U2) Traffic information (U2) Procedural interface with ATC (U2) Collaborative interface with ATC (U3)
Precision Landing	The UAVs need to have a high reliability, to increase it a component is developed to allow a safe and precise landing in case of GPS loss.	UC3-PRF-004 UC3-FNC-010 UC3-FNC-13 UC3-FNC-15 UC3-OPR-003	Take-Off (KET 2.2.1) Landing (KET 2.2.2)
Clearance	When the UAVs are about the drop a sensor they must ensure that the drop point is clear of any unexpected human (operators or intruders), animals or vehicles. If an intruder is detected the drop is aborted.	UC3-FNC-002 UC3-FNC-004 UC3-FNC-005 UC3-FNC-006	Obstacle Detection and Avoidance (KET 2.2.7)

Shared Knowledge Base	The fleet shares the status of the mission and the individual status of each UAV and their progress on their tasks. A Knowledge Base is used to share the information, and each agent extracts information to plan their next tasks and flight trajectories.	UC3-INT-007 UC3-INT-008 UC3-FNC-023 UC3-INT-009	Geo-awareness (U1) Drone aeronautical information management (U1) Geo-fence provision (includes dynamic geo-fencing) (U2) Tactical Conflict Resolution (U3)
Safe Communications	As mentioned above, the fleet share its knowledge. All the communication shall be safe to allow the system to rely on the Knowledge Base, a communication system is developed to fulfil this objective.	UC3-INT-003 UC3-OPR-004	Drone aeronautical information management (U1) Traffic information (U2)

Table 49 - UC3 D1: Features/Subsytems

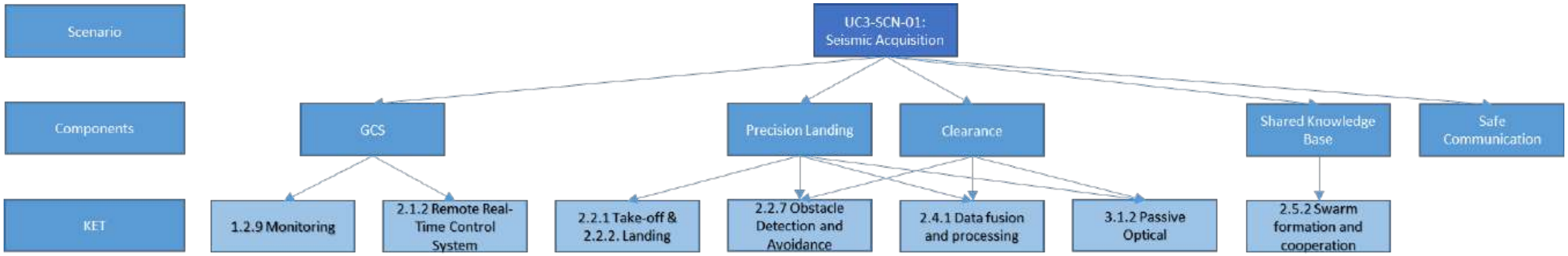
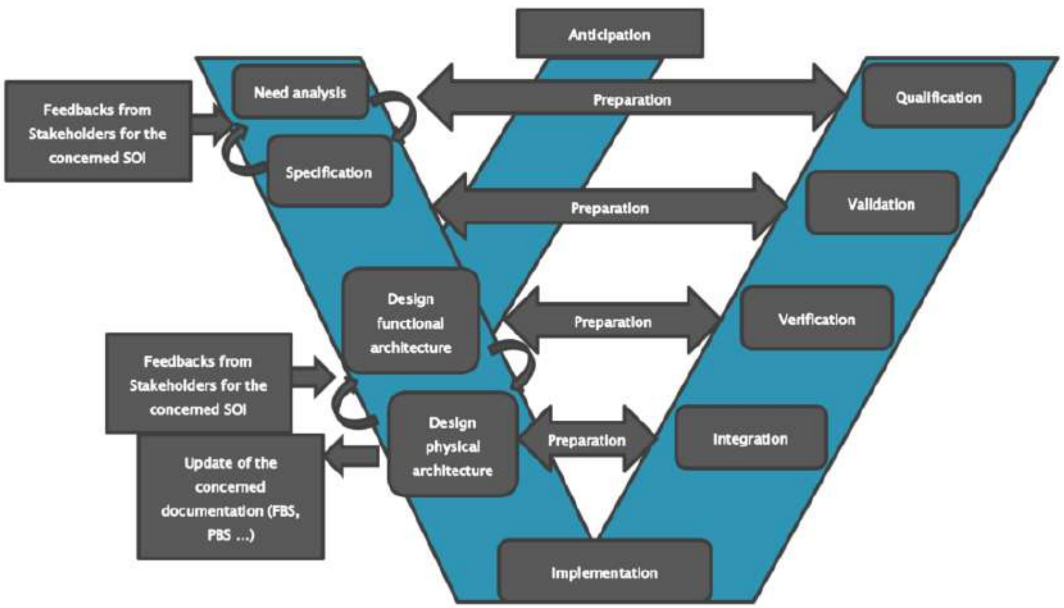


Figure 33 - UC3 D1: Relation between subsystems and KETs

6.2.3.3 Requirements



V&V traceability through the complete V-cycle as illustrated on the left is achieved using the same process as the one deployed for METIS project.

Needs, specifications, components and tests definition and linkage are managed through a database created using Excel with specific VBA macros.

Excel templates are used to define and reference them.

Traceability matrices and test reports are generated can be generated directly using these macros.

Below is the list of main requirements, the complete list can be found in the confidential requirement Excel delivered with this document.

Requirement Type	Requirement ID	Description	Priority (H/M/L)	Source	Linked KPI
Functional Requirement	UC3-FNC-001	The dropping agents shall be able to carry and safely drop sensors.	H	Total	UC3-D1-KPI-4

Interface Requirement	UC3-INT-001	The dropper agents shall communicate with the sensor they drop to check its status when arrived on ground.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Performance Requirement	UC3-PRF-001	The system shall guarantee 95% of delivery integrity	H	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Operational Requirement	UC3-OPR-001	The system shall allow day and night operations.	H	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Functional Requirement	UC3-FNC-034	The system shall operate without pilots. The pilot will be present only for legal purpose.	H	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
Functional Requirement	UC3-FNC-035	The system shall carry and drop 200 sensors per day to reach the production objectives.	H	Altran	UC3-D1-KPI-1 UC3-D1-KPI-3
Functional Requirement	UC3-FNC-036	The system shall reach level 3 in terms of Drone Autonomy Classification. Full automation of flight path creation and follow-up, pilots are presents only as a last resort.	H	Altran	UC3-D1-KPI-1 UC3-D1-KPI-3
Functional Requirement	UC3-FNC-037	The system shall ensure safety for humans (operators and third parties), infrastructures and manned aviation.	H	Altran	UC3-D1-KPI-4
Functional Requirement	UC3-FNC-004	The clearance algorithm shall detect intruders when they are: humans, animals, vehicles.	M	Scalian	UC3-D1-KPI-4
Functional Requirement	UC3-FNC-015	An UAV agent shall rely on the combination of a dedicated external positioning system and a computer-vision algorithm to land precisely. This precision is required to ease reloading operations.	L	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
Operational Requirement	UC3-OPR-003	When an UAV agent takes off and lands, it shall ensure the clearance of the dronepad to ensure the safety of the operators that are servicing it. Both using the clearance algorithm and other means (e.g. perimeter sensors).	H	Scalian	UC3-D1-KPI-4

Interface Requirement	UC3-INT-003	The system must provide a redundant, robust and secure communication so all the agents can have access to the shared knowledge base.	H	Total	
Functional Requirement	UC3-FNC-018	The communication devices used in the system shall be compatible with the regulation of the country where the use-case is carried out.	M	Scalian	
Operational Requirement	UC3-OPR-004	The communication devices and their infrastructure shall be deployable in less than a day.	M	Scalian	UC3-D1-KPI-1 UC3-D1-KPI-3
Functional Requirement	UC3-FNC-020	An UAV agent with the communication-relay role shall fly to a location such that it serves as a relay between different subgroups of agents in the system in order to maintain a quality of service on the communication.	L	Scalian	
Functional Requirement	UC3-FNC-021	The static agents could assume the role of: sensing (e.g. weather station), help operations (e.g. traffic light for ground vehicles), ensure safety (e.g. ground detection means), and so on.	L	Scalian	
Functional Requirement	UC3-FNC-022	The static agents shall be connected to the shared knowledge base and populate it if relevant.	M	Scalian	
Interface Requirement	UC3-INT-007	The mobile agents (UGV and UAV) shall be able to connect to the shared knowledge.	H	Scalian	
Interface Requirement	UC3-INT-009	The knowledge base shall be updated with information from traffic control management, allowing to take external aircraft into account.	H	Total	UC3-D1-KPI-4
Operational Requirement	UC3-OPR-005	The GCS shall be able to handle multiple agents or system of agents.	H	Altran	
Operational Requirement	UC3-OPR-006	The GCS shall be able to handle different types of agents at the same time.	M	Altran	
Interface Requirement	UC3-INT-010	The GCS shall be able to receive feedbacks from the agents or system of agents.	H	Altran	
Interface Requirement	UC3-INT-011	The GCS shall be able to display feedbacks from the agents or system of agents.	H	Altran	
Interface Requirement	UC3-INT-012	The GCS shall be able to send commands to agents or system of agents.	H	Altran	
Interface Requirement	UC3-INT-013	The GCS shall allow for communication with the agent or system of agents pilot.	H	Altran	
Policies & Compliance Requirement	UC3-P&C-001	The GCS shall be compliant with U-SPACE requirements	H	Altran	

Policies & Compliance Requirement	UC3-P&C-002	The GCS shall be compliant with European Union regulations	H	Altran	
Performance Requirement	UC3-PRF-007	The GCS shall be compliant with C4D recommendations regarding safe communications	H	Altran	
Operational Requirement	UC3-OPR-007	The GCS shall be able to manage declared and undeclared agents or system of agents.	L	Altran	
Functional Requirement	UC3-FNC-031	The GCS shall allow Operation Managers to check that the agents or systems of agents usage of their payload is compliant with their limit of use.	H	Altran	UC3-D1-KPI-4
HSSE Requirement	UC3-HSSE-001	The system shall divide by 10 the human exposure compared to human-based operations.	M	Total	UC3-D1-KPI-4
HSSE Requirement	UC3-HSSE-002	The system shall divide by 10 the operator exposure compared to human-based operations.	M	Total	UC3-D1-KPI-4
HSSE Requirement	UC3-HSSE-003	The system shall have CO_2 neutral operations to comply with recommendations from COP21 2°C target.	L	Total	UC3-D1-KPI-2
HSSE Requirement	UC3-HSSE-004	The system shall be compliant with noise-level regulations.	M	Total	UC3-D1-KPI-2
Operational Requirement	UC3-OPR-008	The system shall be transportable worldwide.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Operational Requirement	UC3-OPR-009	The system shall be operable worldwide.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Operational Requirement	UC3-OPR-010	It shall be possible to operate the system in remote location, even with low/no infrastructures.	L	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Operational Requirement	UC3-OPR-011	The system shall perform at least 500 hours of flight free of MRO.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3

Usability Requirement	UC3-USB-005	The system shall allow to be operated without language requirements.	L	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Usability Requirement	UC3-USB-006	The system shall be operated by trained technicians.	L	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Usability Requirement	UC3-USB-007	The system shall use automated payload loading to reduce refill time and increase productivity.	L	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Policies & Compliance Requirement	UC3-P&C-003	The system shall be compliant with CE mark.	M	Total	
Policies & Compliance Requirement	UC3-P&C-004	The system shall be compliant with ISO 9001 standard. Quality standard at every stage of design and manufacturing are mandatory to ensure reliability and safety of the system.	M	Total	UC3-D1-KPI-4
Policies & Compliance Requirement	UC3-P&C-005	The system shall be compliant with ISO 14001 standard. This standard will ensure the system will be compliant with environmental regulations of today and tomorrow.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Policies & Compliance Requirement	UC3-P&C-006	The system shall comply with JARUS requirements. This should increase the possibility to use the system worldwide.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Policies & Compliance Requirement	UC3-P&C-007	The system shall comply with EASA requirements on UAVs.	H	Total	
Design Constraint	UC3-DSG-001	The system shall operate under wind conditions up to 3 on the Beaufort scale.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3
Design Constraint	UC3-DSG-002	The system shall operate under light rain.	M	Total	UC3-D1-KPI-1 UC3-D1-KPI-3

Design Constraint	UC3-DSG-003	The system shall have an IP67 rating.	H	Total	
Ethical Requirement	UC3-P&E-002	The system shall be compliant with the GDPR regulation since its uses a camera.	H	Total	
Ethical Requirement	UC3-P&E-003	The system shall address legal liability across Europe in case of damage to people or infrastructures.	H	Total	UC3-D1-KPI-4
Ethical Requirement	UC3-P&E-004	The system shall not be used for non-civil applications. The system must be designed to prevent malicious usage which could compromise its acceptability by the civil society.	L	Total	
Ethical Requirement	UC3-P&E-005	The system should be designed to allow to be integrated in education program from universities in robotics & automation, key competencies for the young generation.	L	Total	

Table 50 - UC3 D1: Main requirements

6.3 Demonstrator 2

6.3.1 Justification Plan

6.3.1.1 Demonstrator overview

The goal of this demonstrator 2 is to make collaborate a terrestrial droid and an aerial drone. This demonstration will be done in two stages:

Stage 1 (France): the design of the droid and the drone will be done in France as well as their development and tuning on an industrial site. This step, the longest, will show the interest in very large factories to couple a drone and a droid to carry light parts.

Stage 2 (Latvia): the second phase consists of duplicating the factory experiment on a demonstration in another sector, that of hospitals with the transport of medicines / samples with drones and droids.

6.3.1.2 Description and scope

6.3.1.2.1 Stage 1 (France): industrial site logistics

The intended use case is the transportation of spare parts in emergency to very large industrial sites. The site under discussion is the PSA Peugeot Citroën group at Sochaux. This site covers 200 hectares and employs 7,000 people. The Peugeot 308 and 5008 are produced on this industrial site. Production is around one car every minute.

Some machines in the production line may break down. In this case a technician diagnoses the failure and tries to repair it. If he needs a spare part, then he does a request to the central spare parts store. There is only one store on the site and the part can take several minutes to arrive and therefore the production chain is blocked. This can have significant cost implications for the business.

This use case will relate to the coupling between an Atechsys drone and a TwinswHeel droid in order to carry the parcels from point A to B in the most efficient and safe way possible. The droid carries the package on the first and last meters, and the drone on the long distance between the point of departure and arrival. The droid and the drone exchange the parcels.

This use case will enable the French partners to develop and validate the technology of autonomy as well as of the telecom network or the mechanical elements before carrying out the final tests in Latvia (Latvia) on the use case of the Hospital for children (2nd stage). The partners of this demonstrator 2 are: TwinswHeel, Atechsys, ENSMA, ENAC, CEA, Altran, IMCS Sherpa and Siemens.

The requirement providers are TwinsWheels and Atechsys.

The mainly component providers will be: ENSMA, ENAC, CEA, Siemens, Altran and Scalian.

The mainly tools providers will be: CEA, IMCS and Sherpa.

Scenario 1: on one of the production lines, the sheet metal stamping robot breaks down. A technician with his tools comes to diagnose the failure. He cannot repair on site because the part that supports the stamping tool on the robotic arm is broken. The technician immediately orders the part to be replaced using the intranet information system. At the spare part store immediately, they supplied this part and deposits it in droid n ° 1. The droid goes autonomously to the take-off area of the drone. The part is transferred from the droid to the drone automatically. The drone transports the part from the store to the sheet metal building over 1600 meters. The drone will fly over several buildings and roads, but still on the factory's private site. At the end, a droid n ° 2 awaits the drone. The drone transfers the part to the droid automatically. The droid brings autonomously the part to the technician in the building (indoor) by covering the last 500 meters. It is delivery on demand!

Scenario 2: daily delivery of small objects from the reception area to the buildings of the industrial site. Every morning before 10 a.m. must be delivered to buildings distant from the delivery area for small packages arriving just in time from suppliers for the assembly of cars. The logistics department receives the packages and loads them into the droid n°1. The droid leaves the buildings and transfers the package to the drone. The drone will travel between 900 and 3,200 meters to deliver its package. At the reception, droid n°2 collects the package, then enters the building to travel between 300 and 800 meters to deliver the package to the final recipient. It is scheduled and recurring delivery!

Scenario 3: it is for an urgent delivery of the aperitif at 11.45 am on a Friday before holiday. Robert, technician expert in pretzel asks the droid n ° 1 to bring the cookies and the fruit juices to Bernard which is 3 buildings further. The droid n ° 1 transfers everything to the drone which transports it to the Bernard building where the droid n ° 2 awaits it. The droid n°2 retrieves the package and brings Bernard the precious sesame that he has been impatiently waiting for since 11:15 am.

6.3.1.2.2 Stage 2 (Latvia): Urgent transport of medication taken from a children's hospital

The case example for tests on semi-open sites is that of hospitals for the transport of equipment, drugs or blood samples. This case is based on real life situation. Hospital needs a fast and reliable method for transportation of laboratory samples between several points inside relatively large hospital territory with several buildings. Delivery by drones is selected to provide a solution which have to satisfy hospital requirements (special challenge is safety and security requirements as deliveries are inside the hospital campus).

6.3.1.3 Objectives

The C4D project will allow reaching a level of maturity enough to carry out the scenarios described below. The objective of the UC3 is to carry out logistics tasks on closed sites (example: factories, warehouses) and semi-open sites (example hospitals). The goal is to show that we can perform logistics tasks on demand (urgent) and pre-program (recurrent) by coupling a droid and a drone. The droid travels the first and last meters in buildings and near buildings, the drone travels long distances above the sites. We have usage goals and design/technical goals

6.3.1.3.1 Technical / design objectives

1. System engineering to link customer requirements to technical requirements and validation plans (functional and safety).
2. Develop algorithms for the autonomous displacement of drones and droids.
3. Development of algorithms for the secure remote control of drones and droids.
4. Coupling between the drone and the droid in terms of positioning, communication and package transfer.
5. Functional and dysfunctional validation of drones and droids according to the validation plan.
6. Manufacturing of a demonstrator and tuning it in France.

6.3.1.3.2 Usage objectives

1. Management the coupling on a mission between the droids and the drones.
2. Management of a drone and droid fleet on very large industrial sites for different application cases.
3. Acceptability by site staff.
4. Performance of the proposed logistics solution.
5. ROI and economic model.

6.3.1.4 Key concepts and technologies

To achieve the objectives defined by the scenarios, we must implement several key technologies. These key processes and technologies will allow the logistics service to be carried out in complete safety.

6.3.1.4.1 Hardware and software for environmental perception

The drone or droid must perfectly perceive its environment. For this, it is equipped with sensors such as 2D or 3D Lidar, 3D camera, RGB camera, infrared sensor, ultrasonic sensors, inertial unit, etc. All this data is processed (filtering and merging) on on-board computers with GPU and FPGA type.

The algorithms that are embedded on these hardware cards are of the machine learning type with neural networks to classify objects and segment the scenes captured by the various sensors.

6.3.1.4.2 Hardware and software for autonomous displacement

From the knowledge of the environment, the droid or the drone are able to position themselves and perceive potential fixed or moving obstacles on their trajectory. The location is based on pre-established maps of SLAM output type and RTK GPS. From the definition of routes and virtual station, the drone and the droid are able to move autonomously. The hardware must be able to run localization algorithms, scene comprehension, obstacle avoidance algorithms.

When avoiding obstacles, the vehicle must be able to predict the trajectory of moving objects in its environment in order to avoid any risk of collision. This avoidance must be monitored by the onboard software to avoid making decisions that are too random or dangerous.

6.3.1.4.3 Coordination between droid and drone

The drone and the droid must exchange the parcel to be transported. They must therefore be able to communicate with each other either directly or through a supervisor network. The two vehicles will be able to exchange information from their sensors in order to better perceive the environment, or to guide each other. For example, the droid's cameras will guide the drone through the take-off and landing phases.

The droid and the drone must be mechanically compatible to transfer the parcel and it is envisaged that the drone can recharge its batteries on the droid.

6.3.1.4.4 Secure communications

All communications between the droid, the drone and the base station will be highly secure. Our security approach is holistic by design

- Remote server: generation of encrypted keys and certificates.
- Securing the networks of our partners (Orange).
- Firewall in droid and drone.
- Validation of keys / certificates of incoming / outgoing messages (certificate lib).
- Intrusion detection and writing in immutable logs.

Penetration tests and vulnerability scans will be conducted to highlight our level of protection and establish corrective actions to be carried out throughout the project.

6.3.1.4.5 Development methodology supported by tools

To ease the development and qualification of the drone and droid systems while improving the productivity, a number of tools are needed for modelling, code generation and reuse, requirement tracing and schedulability analysis.

Below is a summary of Key concepts and technologies:

Building Blocks	Technological components, sub-system, tools / Responsible Partner(s)	TRL (final objective)
	Droid platform	
Architecture	4-wheel mobile platform that can roll indoors and outdoors (not in the rain). It can carry up to 60 kg for the drone capture and parcel exchange area [TwinswHeel].	TRL 7
Runway	Landing strip for the drone on the droid to guide it. Potential coupling of a drone battery recharge system on the droid [TwinswHeel].	TRL 5
Package transfer	System to automatically transfer the package from the droid to the drone and vice versa [TwinswHeel].	TRL 5
Sensor	Lidar 2D + ultrasonic + camera RGB + IMU + wheel encoder + RTK GPS [TwinswHeel].	TRL 7
Computer	CPU + FPGA or GPU [TwinswHeel].	TRL 7
	Drone platform	
Architecture	Quadcopter drone that can fly between 30 minutes and one hour. The carrying drone is around 4kg and will have a parcel exchange area to transfer parcel from the droid to the drone and vice versa.	TRL 6
Package transfer	Mavlink architecture transfer protocol for all flight command control. Encrypted communication for the rest.	TRL 5
Sensor	Lidar 2D, camera RGB, GPS, drone identifier.	TRL 7
Computing	The autopilot will be Atechsys hardware with the software autopilot acquired during the COMP4DRONES project.	TRL 6
	Communication Layer	
Data Transmission	The droid and the drone must be able to communicate directly in safety when they are close (less than 10 meters) [TwinswHeel].	TRL 5
	All remote communications must go through a remote server based on existing 4G and 5G networks [TwinswHeel].	TRL 6
	Encrypted security systems must be installed between the vehicles and the base [TwinswHeel].	TRL 5
Security	Generation of encrypted keys and certificates.	TRL 5
	Intrusion Detection System module.	TRL 5
Safety	Intrusion detection and writing in immutable logs.	TRL 5
	Software Layer	
Autonomous displacement	Vision and perception of the environment.	TRL 7
	Trajectory planification and obstacle avoidance.	TRL 7
	Localisation.	TRL 7
	Trajectory control.	TRL 7
Safety + SOTIF	Safety + validation plan with critical use cases.	TRL 6
Remote control	Communication and remote control of the droid.	TRL 7
Coupling drone / droid	Guiding the drone from the droid.	TRL 6
	Exchanges of information between the drone and the droid.	TRL 6
	Tools	
Modelling	Language and modelling environment.	TRL 5
Code Generation	Code Generation from models.	TRL 5
Schedulability Analysis	Scheduling Analysis Algorithms and Tools.	TRL 5

Runtime Monitoring	Runtime Safety Monitoring Component with associated configuration tools.	TRL 4

Table 51 - UC3 D2: Summary of Key concepts and technologies

6.3.1.5 Infrastructure and drones

6.3.1.5.1 Stage 1 (France): industrial site logistics

Figure 34 - UC3 D2: Stage 1, industrial site logistics

The PSA Sochaux site is our potential pilot site (under discussion). On this site, 452,000 vehicles are produced per year. It covers more than 200 hectares with many buildings. The site is covered by 4G with a 5G project. We only need 4G for the demonstrator. 5G is necessary for testing with fleets of droids and drones.

If the tests cannot be done at PSA, we are also in discussions with an SNCF TECHNICENTRE in Lyon and a Framatome factory.

6.3.1.5.2 Stage 2 (Latvia): Urgent transport of medication taken from a children's hospital

Figure 35 - UC3 D2: (Left) Laboratory building with laboratory on 3rd floor (see red arrow). (Right) Laboratory room from inside

Figure 36 - UC3 D2: First delivery point

Figure 37 - UC3 D2: Second delivery point

6.3.1.5.3 Droid

TwinswHeel is a French SME that develops logistics rights. TwinswHeel droids are deployed on:

- Closed sites: factories, warehouses.
- Semi-open sites: hospitals, train station, airports.
- City: e-commerce, shopping delivery, services.

For example, some droids for the city of TwinswHeel. The weight indicated between parentheses is the payload of the logistic droids

Fast Courier (40 kg) Pegasus(120 kg) Cargo (300 kg)

Figure 38 - UC3 D2: TwinswHeel droids

The droid that will be used in the COMP4DRONES project is a droid from the TH17 Trottine family. It is a mobile droid base that is used today in factories and in cities. The application is to carry heavy loads. For the city, these droids assist the elderly and disabled. The person with reduced mobility can return to grocery shopping with the droid that follows them in the store. The droid also follows the person at home while rolling on the sidewalks and can take the elevator to enter the person's apartment. This gives mobility to people who have lost it.

For C4D we will use the same mobile base but derived for the case of coupling with a drone. This platform can carry 60 kg, the weight of the docking station, the drone and the parcel. The TH17 droid is a platform with 4 wheels. Each wheel is motorized with an independent electric motor. The 4 wheels are suspended, and the droid can cross borders up to 10 cm. The front and rear wheels are steered for maximum agility. The droid is equipped with a battery giving it a range of 8 kilometers. The droid's mobile base is 70 cm wide by 80 cm long and 50 cm high. The droid run with ROS. The droid can move in 3 modes:

1. Follow-me: the droid follows a person.
2. Remote control: the droid is controlled remotely.
3. Autonomous: the droid moves alone.

For C4D we will create a docking station for the drone which will be fixed on the mobile base. This station will serve as the flight and landing base for the drone. It will also be used to transfer the package from the droid to the drone and from the drone to the droid (automatic). We plan to be able to recharge the drone's batteries from the droid (the source is the droid's batteries) using induction-type technologies. Finally, the height of the droid with the docking station should not exceed 140 cm.

The droid is equipped with the following sensors:

	Sensor	Position	Main characteristic
Mobil base	Lidar 2D	Top, 360 degrees	50 meters
Mobil base	Ultra-sonic	8 – 2 par side	10 meters
Mobil base	Camera RGB	4 – 1per side	1200 pixels
Mobil base	IMU	8 G	
Mobil base	RTK GPS		+/- 5 cm
Docking station	Camera RGB	center	1 looking up
Docking station	Lidar 3D	center	360 degrees & -/+15 degrees
Communication	4/5G modem		

Table 52 - UC3 D2: Droid sensors

6.3.1.5.4 Drone

Atechsys Engineering is a French company developing professional drone customized for the needs of the clients. Thanks to our facilities, we create drones from scratch, and follow the following process of creation:

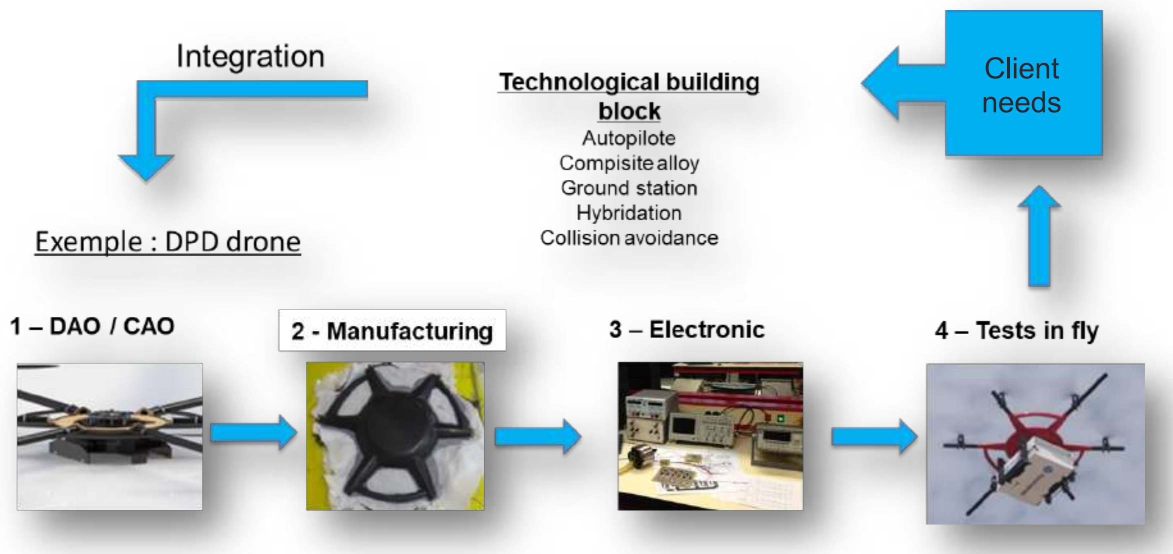


Figure 39 - UC3 D2: Drone creation process

We work in various areas: logistic, agriculture, surveillance, inspection, topography.

More specifically, we work with the DPD company to develop all the infrastructure to deliver parcel by drone. That include a parcel caching system, drone specialized in parcel transport and all the equipment on the ground to sustain the logistic.

For that kind of services, we mainly operate in non-urban area to be conform to the drone regulation. But thanks to the targeted maturity level of technology in the Comp4Drone project, the goal of the company is to operate in sub-urban places. Usually the carrying drone we produce are able to take 3kg and its dimension are around 1m40 in hexa configuration (6 motors).

For COMP4DRONES project, we will use the same architecture but sized to correspond to the needs of the project. In this intended configuration, the drone will be in quadcopter configuration (4 motors), will be able to fly during at least 30 min with an estimated parcel under 1kg. The size of the drone will be decreased to correspond with the functionality of the droid, which means around 70cm*70cm. The drone is equipped with parcel loader adapted to correspond with the droid. The drone will have sensors to locate itself in space, to communicate with the droid for autonomous landing procedure, and control its own environment. The drone has multiple operating modes:

1. Manual mode: the drone is controlled remotely
2. Autonomous mode: the mission is planned before flight and the drone fly automatically.
3. Landing mode: the drone is in landing approach and do the landing procedure automatically.

We plan also to be able to recharge drone batteries thanks to wireless induction system on the droid. Finally, the weight of the drone would be under 5.5kg with the parcel.

6.3.1.6 Implementation

6.3.1.6.1 Stage 1: Technology Validation

All the technological bricks developed in the framework of C4D will be realized according to the principles of ISO16949 and in particular of the system engineering with the V cycle of design/validation. For this, environment/plant models will be built with the help of Siemens: droid, drone and infrastructure. This model will be used to validate the achievement of the functional and dysfunctional (focus on diagnosis and safety mode) objectives and then to validate the coding quality (SIL). MIL platforms will be built with validation scenarios on one side, environment models on the other, and complete software or bricks to validate.

6.3.1.6.2 Stage 2: Technology Experimentation

After passing through the MIL and SIL validation, we implement the software in droids and drones. We will not perform the extremely cached HIL stage that is not relevant for small structures such as SME. The technical validation will resume the catalogue of scenarios already played by simulation for final tuning and validation of the proper functioning of droids and drones. The safety part and in particular the embedded diagnostic will be thoroughly tested at this stage.

The validation/verification and tuning/calibration of the technical bricks developed by Twinswheel will be done on the TH17 droid. These tests will be carried out in our factory in Cahors (France).

6.3.1.6.3 Stage 3: Technology Implementation

All software technology bricks will be developed to be integrated into ROS nodes. This will facilitate their reuse and sharing with consortium members and for some of the international community.

At this stage, the droid and the drone will be tested on the industrial site of PSA Sochaux over a period of several weeks. We will also carry out a week-long demonstration in Latvia within the Children's Hospital.

The macro planning of the stages:

Stage	Period	Description	Milestone
Conception 1	M1-M6	Mechatronic conception of droid and drone.	Plans and launch of manufacturing
Conception 2	M7-M12	Assembly of the droid and the drone and validation of the low-level layers.	Drone that flies and droid that rolls but in manual piloting
Conception 3	M13-M18	Integration of high-level bricks for autonomous flight and rolling.	Drone and droid capable of doing a simple mission in autonomous
Conception 4	M18-M24	Real coupling between the drone and the droid with information exchange and landing/take-off from the droid.	Demonstration of coupling
Experimentation 1	M25-M28	First experiment on the PSA Sochaux site in the form of a test day and workshop return for improvement of the droid and the drone (with intermediate tests in Cahors).	Demo day on the industrial site

Experimentation 2	M29-M32	Long experiment over several weeks with progressive use by the logistics department: at first by not being on the critical supply path, then by taking more and more real missions.	Service performance and potential business model
Implementation	M33-M36	Demonstration and dissemination of the project including a week in the children's hospital in Latvia.	Demo Latvia children's hospital (if we have funds)

Table 53 - UC3 D2: Implementation stages

6.3.2 KPIs

6.3.2.1 Business KPIs

ID	Description	Goal
UC3-D2-KPI-1	Ability to carry out a logistic mission in multimodal autonomous	Collaborative mission with drone and droid done in autonomy
UC3-D2-KPI-2	Ability to achieve industrial deployment of such logistics solution	Adaptation of the standard mission to an industrial environment and POC
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

Table 54 - UC3 D2: Business KPIs

6.3.2.2 Technical KPIs

ID	Description	Goal
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.

Table 55 - UC3 D2: Technical KPIs

6.3.3 Specification Plan

6.3.3.1 Scenario

The scenario is detailed in 4 main phases:

- 1st: Regulatory authorization phase
- 2nd: Recovery phase of the parcel by ground vector then air vector
- 3rd: Carriage parcel phase by aerial le vector
- 4th: Recovery phase of the parcel by the 2nd ground vector then transported inside the 2nd building

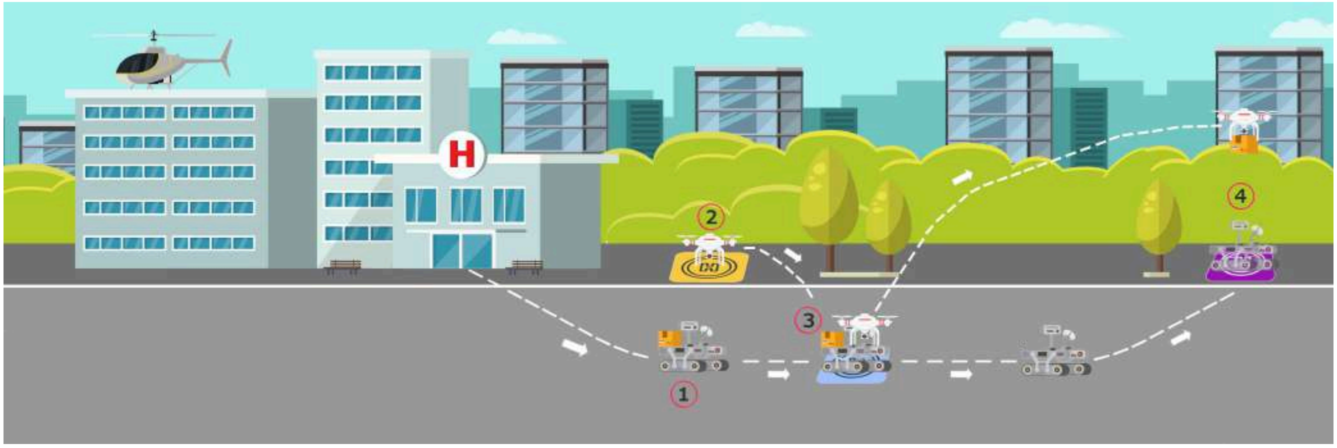


Figure 40 - UC3 D2: Scenario, Phase 1

Figure 41 - UC3 D2: Scenario, Phase 2

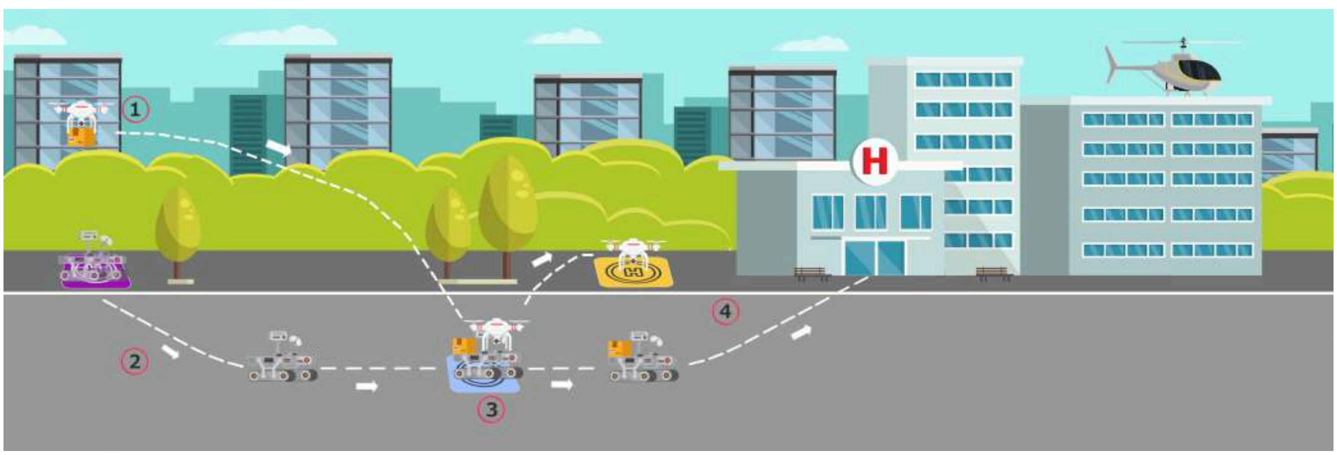


Figure 42 - UC3 D2: Scenario, Phase 3

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
UC3-SCN-02	Drone-Droid collaborative mission in facility	UAV + Rover Autonomous navigation Safe navigation Safe sensor landing Autonomous flight plan decision	H	1

UC3-SCN-02	Drone-Droid collaborative mission of parcel transport in hospital	UAV + Rover Autonomous navigation Safe navigation Parcel transfer between drone and rover Multiple landing technologies	H	1

Table 56 - UC3 D2: Scenarios description

The autonomous level targeted by the global scenario implies the lack of pilot in sight of the vectors. Which means a level 3 of autonomy.

6.3.3.2 Features and/or subsystems

Feature/ Subsystem	Description	Requirements	Constraints	Demonstrator	U-Space
Sub-system 1: Vision and perception of the environment	The droid must perceive its environment through its sensors. This subsystem makes it possible to process and merge information from sensors such as RGB cameras, 3D cameras, radar, Lidar, ultra-sound sensors ... This subsystem must also classify and segment the videos received to indicate the position of potentials. 360-degree obstacles around the droid. For moving objects this subsystem will have to propose a tracking and a prediction of their future trajectories.	UC3-FNC-001-Vision-Fusion UC3-FNC-002-Vision-Filter UC3-INT-001-Vision-Sensors UC3-INT-002-Vision-Occupancy Grid UC3-PER-001-Vision-MinimalSize UC3-PER-002-Vision-Speed	UC3-DSG-001-Vision-Brightness UC3-DSG-002-Vision-Rain UC3-DSG-003-Vision-fog UC3-DSG-004-Vision-temperature	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans. Integrate this vision soft brick into the TwinswHeel droid and realize the validation plans.	Operational Plan Preparation/optimization (U2), Operation Plan processing (U2), Monitoring (U2), Communication Infrastructure Monitoring (U2), Navigation Infrastructure Monitoring (U2), Weather Information (U2), Geospatial Information Service (U3)

Sub-system 2: Trajectory planning and obstacle avoidance	Based on the information delivered by the perception subsystem, the trajectory planning subsystem, while following perfectly predefined virtual routes, will enable the droid to refine its local trajectory. This is in order to avoid fixed and moving obstacles and to precede at-risk collision zones and therefore to anticipate them by proposing safe trajectories and selecting the best ones based on feasibility, safety and optimality criteria such as energetic.	UC3-FNC-003-PathPlanning-route UC3-FNC-004-PathPlanning-fixed obstacle UC3-FNC-005-PathPlanning – moving obstacle	UC3-DSG-005-PathPlanning –Uturn UC3-DSG-006-PathPlanning –droid cinematic	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans. Integrate this path planning and obstacle avoidance soft brick into the TwinswHeel droid and realize the validation plans.	Geo-awareness (U1), Geo-fence Provision (includes dynamic geo-fencing) (U2), Operation Plan Preparation/Optimisation (U2), Operation Plan Processing (U2), Risk Analysis Assistance (U2), Traffic information (U2), Navigation Infrastructure Monitoring (U2), Communication Infrastructure Monitoring (U2), Procedural ATC Interface (U2), Geospatial Information Service (U3)

Sub-system 3: Localisation	Based on the perception information (camera, Lidar…), the subsystem will have to locate the droid in a known environment. That is to say that the droid will be located in a pre-built cartography based on SLAM. The accuracy expected to comply with the regulations is +/- 5 cm This cartography will be established before any rolling in autonomous and above will be defined the virtual routes of the droid.	UC3-FNC-006-Localisation – SLAM UC3-FNC-007-Localisation – Vision localisation UC3-FNC-008-Localisation – GPS localisation	UC3-DSG-006-Localisation –Crowd: Droids	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans. Integrate this path planning and obstacle avoidance soft brick into the TwinswHeel droid and realize the validation plans.	e-identification (U1), Tracking (position reporting submission) (U2), Surveillance data exchange (U2), Geo-awareness (U1), Geo-fence provision (includes dynamic geo-fencing) (U2), Geospatial information Service (U3)
Sub-system 4: Trajectory control	The droid will have to follow very precisely the pre-defined virtual routes. In case of obstacle on this one, the sub-system of trajectory planning will have to define a bypass route which does not stick apart from +/- 1 meter around the virtual route. This subsystem therefore aims to follow this increased route of the local trajectory and ensure the orientation of the droid.	UC3-FNC-009-Control – Trajectory UC3-FNC-010-Control – local obstacle avoidance	UC3-DSG-007- Control – disturbance	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans. Integrate this path planning and obstacle avoidance soft brick into the TwinswHeel droid and realize the validation plans.	Traffic Information (U2), Operation Plan preparation/optimisation (U2), Operation Plan Preparation (U2), Geospatial information Service (U3)

Sub-system 5: Communication	Regulations for security reasons require droids to be under supervision at all times. So if the droid has an accident, it is the responsibility of the safety-driver. For this we have to demonstrate that we are able at all times to take control of the droid and control it remotely.	UC3-FNC-0011-Comunication – remote control UC3-FNC-0012-Comunication – diagnosis	UC3-DSG-008-Communication – Network quality UC3-DSG-008-Communication – Latency UC3-DSG-008-Communication – Bandwidth	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans. Integrate this path planning and obstacle avoidance soft brick into the TwinswHeel droid and realize the validation plans.	Tracking (position report submission) (U2), Surveillance Data Exchange (U2), Tactical Conflict Resolution (U3), Emergency Management (U2), Incident/Accident Reporting (U2), Citizen Reporting Service (U2), Legal Recording (U2)
Sub-system 6: Guiding the drone from the droid	The drone and the droid will have to communicate and guide each other during the coupling phases. During take-off or landing of the drone in the droid will require a relative precision from one to the other very precise (inf to 2 cm) This should allow to transfer the package from one to the other in both ways.	UC3-FNC-0012-Guiding – position UC3-FNC-0013-Guiding – communication	UC3-DSG-009-Guiding – External condition UC3-DSG-010-Guiding – Lighting	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans. Integrate this path planning and obstacle avoidance soft brick into the TwinswHeel droid and realize the validation plans.	Navigation Infrastructure Monitoring (U2), Communication Infrastructure Monitoring (U2), Electromagnetic Interference Information (U3), Navigation Coverage Information (U3), Communication Coverage Information (U3)

Sub-system 7: Parcel transfer	Transfer of the parcel in both directions between the drone and the droid.	UC3-FNC-0014-Parcel – droid side UC3-FNC-0014-Parcel – drone side UC3-FNC-0015-Parcel – transfer	UC3-DSG-010- Parcel – size and weight	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans Integrate this path planning and obstacle avoidance soft brick into the TwinswHeel droid and realize the validation plans.	Registration (U1), Drone Aeronautical Information Management (U1), Geo-awareness (U1), Geo-fence provision (including dynamic geo-fencing) (U2), Traffic Information (U2), Monitoring (U2)

Sub-system 8: Vision and perception of the environment for the drone	The drone must perceive its environment through its sensors. This subsystem makes it possible to send information from sensors such as RGB cameras, Lidar... to the droid for person recognition. Once the data have been treated by the droid, if there is a proximity alert, the drone will wait until the area is without danger.	UC3-FNC-018-Vision-Fusion UC3-FNC-019-Vision-Filter UC3-INT-001-Vision-Sensors UC3-INT-002-Vision-Occupancy Grid UC3-PER-001-Vision-MinimalSize	UC3-DSG-001-Vision-Brightness UC3-DSG-002-Vision-Rain UC3-DSG-003-Vision-fog	Integrate the interpretation of awareness level in the drone and action to take in case of danger. Integrate communication device capable of communicate with the droid during all the drone trajectory.	Weather Information (U2), e-identification (U1), Tracking (position report submission) (U2), Geo-awareness (U1), Geo-fence provision (including dynamic geo-fencing) (U2), Operation Plan Preparation/Optimisation (U2), Communication Infrastructure Monitoring (U2), Navigation Infrastructure Monitoring (U2), Navigation Coverage Information (U3), Communication Coverage Information (U3)

Sub-system 9: Trajectory planning for the drone	Pre-simulate flight to ensure a certain level of safety about each flight intended by proposing safe trajectories and selecting the best ones based on feasibility, safety and optimality criteria such as energetic.	UC3-FNC-020-PathPlanning-route UC3-FNC-021 PathPlanning-control repeated trajectory UC3-FNC-022 PathPlanning – communication UC3-FNC-026-Simulation-flight	UC3-FNC-012-Pathplanning – new type of flight	Integrate this soft brick into a MIL platform (Model In the Loop) to carry out the validation plans. Communicate validated trajectory by the droid to the drone. Interpretation of the flight path by the drone.	Drone Aeronautical Information Management (U1), Risk Analysis Assistance (U2), Operation Plan Preparation/Optimisation (U2), Communication Infrastructure Monitoring (U2), Navigation Infrastructure Monitoring (U2), Navigation Coverage Information (U3), Communication Coverage Information (U3)

Sub-system 10: Localisation for the drone	Based on the perception information and GPS, the accuracy expected to comply with the regulations is +/- 1 m in flight mode and less than 2cm in landing approach. For recursive path, the drone can memorise its environment to localise itself more precisely compare to the GPS function.	UC3-FNC-023 Localization – autonomous flight UC3-FNC-024-Localization – approach phase	UC3-DSG-014-Localisation –GPS based UC3-FNC-013-Localization – compare-2-trajectories	Integrate this path planning and obstacle avoidance soft brick into the Atechsys drone and realize the validation plans.	Registration (U1), e-identification (U1), Tracking (position report submission) (U2), Geo-awareness (U1), Geo-fence provision (includes dynamic geo-fencing) (U2), Communication Infrastructure Monitoring (U2), Navigation Infrastructure Monitoring (U2), Navigation Coverage Information (U3), Communication Coverage Information (U3)

Sub-system 11: Trajectory control for drone	The drone will have to follow very precisely the pre-defined virtual routes. The autonomous flight mode interprets the flight plan sent by the droid after validated simulation and follow it. In case of an emergency, the drone is capable of landing in safe areas predefined as safe point in the trajectory plan.	UC3-FNC-025-Control – Trajectory	UC3-DSG-008- Control – disturbance	Integrate this path planning soft brick into the Atechsys drone and realize the validation plans.	Drone Aeronautical Information Management (U1), Risk Analysis Assistance (U2), Operation Plan Preparation/Optimisation (U2), Communication Infrastructure Monitoring (U2), Navigation Infrastructure Monitoring (U2), Navigation Coverage Information (U3), Communication Coverage Information (U3), Emergency Management (U2), Geospatial Information Service (U3)

Sub-system 12: Communication for drone	Regulations for security reasons require drone to be under supervision at all times. So, if the drone has an accident, it is the responsibility of the safety-driver. For this we have to demonstrate that we are able at all times to take control of the drone and control it remotely.	UC3-FNC-0027-Comunication – remote control UC3-FNC-0028-Comunication – diagnosis	UC3-DSG-008-Communication – Network quality UC3-DSG-008-Communication – Latency UC3-DSG-008-Communication – Bandwidth	Integrate this path planning and obstacle avoidance soft brick into the Atechsys drone and realize the validation plans.	e-identification (U1), Tracking (position reporting submission) (U2), Surveillance data exchange (U2), Geo-awareness (U1), Geo-fence provision (includes dynamic geo-fencing) (U2), Geospatial information Service (U3), Communication Infrastructure Monitoring (U2), Navigation Infrastructure Monitoring (U2), Navigation Coverage Information (U3), Communication Coverage Information (U3)

Table 57 - UC3 D2: Features/Subsystems

6.3.3.3 Requirements

Requirement Type	Requirement ID	Description	Priority (H/M/L)	KPI
Functional Requirement	UC3-FNC-001	Shall merge all the perception sensors of the droid to perceive the environment and return an occupancy grid up to 30 m around the droid.	H	UC3-D2-KPI-2
Functional Requirement	UC3-FNC-002	Shall remove noise and tools measured by sensors.	H	UC3-D2-KPI-3
Functional Requirement	UC3-FNC-004	The road must allow the droid to avoid fixed obstacles without endangering other road users.	H	UC3-D2-KPI-1
Functional Requirement	UC3-FNC-005	The local droid route shall be adapted at all times depending on the presence of obstacle on this virtual route. The trajectory is defined around the virtual road within a certain margin.	H	UC3-D2-KPI-2
Functional Requirement	UC3-FNC-010	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 shall still be avoided.	H	UC3-D2-KPI-3
Functional Requirement	UC3-FNC-012	Always, the droid shall report its state of health to the remote safety driver. This allows him to determine if the droid can continue to roll in 100% autonomous mode, if it must regain control over it or if it must stop it in an emergency.	H	UC3-D2-KPI-3
Functional Requirement	UC3-FNC-013	The drone shall be positioned in X, Y, Z and heading within 2 cm of error and 5 degrees of error. This position must be established by the drone and droid measuring instruments.	H	UC3-D2-KPI-3
Functional Requirement	UC3-FNC-015	The droid shall be able to accommodate the drone and offer it a landing zone and beacons to locate it.	H	UC3-D2-KPI-1
Functional Requirement	UC3-FNC-017	The droid shall be able to order the drone to grab or drop the package.	H	UC3-D2-KPI-1
Functional Requirement	UC3-FNC-018	Shall merge all the perception sensors of the drone to perceive the environment and return an occupancy grid up to 30 m around the drone.	H	UC3-D2-KPI-2
Functional Requirement	UC3-FNC-019	Shall remove noise and tools measured by sensors on the drone.	H	UC3-D2-KPI-3
Functional Requirement	UC3-FNC-020	Define a virtual route on the map established by the simulation validation in the droid. The drone must only follow this virtual route. The route must have safe points to land the drone in case of emergency.	H	UC3-D2-KPI-2 UC3-D2-KPI-1
Functional Requirement	UC3-FNC-026	Thanks to sensors and weather condition, shall simulate the flight and be able to validate the conditions to launch the flight. This module is integrated on the ground station or droid.	H	UC3-D2-KPI-3

Functional Requirement	UC3-FNC-027	The drone shall be able to be controlled remotely at all times and the communication system shall be redundant.	H	UC3-D2-KPI-1
Security requirement	UC3-DEM2-SEC-01	Runtime monitoring techniques with supported tools should be needed to enable safe decision making.	M	UC3-D2-KPI-3
Design constrains	UC3-DSG-004	Should be respected temperature from -15 degC to + 45 degC.	M	UC3-D2-KPI-4
Design constrains	UC3-DSG-005	The trajectory shall allow on particular points to the droid to be able to turn around.	H	UC3-D2-KPI-2
Design constrains	UC3-DSG-006	Droids can have very different features: differential drive, 4-wheel steering, trailers ... and the definition of the virtual roads shall take this into account.	H	UC3-D2-KPI-3
Design constrains	UC3-DSG-007	The control shall be robust to disturbances such as noise on the location system or noise on the obstacle detection system.	H	UC3-D2-KPI-4
Design constrains	UC3-DSG-011	The drone shall fit the size of the droid. It will be under 70cm x 70cm.	H	UC3-D2-KPI-1
Design constrains	UC3-DSG-012	The drone path shall be check by the operator before each new kind of flight.	H	UC3-D2-KPI-1
Design constrains	UC3-FNC-013	The ground station or the droid shall compare the current video from the drone and shall do a relative localization that give more accuracy for the final landing phase.	H	UC3-D2-KPI-2

Table 58 - UC3 D2: Main requirements

To keep a track on the requirement progression, we will use an excel file shared among the UC3 demo 2 contributors.

7 UC4: Surveillance and Inspection

7.1 Overall motivation and ambition of the Use Case

7.1.1 Use Case concept and challenges

This use case shows the developments of the COMP4DRONES project in the field of automatic and autonomous inspections in harsh environments. This involves enhanced sensory capabilities and novel control strategies augmented by real-time data-analytic algorithms.

The main application areas for such drones are the field of industrial inspections and rescue operations in disaster situations. The common denominator of both cases is that both take place in areas that are very difficult to reach. Moreover, that the novel strategies for perception, planning and control deal require the development of efficient computational strategies, dealing with limited computational resources.

- The main applications of the drones will be in indoor and outdoor environments such as:
  - Industrial inspection
  - Rescue operations:
    - Finding targets
    - Mapping environments
- Development of efficient computational strategies, dealing with limited computational resources.
- Perception, planning and control to be determined by high-level data-analytics system.
- High-availability communication channels, closed-loop algorithms implemented in FPGA-based accelerators are to be developed.

In this use case two demonstrators will be implemented, addressing each the specific boundary conditions of the different application areas. The main goal of this use case is the realization of autonomous UAV with enhanced sensory capabilities and novel control strategies augmented by real-time data-analytics algorithms.

7.1.2 Use Case objectives

In this use case two demonstrators will be implemented, addressing each the specific boundary conditions of the different application areas.

Demonstrator 1: Inspection of offshore turbines structure with hyperspectral technology carried by automatically flown drones. The focus is here on the addition of a new sensor (a hyperspectral camera), and the specific challenge addressed is to have a safe flight, with the avoidance of environmental effects, such as windmill effects, by means of automatic control loops. Targeted innovations are: the hyperspectral camera in combination with the drone and the data-analytics with varying (outdoor) lighting conditions and analyse images to detect imperfections, like corrosion deterioration of paint, real-time or offline, and robust collision avoidance in harsh environment (strong wind, keep safe distance from the jacket).

Demonstrator 2: Fleet of multi robot navigating and mapping in an unknown environment, consisting of small, lightweight drones; and larger drones with processing. The focus here is on the multi-drone collaboration in a GPS denied environment where collaborating drones have to create a common model of the environment, which includes the automatic detection of points of interest. The multi-drone collaboration includes collaboration between drones with various processing constraints.

7.1.3 Contribution to project objectives

Proposal Objective	Use Case Contribution
Objective O1: Ease the integration and customization of embedded drone systems.	The UC contributes to this objective in the following sense. For both indoor and outdoor application area this UC will provide a reference architecture for a modular and embedded drone platform. This reference architecture will be based on a number of hardware independent application components and will be targeted towards the applications addressed by the UC.
Objective O2: Enable drones to take safe autonomous decisions.	As a whole, the UC leads to methods to increase the autonomy of Unmanned Aerial Vehicles (UAV) with enhanced sensory abilities for safe autonomous navigation, or at least automatic navigation taking into account environmental conditions. These enhanced UAV can then be safely applied in indoor and outdoor environments applications such as industrial inspection, security, surveillance, and in rescue operations (for example in finding targets and mapping indoor or outdoor environments).
Objective O3: Ensure the deployment of trusted communications.	This UC involves the development of a high-availability radio communication system for stable long-range connections. Multi-path communications is also a specific topic in the realization of trusted communications. Store-and-forward based communications, for robust networking under difficult conditions.
Objective O4: Minimize the design and verification effort for complex drone applications.	The UC contributes to this objective through the use of simulations as a design and verification tool. Through incremental complex simulations, the UC supports the agile approach to development of a shared drone architecture, by allowing components early integration opportunities in a (simulated) realistic environment, augmented by stub implementations of surrounding components. The simulations will incorporate hardware-in-the-loop integration with real drone & rover hardware, further supporting the agile verification efforts.
Objective O5: Ensuring sustainable impact and creation of an industry-driven community.	The UC helps achieving this objective by contributing to the ecosystem of COMP4DRONES software components tools and methods. Furthermore, the UC helps achieving this objective by actively contributing to the community for maintenance, evaluation and industrialization of the ecosystem. Parts of the developments are integrated into university courses contributing to sustainability.

Table 59 - UC4: Contribution to project general objectives

Technical Objective	Use Case Contribution
STO1: Integrated Modular Architecture for Drones.	The UC addresses this scientific objective by developing an architecture for drone, consisting of various functional components that support the applications in the UC, and that further detail the ideas and requirements around processing partitioning, communication partitioning, functional independence of applications and standardized interfaces between the components.

STO2: Safe Intelligent Navigation.	The UC addresses this scientific objective by contributing to advanced navigation principles that decrease the dependency on GPS systems, by using information from other sensors such as camera's, lasers, and sonar. Partners in the use case address specifically event-based camera in combination with radar to assist navigation. Also, autonomous decision making for planning will play an important role in the UC. Both these aspects support the scientific objective of Safe Intelligent Navigation.
STO3: Trusted Communication.	The UC addresses this scientific objective by contributing to the topic of lightweight robust communications, by means of store and forwarding technologies. Also, the topic of multi-link communications is specifically addressed by partners in the use case.
STO4: Design Performance and Verification Tools.	The UC addresses this scientific objective by using the components developed within the COMP4DRONES WPs. Because of the heterogeneity of these components and tools, even as they share a common model, it is vital to start integration efforts as early as possible. For this purpose, COMP4DRONES will take a modelling approach to clearly define interfaces between components. This in turn allows simulators to provide simulated implementations of components that can be replaced by real implementations during the project lifecycle. This UC will provide an approach to integration using such a simulated environment, which will be enriched towards a full-scale life demonstration, in an agile, recursive manner.

Table 60 - UC4: Contribution to project technical objectives

7.1.4 Boundary conditions

This UC consists of two demos. Demo 1 takes place outdoors, so there the drones are governed by the usual regulations around drones flying outside. UC1 will have to be performed within the local UAS Legislation. From January 1st 2021, the European will be applicable in Belgium. An inspection of a wind turbine, bridge or other infrastructure far away from uninvolved people will fall in the Open Category, subcategory A3. The UAS will fall under the C3 Class.

Additionally, for tests will be performed offshore, the staff involved will need to have a number of certificates to be able to work offshore:

- OPITO Basic Offshore Safety Induction & Emergency Training (BOSIET).
- VCA (Certificate 'Veiligheid, gezonheid, milieu Checklist Aannemers').

Demo 2 takes place indoors, and for this standard safety guidelines apply[5].

For Demonstrator 1 the following operational limitations apply:

- The flights will not be performed in a fully autonomous way. The goal is demonstration of the hyperspectral technology.
- Meteorological conditions in which the flights should be executed.
  - wind up to 5 Beaufort

[5] https://drones.princeton.edu/sites/drones/files/indoor_safety_guidelines.pdf

  - wave heights up to 1,2-1,5m
  - minimum temperature of -10°C
- Legal limitations: Staff and drone/infrastructure needs proper certifications for offshore operations.
- Emergency scenarios defined: Insufficient GNSS satellites available, communication link lost

Also, Demonstrator 2 has several operational limitations defined:

- Drones will only fly in **indoor environments, without human presence**.
- This is reflected in the requirements, and removes the need for specific emergency KPIs
- A significant part of the demonstrator will be **simulated**, with some hardware-in-the-loop where useful. This will introduce a laboratory environment as well, again reducing safety risks
- The use-case envisions to use both a **mobile rover platform and several drones**. This allows computational heavy tasks to be offloaded to the rover Communication between the rover and the groundstation/human operator, is assumed to be reliable and secure. Potential implementation could be tethering (having a data cable to the rover)

The requirements will be maintained in an excel file. A subset of the high-level requirements can be found below in Section 7.2.3.3 (Demonstrator 1) and Section 7.3.3.3 (Demonstrator 2). Each workpackage formulates requirements for the subsystems addressed in this workpackage. These requirements will be manually linked to the high-level requirements (backward traceability). These links will be manually maintained via an excel file.

7.2 Demonstrator 1

7.2.1 Justification Plan

7.2.1.1 Demonstrator overview

The goal of this demonstrator is to showcase the benefits of hyperspectral camera technology on unmanned aerial vehicles (drones) for monitoring soil movements on construction sites. On large construction sites, it's important that the flow of different types of soil is tracked and that polluted soil is kept separate. However, it is not always easy to visually see the different types of sand. Additionally, companies have to make sure that soil with specific types of vegetation, e.g. Japanese knotweed, is not present.

The first goal of this demonstrator is to validate that hyperspectral technology on drones can also be used to monitor the movement of soil. Secondly, research will be carried out on Artificial Intelligence and deep learning algorithms to process hyperspectral data to automatically detect the type of soil and specific types of vegetation.

External stakeholders for this demonstrator are: DEME and SWECO. These stakeholders have been involved in the requirement elicitation process. Also other construction companies have been consulted.

7.2.1.2 Description and scope

For the demonstration, flights will be performed on an earth movement construction site where different types of soil are moved around. Two automated flights will be performed. The first one will be performed with a multirotor drone which will be used to scan stockpiles at regular intervals. A second flight will be performed with a VTOL drone carrying the same payload. These drones will collect accurately geo-referenced hyperspectral and RGB images. These images will be processed on a local server or in the cloud -and the results will be visualized as soon as they are available to show that hyperspectral imaging can be used to detect different types of soil.

7.2.1.3 Objectives

The general objectives of this use case demonstrator are:

- Increase the speed of collecting and processing volume data from construction site
- Accurate automated classification of soil types
- Accurate automatic detection of Japanese Knotweed
- Enable automated, BVLOS flights over construction sites under STS-02 rules.

For a more detailed list with indicated performance targets, we refer the reader to the KPI section.

7.2.1.4 Key concepts and technologies

In this demonstrator we envision the following novel technologies / improvements:

- Demonstrate that hyperspectral cameras can be used to automatically classify types of soil and detect the presence of Japanese Knotweed.
- Reliable and safe automated BVLOS flight above construction sites under STS-02 rules

7.2.1.5 Infrastructure and drones

7.2.1.5.1 Drone: based on Airobot Mapper

Airobot's technology focuses on automating complete flow of collecting and processing of accurate data. For the collection we created the AiroCore: a complete flight and payload management core to turn a drone into a flying robot. It also allows to remotely connect to the drone via a multitude of wireless technologies (4G/LTE, 2.4GHz, 5.2GHz…). As the flight planning software runs on the drone no additional software needs to be installed on a local PC. This allows Airobot to program a drone for almost any application.

The AiroCore is integrated on an all-weather platform, the Airobot Mapper, which is capable flying in winds of 35knots and has an IP rating of IP48. Additionally, the AiroCore is integrated on a VTOL drone platform, creating the Airobot VTOL Mapper. This platform has an autonomy of 1-2 hours and will be able to cover large areas. During the project, the AiroCore will be expanded to be able to support hyperspectral technology.

At the side of Imec, the hyperspectral payload will be based on imec.be's uav platform: (dual)mosaic sensors/cameras with Ximea break out board and Jetson TX2 board. Regarding the software blocks, we can reuse Airobot's server-based interface for ground controller with Imec's camera commands. The imec.ipi platform can reuse the hyperspectral processing software pipeline as a start base and rely on the in-house built Quasar programming framework to efficiently implement algorithms on the Nvidia Jetson boards.

Figure 43 - UC4 D1: Airobot Mapper UAV and AiroCore

7.2.1.5.2 Infrastructure

Airobot will use the AiroCollect Cloud based server infrastructure to implement the processing of hyperspectral data. Today, this platform is currently set up to perform traditional photogrammetry based on RGB images and share the results with all stakeholders.

7.2.1.6 Implementation

The role of imec.be is to deliver the hardware hyperspectral payload that is able to communicate with the AiroCore platform. The imec.ipi platform will provide the software processing algorithms for limited real-time hyperspectral classification and image enhancement (e.g. contrast). Airobot will integrate the hyperspectral technologies on its drone platform and provide workflow to also geo-reference the data and organization.

7.2.1.6.1 Stage 1: Technology Validation

Airobot will validate its platform for realistic offshore conditions and imec will perform corrosion analysis with hyperspectral technology (snapscan and mosaic sensor cameras).

7.2.1.6.2 Stage 2: Technology Experimentation

We will perform data collection in the field with several flights, e.g. one flight to get the accurate 3D information of the terrain, and flights with hyperspectral imaging cameras (and additional sensors) The algorithms (spectral corrections and classification) will be further optimized for outdoor realistic data.

7.2.1.6.3 Stage 3: Technology Implementation

We will further optimize the workflow (e.g. partitioning of software processing between drone platform versus cloud/offline PC - AiroBox), embedded onboard implementation of the analysis tools, etc. We will also perform new flights for validation and improvements of the final demonstrator.

7.2.2 KPIs

We list the following Key Performance Indicators for the use case demonstrator.

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 61 - UC4 D1: KPIs

7.2.3 Specification Plan

7.2.3.1 Scenarios

The Drone Autonomy level targeted for these scenarios is Drone autonomy level 3 "Conditional automation". This means that a pilot can still take control during the demonstrations.

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
UC4-SCN-01	Automated Mapping of Stockpiles with Multirotor	Collect spectrally corrected hyperspectral data and RGB images	H	UC4-D1
		Accurate Georeferencing	H	UC4-D1
		Safe BVLOS flight	H	UC4-D1
		Onboard interpretation of data.	M	UC4-D1
		Offline processing to make complete assessment of data	H	UC4-D1
UC4-SCN-02	Automated Mapping of Large sites with VTOL	Collect spectrally corrected hyperspectral data and RGB images	H	UC4-D1
		Accurate Georeferencing	H	UC4-D1
		Safe BVLOS flight	H	UC4-D1
		Onboard interpretation of data.	M	UC4-D1
		Offline processing to make complete assessment of data	H	UC4-D1

Table 62 - UC4 D1: Scenarios description

7.2.3.2 Features and/or subsystems

Feature/Subsystem	Description	Requirements	U-Space services
Hyperspectral camera payload	Collecting and storing spectrally corrected hyperspectral data.	Functional and interface	Passive Optical Sensor (KET 3.1.1)
Accurate Georeferencing of data	Store accurate position and orientation of the drone, gimbal to estimate location on ground.	Functional	Tracking (U2) Positioning (KET 2.4.1)
Onboard Hyperspectral Cube generation	Automated generation of hyperspectral cube based on raw sensor data.	Functional and interface	Data Fusion & Processing (KET 2.4.1)

Offline detailed data processing	Detailed offline processing of the data to classify the results	Functional	Data Fusion & Processing (KET 2.4.1)
Accurate (3D) flight planning	Perform an accurate, pre-programmed, (3D) Flight using RTK GNSS technology.	Functional	Operation plan preparation/optimisation (U2) Geo-awareness (U1) Flight Planning and Scheduling (KET 2.2.3)

Table 63 - UC4 D1: Features/Subsystems

7.2.3.3 Requirements

Requirement Type	Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI
Performance requirement	UC4-PRF-01	Perform automated (3D) flight plan	Perform an automated (3D) flight plan above a terrain.	M	Airobot	UC4-D1-KPI-05
Security requirement	UC4-SEC-01	Perform manual flight	Perform a manual flight to test sensor technology	M	Airobot	UC4-D1-KPI-05
Performance requirement	UC4-PRF-02	Geo-referencing	Provide the estimated 3D coordinates of the hyperspectral & RGB images	H	Airobot	UC4-D1-KPI-02
Performance requirement	UC4-PRF-03	Safe BVLOS flight	Perform safe BVLOS flights under STS-02 conditions	H	Airobot	UC4-D1-KPI-02
Interface requirement	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
Performance requirement	UC4-PRF-04	Collect RGB & hyperspectral data	Collect RGB & hyperspectral data simultaneously.	H	Airobot & imec.be	UC4-D1-KPI-02
Performance requirement	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
Interface requirement	UC4-INT-04	Annotation	Have the possibility to annotate hyperspectral data (select areas of soil & assign type).	M	Airobot	UC4-D1-KPI-02
Performance requirement	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
Interface requirement	UC4-INT-06	Create (3D) mission plan	Create a (3D) mission plan around a predefined structure.	H	Airobot	UC4-D1-KPI-05
Interface requirement	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
Interface requirement	UC4-INT-08	Hyperspectral settings	Allow operator to change the settings of the hyperspectral camera remotely.	H	imec.be	UC4-D1-KPI-04
Performance requirement	UC4-PRF-13	Weather – wind	Be able to execute the flight in winds of up to 5 beaufort.	H	Airobot	UC4-D1-KPI-05
Performance requirement	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

Performance requirement	UC4-PRF-15	Data rate	Be able to process the data in real-time, which will depend on the frame rate, overlap in images, etc.	M	imec.ipi	UC4-D1-KPI-04
Security Requirement	UC4-SEC-04	Outdoor environment, no-public space	Collision with onsite infrastructure should be avoided.	M	Airobot	UC4-D1-KPI-05
Performance requirement	UC4-PRF-01	Perform automated (3D) flight plan	Perform an automated (3D) flight plan above a terrain.	M	Airobot	UC4-D1-KPI-05
Security requirement	UC4-SEC-01	Perform manual flight	Perform a manual flight to test sensor technology	M	Airobot	UC4-D1-KPI-05
Performance requirement	UC4-PRF-02	Geo-referencing	Provide the estimated 3D coordinates of the hyperspectral & RGB images	H	Airobot	UC4-D1-KPI-02
Performance requirement	UC4-PRF-03	Safe BVLOS flight	Perform safe BVLOS flights under STS-02 conditions	H	Airobot	UC4-D1-KPI-02
Interface requirement	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

Table 64 - UC4 D1: Main requirements

7.3 Demonstrator 2

7.3.1 Justification Plan

7.3.1.1 Demonstrator overview

The second demonstrator consists of a fleet of ground and unmanned robots navigating and mapping in an unknown environment where there is no GPS signal available.

7.3.1.2 Description and scope

The second demonstrator has the following description: From a (mobile) control station near the unknown, cluttered, radio-hampering, GPS-denied site, 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. 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. This model can be used to find safe routes of access to these points of interest, for example to extract victims. The system provides a live view of the exploration to the control station operator. 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.

This demonstrator is aiming at TRL level 4-6 at the end of the project. This will be reflected in the chosen KPI's (in Section 7.3.2). The use case is focusing on major technological enhancements from the SOTA as addressed by partners. This demonstrator is relatively broad with 11 different technical partners, there are no formal external stakeholders. Partners act as product owners. 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.

7.3.1.3 Objectives

The main objective of this demonstrator to enable mapping operations in unknown environments prior or without human intervention in the environment. To this end this demonstrator will need to combine and develop various state-of-the art sensing and computing technologies.

The following are the specific objectives for the use case:

- Reduce costs for surveillance.
- Increase reliability via automated process.
- Increase frequency of surveillance.
- Automatic detection of anomalies.
- Minimizing manned entries in confined or hazardous environments/spaces.

The following novel technologies / improvements are introduced in this UC:

- Real-time data analytics and closed-loop dynamic control.
- Safe autonomous navigation, 3D SLAM.
- Multi-drone collaboration.

7.3.1.4 Key concepts and technologies

To implement the demonstration scenario, the use case will need to integrate several technologies provided by the WPs of COMP4DRONES. These technologies are listed in the requirements section of this demonstrator description. They can be grouped into several categories:

- **Sensors and sensor fusion:** Optic-flow object detection, neuromorphic image processing, and their integration and fusion to provide collision avoidance.

- **SLAM:** Collection of point cloud data, 3D geographical model definition, mapping of the point cloud data into the geo-model(s), grounding, joining and merging of multiple models into a single common 3D model of the building.
- **Communication:** Robust data networking to allow the aerial drones to communicate with the rover (and potentially with each other) also in a closed-off, cluttered environment through concurrent use of multiple wireless technologies, and store-and-forward mechanisms.
- **Simulation:** Visualisation of the 3D model, co-simulation to support the real drones with (simulated) extra information about the building, prediction of drone interactions for path planning and collision avoidance. Demonstration support through simulation of potentially hard to setup environmental aspects. (Fire, wind, dust/smoke, etc.) Augmented- and/or virtual reality techniques will be added to the simulation to support the human-system interaction.
- **Strategy:** Online reconfiguration of drones for failure handling, advanced path planning and smart control logic, cooperation strategies between drones.

7.3.1.5 Infrastructure and drones

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 passways, 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.

For this demonstration several assets and infrastructure will be provided by the partners in the UC. This includes the following: (The mentioned providers are all tentative and subject to change)

- A vehicle platform (provided by DemCon and/or TUe).
- Several micro-drones (provided by TUDelft).
- One or more aerial drones (provided by DemCon, AnyWI, IMEC-NL, Almende).
- Control station station, one or more laptops.
- Simulation platform (provided by Almende).
- A demonstration location (provided by TUDelft and/or DemCon).

7.3.1.6 Implementation

7.3.1.6.1 Stage 1: Technology Validation

The demonstration is developed in three stages, starting with a validation stage to check the suitability of the expected technologies for demonstration purposes. This stage includes the requirements capture, high-level system design and a simulation-based demonstration of the UC.

7.3.1.6.2 Stage 2: Technology Experimentation

During the second stage of the UC the various implementations of the required technologies are provided by the WPs. These are tested in isolation by the UC for suitability for the demonstrator. For this purpose, the simulation tools can be used to provide mock-up environments, actors and test sensor data. Where relevant the technologies will be integrated into the drones/rover.

7.3.1.6.3 Stage 3: Technology Implementation

In the final stage, the technologies are integrated into a fully featured demonstration system, according to the above-mentioned storyboard. This will result in a fully featured demonstration. The results of the integration process will be documented and analysed for future projects and dissemination.

7.3.2 KPIs

The following KPI's are addressed by this use case. These are split into business application-oriented metrics.

The following KPI's are addressed by this use case. These are split into business and technical key performance indicators. From the very generic business KPIs related to financial, project management and marketing, we derive KPIs in the areas of:

- Resource utilization
- Benefits
- Costs reduction
- Risks

This leads to the business KPIs described in the section below. Note again that 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

The basic vision: Increase "autonomy" of drones for the purpose of inspecting cluttered, hazardous, GPS-denied environments, with reduced human presence.

KPI ID	Description	Goal
	Business KPIs	
UC4-D2-KPI-07	Minimize manned operations/entries in hazardous environments: Enable drones to provide a map of an unknown, cluttered, indoor environment within a target value of one hour.	Value to reach
UC4-D2-KPI-08	Enabling drones to take safe autonomous decisions, autonomy of fleet during indoor exploration mission without human intervention.	Functionality to demonstrate
UC4-D2-KPI-09	Enable drones to explore autonomously without human pilot intervention for 90% (target value) of the mission time.	Percentage to reach
	Technical KPIs	
UC4-D2-KPI-10	Demonstrate accelerated HW/SW able to do classification 10x faster than SOTA and 10 x lower power, compared to current non-accelerated solutions.	Value to reach
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. Capabilities in terms of channels used, packet delay/round trip times, bandwidth estimates and available channels employed. Target value: on average reach a 10-fold decrease in packet loss ratio, with < 10% added overhead.	Percentage to reach

Table 65 - UC4 D2: Business and Technical KPIs

7.3.3 Specification Plan

7.3.3.1 Scenarios

The Drone Autonomy level targeted for these scenarios is Drone autonomy level 3 "Partial automation" (TBC CHECK @LudoStellingwerff). This means the drone can perform all function "given certain conditions". See also the Section "Boundary Conditions".

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
UC4-SCN-03	Inspection of area by drones	Automatic navigation of drones	H	UC4-D2
		Combining radar and optic flow for obstacle avoidance	H	UC4-D2
		Return to beacon	M	UC4-D2
UC4-SCN-05	Mapping of area by drones	Automatic navigation of drones	H	UC4-D2
		Mapping of the environment	H	UC4-D2
		Detection of a heat source (victim)	H	UC4-D2
		Path planning to the heat source	H	UC4-D2

Table 66 - UC4 D2: Scenarios description

7.3.3.2 Features and/or subsystems

The Demonstrator 2 has been decomposed in the following subsystems, with a number of main features. The following two tables address this decomposition, first on based on the subsystem, with a high-level relation to the requirements. Then a table with a detailed relation from the features to the requirements.

Feature/Subsystem	Description	Requirements	U-Space/KET
Sensors subsystem	Contains the components dedicated to improvement of the sensors. This relates to obstacle detection by for neuromorphic image processing and for optic flow object detection and avoidance.	Functional and interface	Obstacle Detection an Avoidance (KET 2.2.7) Data fusion and processing (KET 2.4.1) Passive Optical (KET 3.2.1)
Tightly constrained platform subsystem	This contains components that are working in a tightly constrained environment, with strong restrictions on size, weight and power. An example is an aerial platform itself (the "hardware"). The software should be able to perform simultaneous localization and mapping	Functional Interface Security	Simultaneous Localization and Mapping (KET 2.3.3) Obstacle Detection an Avoidance (KET 2.2.7)

Relaxed constrained platform subsystem	Prevent the drone from flying into infrastructure during inspection flight This contains components with relaxed constraints, with more relaxed constraints on size, weight and power. An example is a vehicle platform itself (the "hardware"). The software should be able to have more functions than the tightly constrained platform. An example is the communication between drone to ground and the relaying of this type of communication via robust networking components.	Functional Interface Security	Drone and Rover (KET 2.5.1) Obstacle Detection an Avoidance (KET 2.2.7)
Strategy subsystem	This subsystem contains the 'intelligence' of the various systems: it contains the Smart control logic (which allows for example drones to return to base for recharging when their energy runs low); Simultaneous localization and mapping, for creating a uniform situation sketch based on camera images; Failsafe online reconfiguration to allow for failsafe configuration updates when the system is operational; Decisions strategies for the drone fleet allows for assigning tasks to different drones, based on their capabilities and actual status.	Functional and interface	Intelligent Mission Management (KET 2.1.1) Simultaneous Localization and Mapping (KET 2.3.3) Fail-safe Mission (KET 2.2.4) Swarm formation and cooperation (KET 2.5.2)

Table 67 - UC4 D2: Features/Subsystems

The subsystems and their features are depicted in Figure 44 below.

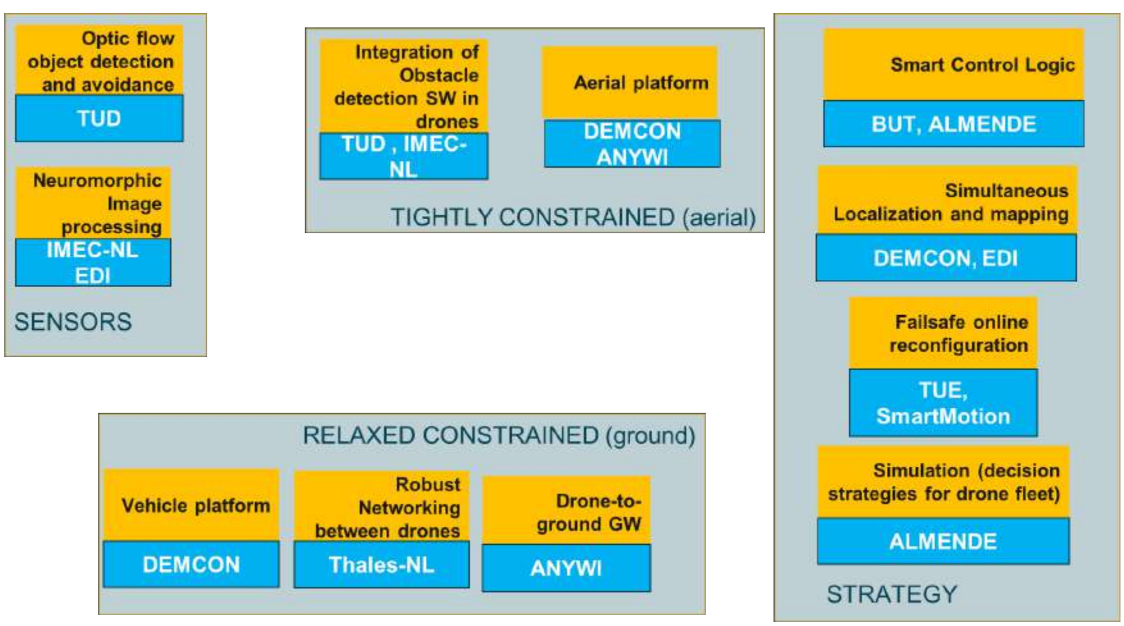


Figure 44 - UC4 D2: Subsystems with their features

Feature/Subsystem	Description	Requirements
Optic flow object detection and avoidance	This feature detects objects by means of optic flows.	UC4-DEM2-PRF-01 UC4-DEM2-PRF-02 UC4-DEM2-PRF-03 UC4-DEM2-PRF-09
Neuromorphic image processing	Image processing via neural networks combining optic flows and radar.	UC4-DEM2-PRF-03
Object detection SW in drones	Object detection by means of daylight and IR cameras.	UC4-DEM2-PRF-01 UC4-DEM2-PRF-02 UC4-DEM2-PRF-03 UC4-DEM2-PRF-04
Aerial platform	Embedded platform with tight constraints on weight and processing power.	UC4-DEM2-PRF-01 UC4-DEM2-PRF-02 UC4-DEM2-PRF-03 UC4-DEM2-PRF-04 UC4-DEM2-FNC-05 UC4-DEM2-FNC-02 UC4-DEM2-FNC-03 UC4-DEM2-SEC-04 UC4-DEM2-INT-04 UC4-DEM2-SEC-05 UC4-DEM2-PRF-06 UC4-DEM2-INT-13 UC4-DEM2-SEC-02
Vehicle platform	Embedded platform with relaxed constraints on weight and processing power.	UC4-DEM2-FNC-06 UC4-DEM2-INT-03 UC4-DEM2-INT-02 UC4-DEM2-SEC-04 UC4-DEM2-INT-04 UC4-DEM2-INT-13 UC4-DEM2-SEC-02
Robust Networking	Component to provide store and forward communications to guarantee message delivery in difficult communication situations.	UC4-DEM2-SEC-03 UC4-DEM2-SEC-09
Drone to Ground GW	Component to provide robust communications between drone and ground station.	UC4-DEM2-INT-02
Smart Control logic	Control logic to provide early detection of low energy situations.	UC4-DEM2-INT-09 UC4-DEM2-INT-07 UC4-DEM2-INT-12 UC4-DEM2-PFR-05 UC4-DEM2-INT-11 UC4-DEM2-INT-10 UC4-DEM2-FNC-07 UC4-DEM2-FNC-08 UC4-DEM2-FNC-09 UC4-DEM2-FNC-10 UC4-DEM2-FNC-11 UC4-DEM2-INT-06 UC4-DEM2-INT-05 UC4-DEM2-PRF-07 UC4-DEM2-FNC-13

Simultaneous localization and mapping	Logic to provide localization based on images.	UC4-DEM2-FNC-01 UC4-DEM2-PRF-05 UC4-DEM2-SEC-09
Failsafe online reconfiguration	Tools to provide online reconfiguration of drone software in such a way that critical safety aspects remain guaranteed.	UC4-DEM2-FNC-04
Decision strategies for drone fleet	Logic to assign tasks to drones based on their status and the current situation.	UC4-DEM2-SEC-01 UC4-DEM2-INT-08 UC4-DEM2-INT-01

Table 68 - UC4 D2: Features/Subsystems

As UC4 demo 2 is taking place indoors, there is no link to U-space services.

7.3.3.3 Requirements

Requirement Type	Requirement ID	Short Description	Description	Priority (H/M/L)	Source	KPI
Functional Requirement	UC4-DEM2-FNC-01	Autonomy	The system shall be able to create a reference framework definition without the need of GPS.	H	ALMENDE, EDI	UC4-D2-KPI-07 UC4-D26KPI-08 UC4-D2-KPI-09 UC4-D2-KPI-11
Functional Requirement	UC4-DEM2-FNC-02	Autonomy	The system shall be able to navigate to waypoints in a local reference framework.	H	N/A	UC4-D2-KPI-07 UC4-D2-KPI-08 UC4-D2-KPI-09 UC4-D2-KPI-11
Functional Requirement	UC4-DEM2-FNC-03	Autonomy	The system should be able to navigation based on the relative location, compared to a beacon placed on a moving rover following the attractor-based navigation principle.	M	ALMENDE	UC4-D2-KPI-07 UC4-D2-KPI-08 UC4-D2-KPI-09 UC4-D2-KPI-11
Functional Requirement	UC4-DEM2-FNC-04	Autonomy	The system should be able to reconfigure itself in real-time while maintaining operational.	M	TUE	UC4-D2-KPI-09
Functional Requirement	UC4-DEM2-FNC-05	Common model creation	The aerial platform shall use SLAM for modelling the environment.	H	DEMCON, EDI, ALMENDE	UC4-D2-KPI-07 UC4-D2-KPI-11
Functional Requirement	UC4-DEM2-FNC-06	Common model creation	The System shall use SLAM for semantical rich modelling and simulation.	H	ALMENDE	UC4-D2-KPI-07

Functional Requirement	UC4-DEM2-FNC-07	Autonomous Battery Management	The DronePort system shall provide landing spot for autonomous landing.	H	SmartMotion, UWB	UC4-D2-KPI-09
Functional Requirement	UC4-DEM2-FNC-08	Autonomous Battery Management	The DronePort system shall autonomously exchange or charge battery of the drone.	H	SmartMotion, UWB	UC4-D2-KPI-09
Functional Requirement	UC4-DEM2-FNC-09	Autonomous Battery Management	The DronePort system shall handle battery management.	H	SmartMotion, UWB	UC4-D2-KPI-08 UC4-D2-KPI-09
Functional Requirement	UC4-DEM2-FNC-10	Autonomous Battery Management	The drone shall autonomously land on predefined landing spot.	H	SmartMotion, UWB	UC4-D2-KPI-08 UC4-D2-KPI-09 UC4-D2-KPI-11
Functional Requirement	UC4-DEM2-FNC-11	Autonomous Battery Management	The Droneport control software shall handle battery management.	H	UWB,SmartMotion	UC4-D2-KPI-08 UC4-D2-KPI-09
Functional Requirement	UC4-DEM2-FNC-12	Autonomous Battery Management	The Droneport communication protocol shall support command for the refuelling process.	H	UWB,SmartMotion	UC4-D2-KPI-11 UC4-D2-KPI-12
Functional Requirement	UC4-DEM2-FNC-13	Autonomous Battery Management	The Droneport control software shall plan the refuelling mission.	H	UWB	UC4-D2-KPI-08 UC4-D2-KPI-09
Functional Requirement	UC4-DEM2-FNC-14	Drone platform	The system shall support aerial drones to be deployed in a cluttered and unknown environment.	H	TUD, DEMCON	UC4-D2-KPI-08 UC4-D2-KPI-11

Performance Requirement	UC4-DEM2-PRF-01	Detection and collision avoidance	The system shall detect the fixed objects in the environment. The system is able to detect static an object within 5 meters of the drone.	H	TUD	UC4-D2-KPI-07 UC4-D2-KPI-10 UC4-D2-KPI-11
Performance Requirement	UC4-DEM2-PRF-02	Detection and collision avoidance	The system shall detect moving objects. The system shall be able to detect moving objects with a minimum diameter of the deployed drone and maximum diameter of 3 times the deployed drone.	H	TUD	UC4-D2-KPI-10 UC4-D2-KPI-11

Table 69 - UC4 D2: Main requirements

8 UC5: Agriculture

8.1 Overall motivation and ambition of the Use Case

This use case shows the developments of the COMP4DRONES project in the field of agriculture.

Agriculture is the science, art, or practice of cultivating the soil, producing crops, and raising livestock as well as the preparation and marketing of the resulting products. From the perspective of environmental and climate protection novel resource-saving agricultural technologies are necessary.

The concept of precision farming is based on the observation, measurement and response to variability between and within the field in cultivated plants. Through the precise determination of the condition of all plants and the soil, water or nutrient deficiency but also diseases and vermin infestation can be recognized. This enables a timely and targeted treatment of the plants and the soil. The deployment of an autonomous rover can reduce the impact on the ground of bigger and heavier tractors. Moreover, advanced and more intelligent models can help both in water efficiency use and in reducing the cost/impact on the environment of herbicides/pesticides.

The use of drones and rovers is always associated with the exchange of data via a communication or data link. It is conceivable that over the next few decades the use of drones and rovers for monitoring plant growth and health, as well as for treatments and harvesting will multiply. Likewise, the use of sensors on the ground will also increase. Drones and rovers will collect sensor data, coordinate with each other and communicate with base stations. This can lead to considerable problems if security is not guaranteed, therefor special attention is paid to secure communication in this use case.

The agricultural domain is provided with a basic drone platform which can be configured as a modular system for multiple and generic tasks as well as for specific tasks in the agricultural domain. Technologies for real-time monitoring and more precise analysis purposes as well as for a trustworthy interaction between land-based sensors and drones as gateways are being developed. The development process of the drones and components is supported by a workflow and toolchain environment as well as a reliability modelling system.

8.1.1 Use Case concept and challenges

In this use case two demonstrators will be implemented, which are located in very different areas of agriculture and address their special boundary conditions. The first demonstrator is in the area of wide crop production and deals with the technology requirements for plant monitoring, with a focus on health and growth management, whereby a rover is also used in addition to the drone. On the other hand, the specific technological needs of viticulture in a remote area with poor infrastructure are illuminated, where the drone serves as a gateway for images and land-bound sensor data.

In both demonstrators of this use case, the architectures for drone systems-of-systems composition to enable self-adaptability and secure communication will be demonstrated. This relates to the challenges of expanding drone capabilities by embedding additional functions and setting up a system engineering framework and a development workbench.

Challenges of this use case:

- Energy management.
- Secure communication and coordination between UAV and UGV.
- Secure communication between UAV and land-bound sensors or base station.
- Weak infrastructure (communication network, power supply) in remote areas.

This use case will focus on 6 main challenges, which are aligned with the ECSEL Multi-Annual Strategic Plan (MASP) challenges:

- Ensuring safe and secure spaces (Digital Life - Challenge 10.3.1):
    - Safety and security in all other work environments are within the scope, covering office environments, agricultural and farming, construction sites, etc.
- Ensuring anticipating spaces (Digital Life - Challenge 10.3.3):
    - Saving human effort and improve usability of advanced technologies by non-expert operators.
    - Facilitate daily routines in all aspects of the digital life.
    - Pro-actively support individuals in their daily affairs.
- Ensuring sustainable spaces (Digital Life - Challenge 10.3.4):
    - Reducing the impact on the environment, support smart water management, and "green" facilities in smart environment.
- Secure connected, cooperative and automated mobility and transportation (Transport and Mobility - Challenge 6.3.3):
    - A special focus is on the secure communication between drones, base station and local sensors. A customizable secure element which can be adapted to different usage scenarios will enable secured communication.

8.1.2 Use Case objectives

The goal of this use case is to use the latest drone and robotic technology for the agricultural domain in order to reduce the costs and times of data collection, human effort and impact on the environment. The main objectives targeted by the Agricultural use case are supporting:

- Dynamic management of energy.
- Emergency navigation.
- Trusted communication.
- Efficient design, integration verification and validation.
- Dependability metric based self-adaptability.
- Communication security by a secure element for drones and a cryptography library.
- Connect remote areas to ensure drone results upload.
- Enable more advanced onboard computations through (but not limiting to) AI.
- Extend the impact of this technology by pushing more advanced functionalities on board, without affecting the design time and usability.

The following chapter presents the UC5 objectives in more detail and explains the relation to the overall project objectives.

8.1.3 Contribution to project objectives

8.1.3.1 Project Objectives

The use case is contributing to the achievement and assessment of the following project objectives:

Proposal Objective	Use Case Contribution	Measurable Outcomes
O1: Easing the integration and customization of drone embedded system	Simplifying integration and customization of the computing layer of drone systems	Architectural template based on heterogeneous FPGA SoCs where custom accelerators can seamlessly and effortlessly be integrated with the general-purpose CPUs, interconnect and main memory.
	Core system blocks accelerators definition	Network accelerators design and implementation.
		Flight controller accelerators design and implementation.

	Dynamic management of energy requirements	Energy management and optimization system continuously monitoring important system parameters, while dealing with the varying power demands.
	Emergency navigation and positioning system that can intervene in case GPS signal is corrupted or totally missing	Simultaneous localization and mapping (SLAM) systems exploiting a combination of geomagnetic, radio and time to flights (ToF) sensors, to achieve high precision no-GPS navigation.
	Logistic for cooperative operations	Leader-follower schemes development to guarantee cooperation between a terrestrial and an aerial drone.
	Dependability metric based self-adaptability	Framework which enables drones to monitor safety, security and performance and balance computation needs to ensure dependable operation in all mission phases and equipment variations.
O2: Enable drones to take safe autonomous decisions	Improve integration of weather conditions in mission planning	Enable weather-based mission planning, e.g. short term (during mission) or mid-term (before mission) consideration of weather data and adaption of mission based on weather conditions.
O3: Ensuring the deployment of trusted communications	Advanced data transmission support drone-to-drone, drone-to-base station coordinator and base station coordinator to cloud	Systematic approach for safety hazard identification and risk management for drone.
		Definition of a cloud solution for data storage and analysis using different tools and methodologies (i.e. STAMP and hybrid cryptography schema).
	Methodology for risk assessment to support the engineering and design phase of drone's operations	New systemic approaches for safety assessments in complex and heterogeneous systems.
	Methodology for security guarantees	Lightweight cryptographic modules for data-privacy, authentication and communication integrity.
		Intrusion Detection System module to protect both the drones and the central infrastructure from malicious attacks.
	Secure element for drones and security (cryptography) library	Reducing CPU usage for cryptography by 15%.
O4: Optimize the design and verification effort for complex drone applications	Methodologies and tools for HW accelerators design and deployment	Automated design/mapping strategies for accelerators deployment, from high-level languages down to HDL specification and FPGA overlays customization.

		Support for high-level programming models and associated offloading mechanisms (e.g., OpenCL, OpenMP) for the development of the target applications.
	Methodologies and tools for system/components verification	Techniques for correct tracking behaviour exploiting Temporal Logic for formal analysis and verification of the executions.
		New techniques based on hybrid reasoning methods for complex hardware (Deep) Neural Networks verification.
		Lightweight monitoring techniques derived from the verification phase, to track runtime behaviour of the control software.
	Simplified design/integration of system components	Development of a flexible platform, with software-in-the-loop (SIL) and hardware-in-the-loop (HIL) capabilities, so to enable easier/incremental components design, integration, and rapid prototyping.
	Toolchain, automating testing and verification of drone components	Reduce effort to prepare drone components for certification by 10%.
O5: Ensuring sustainable impact and creation of an industry-driven community	Including use case experiences and work in master courses at FH Burgenland and FH Campus	2 contributions from students (e.g. reports or papers) based on the use case.

Table 70 - UC5 Contribution to project general objectives

8.1.3.2 Technical Objectives:

The use case is contributing to the achievement and assessment of the following technical objectives:

Proposal Technical Objective	Use Case Contribution
ST01: Integrated Modular Platform	Architectural template based on heterogeneous FPGA SoCs
	Core system blocks accelerators definition
	Modular and reusable secure element for enabling trustworthy communication
ST02: Safe Intelligent Navigations	Dynamic energy management
	GPS-less emergency navigation and positioning system
	Logistic for cooperative operations
	Weather based mission
ST03: Trusted Communication	Data transmission support
	Methodology for risk assessment
	Methodology for security guarantees
	Development of a certifiable communication module which can be added to drones to enable their role as “secure flying gateways”

ST04: Design, Performance and Verification Tools	Methodologies and tools for HW accelerators design and deployment
	Methodologies and tools for system/components verification
	Simplified design/integration of system components
	Automated testing and analysis for dependability properties

Table 71 - UC5 Contribution to project technical objectives

8.1.4 Boundary conditions

The following boundary conditions must be taken into account (see Table 72):

Demonstrator	Scenario	Name	Short Description
Demo 1	Scenario 5.1.1	Temporal Constraints	The temporal constraint for UAV and UGV are linked to the vine's production period and the number of observations (flights) scheduled during the 7 months of production (from March to the end of September for the vine and from July to February for the artichoke).
		Weather Conditions	Weather conditions must be ideal, cloud-free sky and with the presence of the sun at the zenith in the hottest hours of the day (12 am to 14 pm) for use only the UAV the same for UGV.
	Scenario 5.1.2	Temporal Constraints	The temporal constraint for UAV is linked to the vine's production period and the number of observations (flights) scheduled during the 7 months of production (from March to the end of September for the vine and from July to February for the artichoke).
		Weather Conditions	Weather conditions must be ideal, cloud-free sky and with the presence of the sun at the zenith in the hottest hours of the day (12 am to 14 pm)
	Scenario 5.1.3	Temporal Constraints	The temporal constraint for UAV and UGV are linked to the vine's production period and the number of observations (flights) scheduled during the 7 months of production (from March to the end of September for the vine and from July to February for the artichoke).
		Weather Conditions	Weather conditions must be ideal, cloud-free sky and with the presence of the sun at the zenith in the hottest hours of the day (12 am to 14 pm)
		Orographic Constraints	The rover can move on different soils with reduced slippage if the frontal gradient is less than 57% and lateral gradient is less than 37 %.
Demo 2		Weather conditions	The flights should take place in dry weather, as rain and wet leaves influence the (multispectral image) data significantly.

	Max. Windspeed	With respect to the image quality of the multispectral camera, the windspeed should be as low as possible (max 10 m/s).
	Temporal Constraints	Multispectral images make sense in a small period of growth in order to analyze health and growing conditions of the vineyards as the object to be analysed are mainly the leaves of the plants.
	Pilot (Legal Constraint)	Actual legal situation in Austria requires a pilot operating the drone (Drone Class 1). The operation must be in line of sight (flight radius of about 500m) and pilot must have the possibility to react on unexpected situations (semi-autonomous operation).
	Drone registration (Legal Constraints)	The Austrian Airspace authority restricts all drones with more kinematic energy of 79J to be registered. All drones >5kg TOW (take-off weight) must be redundant with respect to the document[6] .
	Infrastructure Constraint	None or insufficient availability of communication networks and power supply in remote areas.

Table 72 - UC5 Boundary conditions of agricultural domain

8.2 Demonstrator 1

The test sites will be carried out in 2 experimental farm located in Sardinia.

The first one is called Carpante (Viticoltura Usini): the area planted with vines consists of 9 hectares spread over 4 plots located in the municipality of Usini. All the hilly plots are located at an altitude between 200 and 260 meters above sea level.

The cultivated varieties are the Cagnulari (5 ha), the Cannonau (1 ha), the Vermentino (2.5 ha) and the cultivars Merlot, Cabernet and Carignano (for a total of 0.75 ha). Thanks to the different composition of the soil, the experimental area allows the study of the relationship between the soil's variability and the plant's condition. Among the cultivated varieties, both the Cagnulari and the Cannonau, are red berry varieties characterized by having the same rootstock 140R (no rootstock-grafting influences). The rows available for the test are 2 per field (2 different variety). The length of the same is about 200 meters, 250 vines per row and a distance of 0.80 m between the plants. The bottles produced annually are about 40 thousand.

In this Demonstrator different stakeholder will be involved. We have already collected support letters from Sarciofo, Cantine Tollo and Carpante, which have been considered when defining the assessment scenarios described hereafter.

[6] https://www.austrocontrol.at/jart/prj3/ac/data/dokumente/LTH_LFA_ACE_067_2019-01-31_0901379.pdf

With respect to this demonstrator the UNISS Department of Agriculture can be considered an internal stakeholder regarding the problem definition and end-user requirements, since they do research on fields and have a solid background/experience on this kind of problems.

Regarding additional external stakeholders, Abinsula had additional preliminary contacts with other winemakers.

8.2.1 Justification Plan

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.

8.2.1.1 Demonstrator overview

This demonstrator is mainly focused on crop monitoring, with special emphasis on health and growth crop management. Here follows a short story-board of the scenario:

1. Uncle John is a wise farmer that wants to improve its business by going green, using as little pesticides as possible and wasting as little water as possible.
2. Uncle John, to be able to properly size the amount of pesticides, needs to assess the growth of the crops (for example by determining the volume of the tree crowns) and their status (for example by determining the presence and amount of nutritional deficiencies, other disease or insect infestations).
3. **[Scenario 5.1.1[7]]** To gather more precise knowledge of the growth, Uncle John buys a drone and starts its usage to observe his fields. Image campaign acquisitions can be performed to determine the precise tree crowns and also to be able to determine exactly how much water will be needed for irrigation. This first improvement results into:
    a. The possibility of using just the exact amount of water needed, meaning less impact on the planet's resources.
    b. The reduction of pollution and costs determined by a non-properly sized irrigation when water tankers are adopted. Indeed, you may certainly want to minimize useless irrigation missions that have a cost in terms of effort and fuel at least.

    At this stage, the treatment is still distributed to all the crops instinctively, and irrigation and treatment actions will not be part of the demonstration scenario being carried out in a manual classical manner.
4. [Scenario 5.1.2[8]] To become greener, and to be able to intervene promptly and locally on unhealthy crops/plants, Uncle John invests on a smarter drone with augmented capabilities, smart enough to determine where actions are needed. This second improvement results into:
    a. The possibility of addressing the most important best practice in agriculture performing treatment when is needed only where needed.
    b. The reduction of pollution and costs determined by a non-properly sized treatment.

    At this stage the treatment is distributed locally, but it will still not be part of the demonstration scenario being carried out in a manual classical manner.

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[7] Scenario 5.1.1 stands for UC5, demonstrator 1 and execution scenario 1
[8] Scenario 5.1.2 stands for UC5, demonstrator 1 and execution scenario 2

5. [Scenario 5.1.3[9]] Uncle John, as a wise farmer, knows that it would be good to save also a bit of his own effort without losing money in hiring someone to do the treatments. Therefore, he buys a rover that under the lead of its master (the image acquisition drone) actuates the treatment as determined in the acquisition campaign. This third improvement results into:
    a. The possibility of saving Uncle John precious time and effort.
    b. The possibility of promptly intervening on nutritional deficiencies, other disease or insect infestations to avoid their worsening/spreading.

Scenario	Aerial Drone Autonomy level
Scenario 5.1.1	3
Scenario 5.1.2	3
Scenario 5.1.3	3

Table 73 - UC5 D1: Autonomy level of aerial drone

Scenario	Ground Rover Autonomy level
Scenario 5.1.3	3

Table 74 - UC5 D1: Autonomy level of Ground rover. Rover is involved only in scenario 5.1.3.

8.2.1.2 Description and scope

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, 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.

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. automatic disease detection 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.

8.2.1.3 Objectives

COMP4DRONES will enable technologies for real-time monitoring and more accurate analysis purposes and trustworthy interaction between land-bound sensors and drones as gateways. The **user needs** are listed below:

[9] Scenario 5.1.3 stands for UC5, demonstrator 1 and execution scenario 3

1. To gather precise knowledge and awareness of the health status and growth evolution of the crops/plants minimizing the effort for human operators, an autonomous system capable of advanced acquisition, monitoring and actuation capabilities **SHALL** be made available.
2. The acquisition/monitoring system **SHOULD** be able to recognize nutritional deficiencies or other diseases. The objects/areas to be recognized **SHOULD** be in the range of 1-2 centimetres.
3. The acquisition/monitoring system **SHOULD** be able to collect and store image (RGB or NIR or thermal) up to 300 pictures per hectare to determine in post processing the crown tree volume. The number of required megapixel per picture may vary depending on the sensor used, but standard RGB pictures used for this purpose reach 21-24 megapixel.
4. The actuator, based on the autonomous spraying system, **SHOULD** be able to treat plants from a distance in the range of 3 to 5 meters to guarantee the effectiveness of the treatment itself.

To be able to address the described needs in this demonstrator we intend to leverage advanced drone technologies - in a field where there is still little-to-none usage of them - by enabling more, and more complex, compute capabilities on board, along with an efficient and autonomous cooperation among drone and rover. Together with the abovementioned user needs, this demonstrator will then respond to the following **business and high-level needs**:

- Easing the integration and customization of smart drone system.
- Ensuring the deployment of trusted communications.
- Optimize the design and verification effort for complex drone applications.

8.2.1.4 Key concepts and technologies

Given the scenarios described in Section 8.2.1.1 from the user point of view, we built a technological view of tasks and components that is summarized in Figure 45, Figure 46 and Figure 47. As you could see there the complexity of the Observe, Orient; Decide and Act phases is incrementally growing along the three scenarios of execution, and this will map the COMP4DRONES principle of modular composability of drone technologies.

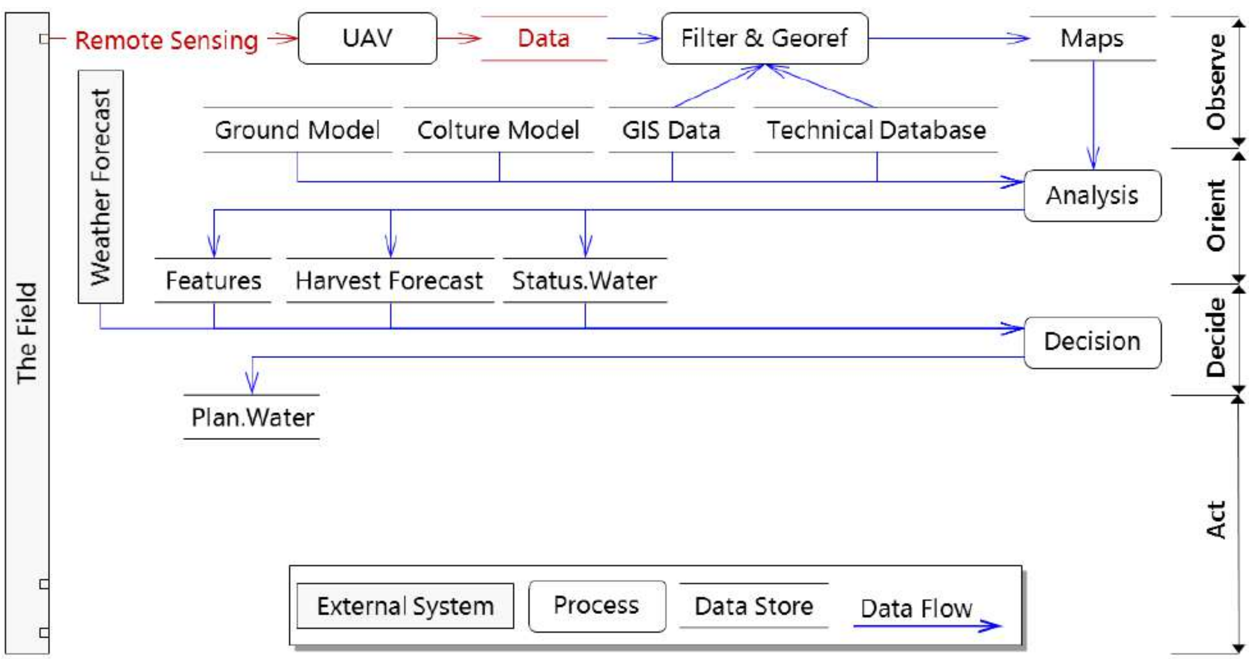


Figure 45 - UC5 D1: Scenario 5.1.1 of demonstrator overview, monitoring and post-processing

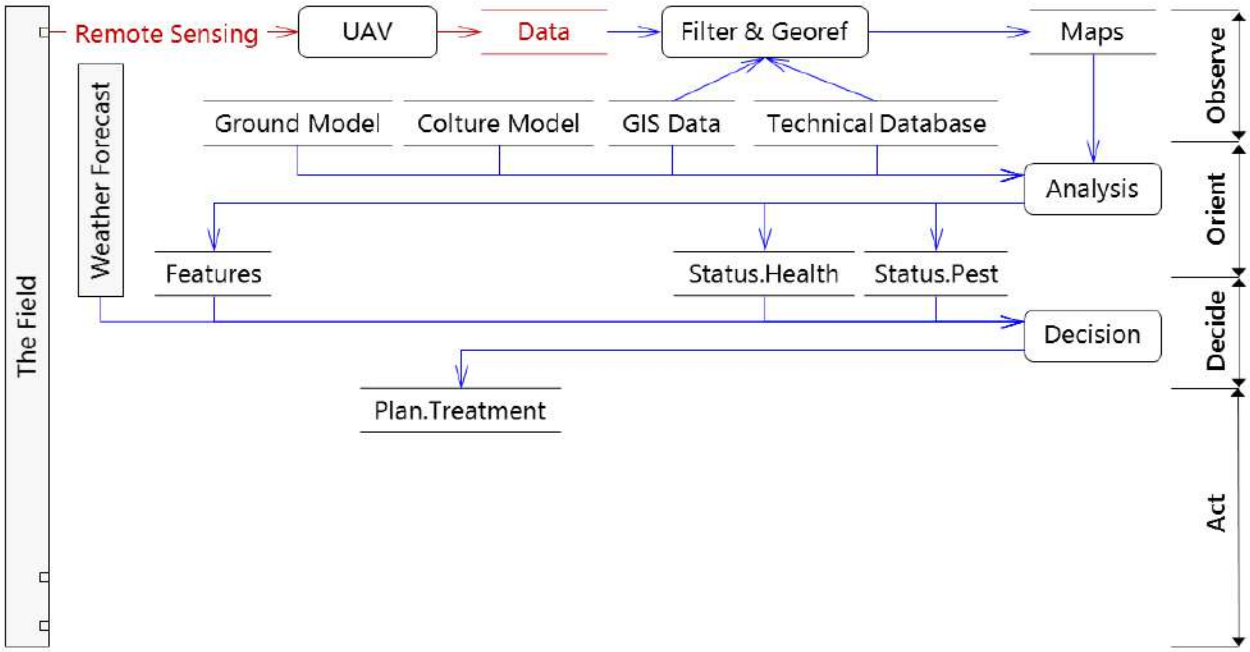


Figure 46 - UC5 D1: Scenario 5.1.2 of demonstrator overview, monitoring, online processing and classical manual intervention

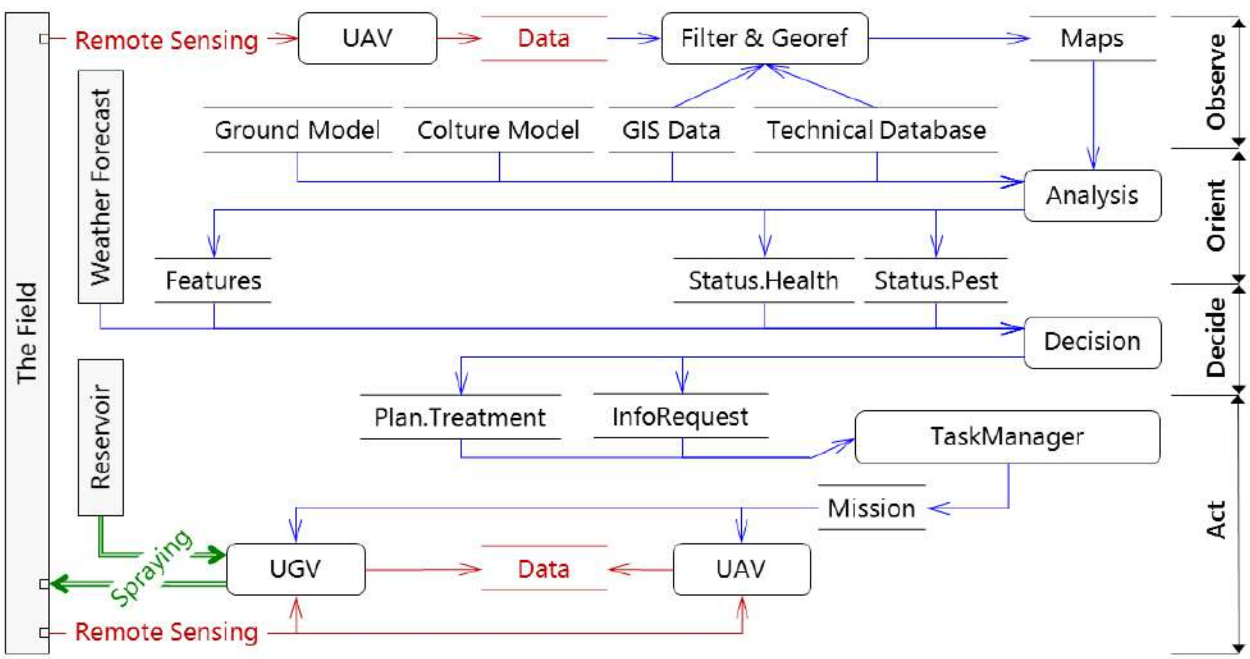


Figure 47 - UC5 D1: Scenario 5.1.3 of demonstrator overview, monitoring, online processing and rover-based intervention

Here follows a list of technological features, and related components, that will contribute to build the technological view of tasks and components presented in the pictures above. Please note that more components/techniques may contribute to the same feature that the demonstrator will embed/assess and represent the system requirements.

8.2.1.4.1 Feature 1 - Advanced on-board information processing capabilities

1. **[F1.1]** Onboard video acquisition and processing will be used to monitor the status of the plants and to monitor the growth volume. Different types of cameras can be used (e.g. RGB and/or NIR cameras) as well as different types of video processing algorithms based on traditional computer vision and on Artificial Intelligence (AI) and, more specifically, deep learning (DL) techniques. In particular, DL approaches are quite resource demanding; therefore, an appropriate optimization is needed to limit the power consumption allowing video processing execution at runtime, onboard. Moreover, the drone and/or the rover will stream the collected video and images to the ground station enabling a (post-) processing with a dedicated HW capable to provide a more advanced (and more power demanding) analysis. *Data elaborated on board **SHALL** enable efficient and effective Analysis, Decision and Optimization phases in the diagrams presented above.*
   [main contributors: Aitek, UDANET, MODIS]
2. **[F1.2]** Advances on system customization and processing platforms to provide a modular system (based on COTS FPGA SoCs) to ease customization of drone behaviour to different payloads and sensor inputs that **SHALL** enable flexible onboard computation and also extend computational power by leveraging on heterogeneous co-processing units that **SHALL** enable advanced onboard computation.
   [main contributors: UNISS-ENG, UNIMORE, UNIVAQ]
3. **[F1.3]** Pipelining implementation of the controllers enabling new features (situation awareness and management of critical situations, power autonomy awareness, compensation of environmental perturbations, autonomous cooperation). This ***SHALL** enable efficient implementation of the digital controller*.
   [main contributors: UNIVAQ]

8.2.1.4.2 Feature 2 - Drone/rover safe coordination and general functional cooperation.

1. **[F2.1]** In general, Unmanned Aerial and Ground Vehicles (UAV and UGV) can cooperate in different ways to exploit their heterogeneity and complementarities (Chen, Zhang, Xin, & Fang, 2015)[10]. Functionally, in the proposed Demonstrator:
   - Both *UAV and UGV **SHOULD** cover the role of mobile sensors*.
   - The *UGV **SHOULD** also act as a mobile actuator*, the UAV can be an auxiliary facility since it may relay or provide information useful for on-line decisions.
   - *Both UAV and UGV **SHOULD** enable and put in place coupled remote sensing goals*:
     - UAV is for rapid reconnaissance, while UGV is for details.
     - Both UAV and UGV can contribute to the reconstruction of complex images.

   The computing platform of the Ground Station could be moved on to the UGV for a hybrid decision making or for operating in communication denied areas. In these scenarios *the different vehicles **SHOULD** be enabled with a direct communication link that completes the Ground Station link*, that has all the security features of the latter, and that provides services for timely identification and anti-collision.

   The working hypothesis from which the project moves is an Ultra-Wideband based short-range link that can contribute to the UGV guidance too by means of optional beacons (Figure 48). The project also considers integration with the long-range links such as Low-Power Wide Area Networks.

[10] J. Chen, X. Zhang, B. Xin e H. Fang, "Coordination between unmanned aerial and ground vehicles: A taxonomy and optimization perspective," *IEEE transactions on cybernetics,* vol. 46, pp. 959-972, 2015

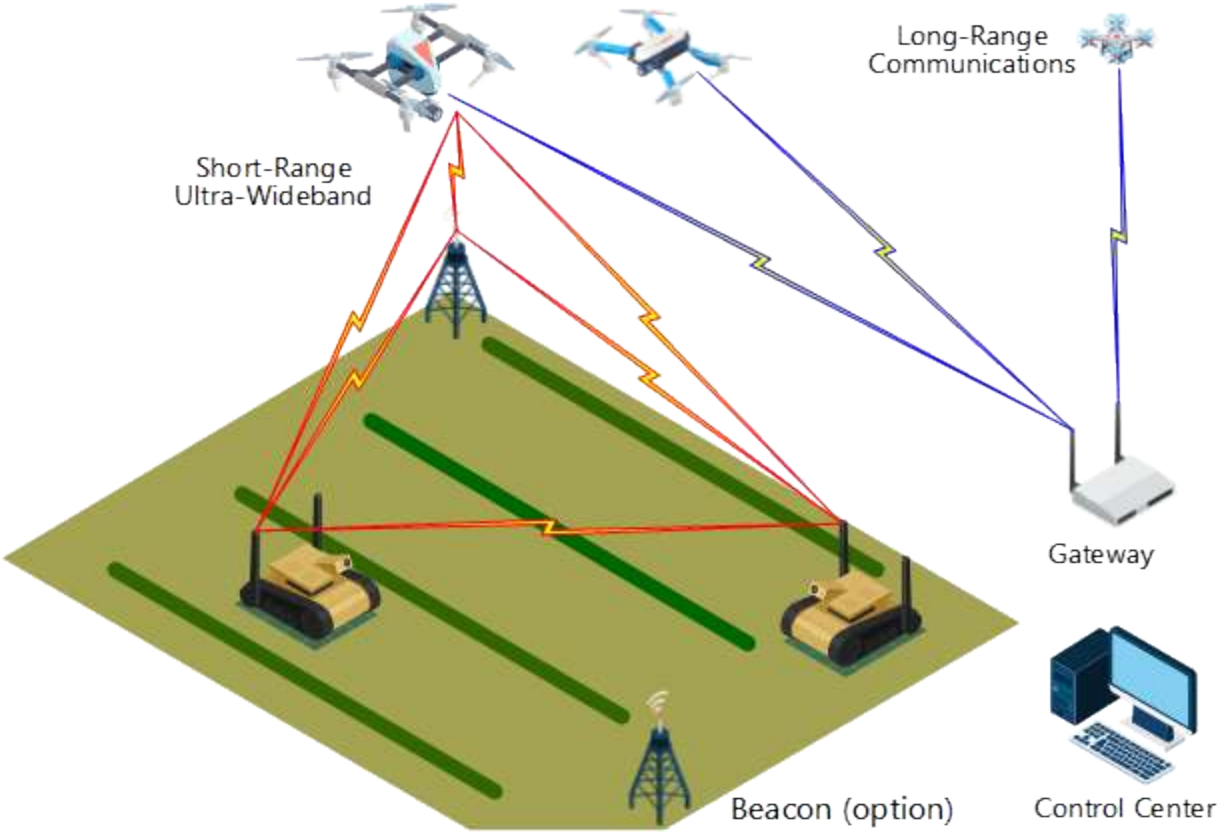


Figure 48 - UC5 D1: Concept of short and long-range communications

2. **[F2.2]** Operating a drone safely is the most important factor for all drone pilots. It does not matter whether a drone is used for public or private scopes: keeping health and safety at the forefront of our mind is a definite must. For this reason, it is primarily important <u>to operate a Risk Assessment to identify any potential hazards that may harm something or someone when a drone a drone operates</u>. The assessment evaluates the potential hazards and the possible risk to safety, then outlines the actions to be taken either to remove or reduce the chance of harm. *Risk Assessment **MUST** be operated prior execution to remove or reduce the chance of harm. In order to operate safely, the controller **SHALL** enable the following functionalities:*
   a. *Compensation of environmental perturbations acting on the drone.*
   b. *Autonomy and cooperation.*
   c. *Management of critical situations via improved situation awareness.*
   d. *Power autonomy awareness.*

   [main contributors: TEKNE, AITRONIK, RO-T, UNIVAQ]

8.2.1.4.3 Feature 3 - Planning and Navigation

1. **[F3.1]** Provide <u>automatic runtime path planning</u> to calculate the minimum path for the slave sprayer for treatment execution. Standard path planning algorithms (e.g., RRT* or A*) will be implemented in Python or any other general-purpose language that will be interfaced to ROS (Robot Operating System), Gazebo and MATLAB/Simulink so to validate the behaviour through a Software-in-the-Loop methodology. Such technologies (ROS, Gazebo and Matlab/Simulink) will be used also for other verification and validation activities aimed to verify the drone/rover behaviour before the real experiments.
   - *Automatic and runtime path planning **SHALL** enable automation among the Decide and Act phases in the diagrams presented above by enabling the spraying rover to operate as a slave of the drone.*

- *Also, the controller **SHALL** enable reference generation for autonomous navigation and accident avoidance.*

  [main contributors: UNISANNIO, UNIVAQ]

2. **[F3.2]** An energy management system is vital to optimize the energy life and the purpose of the UAV: it will continuously monitor important system parameters, while dealing with the varying power demands of the many aspects, the objectives of the mission and optimizing the usage of the energy. The designed predictive energy management system will be verified and tested via Software in The Loop. *The automatic energy management system **SHOULD** provide indications on the implementation to save energy during the motion, taking into account the physical constraints of the UAV, the mission to be performed and any temporal constraints to be taken into account.*
   [main contributors: UDANET]

8.2.1.4.4 Feature 4 - Secure communications and safety guarantees.

1. **[F4.1]** *The system **SHALL** be capable of providing secure links to avoid hijacking and malicious attacks that may alter the correct functional behaviour*. To guarantee low energy communications, it is assumed that hybrid encryption algorithms will be used where possible, based on protocols used in the WSN framework. A second hypothesis foresees the study of an algorithm that takes into account the energy power and calculation of the single components, distributing the load according to these factors. Both solutions could use cluster tree or mash configurations. A preliminary configuration of the nodes has been devised with the purpose of their recognition of possible intrusions.
   [main contributors: ABI, RO-T]
1. **[F4.2]** Provide an embedded management system for drones, backed with artificial intelligence capabilities that supports autonomous safe navigation. In particular, reinforcement learning algorithms might be used to allow drones for navigating autonomously and detect obstacles. *The system **SHALL** integrate with SLAM algorithms to allow the drones to safely navigate and interact with unknown* environments.
   [main contributors: MODIS]

8.2.1.4.5 Feature 5 - Advanced geo-localization techniques

2. **[F5.1]** Advanced SLAM algorithms and sensing capabilities to allow autonomous positioning and map-construction of the area of interest even in presence of failures of the GPS. In particular, lack of GPS might be compensated by magnetic field, odometry or other kind of measurements (e.g., infrared camera, lasers and so on). Different types of algorithms can be considered both for the positioning and the map-construction problem. Popular solutions rely on Approximate Bayesian Inference techniques that are notoriously eager of data and computational power. This calls for a careful co-design of hw/sw in order to meet the low-power requirement of the considered application. Overall, the algorithm ***SHALL** allow the drone to perform an effective, efficient and continuous positioning and field reconstruction.*
   [main contributors: MODIS]

Given the above-described features, the activities, blocks and functionalities that will contribute to this demonstrator are listed in Table 75.

Building Blocks	Technological components, sub-system, tools / Responsible Partner(s)	TRL (Expected)
Drone Platform Layer		
Control	Autopilot tailoring with accurate GNSS receivers + Ground Infrastructures [TOPVIEW]	TRL4
	Flight missions' accuracy and repeatability (GNSS aided) [TOPVIEW]	TRL5

	SIL and HIL [UNISANNIO]	TRL5
	Efficient digital implementation of discrete–time controllers on FPGAs [UNIVAQ]	TRL4/5
	Compensation and rejection of environmental perturbations, measurement uncertainties, and possible faults [UNIVAQ]	TRL4/5
Compute	Low-power embedded SoC template and dedicated accelerators, programmability support and automated design support [UNIMORE, UNISS-Eng, UNIVAQ]	TRL4
Sensors	Infrared thermal imaging [MODIS]	TRL4
Communication Layer		
Data Transmission	Stack protocol communication and network topology configuration [RO-T, ABI]	TRL3/4
	Cloud architecture for data storage [RO-T, ABI]	TRL3/4
	hazard identification and risk management [ROT]	TRL3/4
Security	Lightweight cryptographic modules [ROT]	TRL3/4
	Intrusion Detection System module [ROT]	TRL3/4
Safety	Runtime safety-rules checker [ROT]	TRL3/4
Software Layer		
Advanced Image Acquisition	Video acquisition and processing to detect information about the status of the plants [AITEK]	TRL 4/5
Cooperative drone operation	Autonomous and cooperative flight aerial-terrestrial drones, reference generation for autonomous navigation [UNIVAQ]	TRL3/4
	Management of critical situations, with improved situation awareness [UNIVAQ]	TRL3/4
	Provide automatic runtime path planning UNISANNIO	TRL 4/5
	Communication link for identification and anti-collision [TEKNE]	TRL5
Predictive energy management	Continuous monitoring and optimization [UDANET]	TRL3/4
	Power autonomy awareness [UNIVAQ]	TRL3/4
GPS-less	GNSS positioning [MODIS]	TRL4
	No-GPS navigation [MODIS]	TRL4
Application Software	AI Algorithms for monitoring and prediction purposes to identify leaf diseases [UDANET]	TRL3/4
	Creation of dataset to train the system model and to consider the disturbance [UDANET]	TRL3/4
	Learning-based obstacle detection and avoidance [AIK]	TRL4
Services Towards Users		
Towards the End-User: support and services	Mobile monitoring [Ro-T]	TRL4
	Flight Controller Interface [TOPVIEW]	TRL4
	Dashboard [Abi Ro-T]	TRL6/7
	Compliance with E-UTM Scenarios [TOPVIEW]	TRL3

Table 75 - UC5 D1: Building blocks and technologies

8.2.1.5 Infrastructure and drones

As general infrastructure set-up we expect to enable in-field cooperation of two different types of autonomous vehicles: a field rover and a drone.

8.2.1.5.1 The Rover

The field rover is a robotic platform based on the ATR-Orbiter robot, manufactured in Italy by ATR-Robotics (www.allterrainrobots.com). ATR-ORBITER is a powerful, robust, fully radio-controlled mobile robot crawler and is able to tackle any type of terrain and suitably used for a wide variety of applications. ATR-ORBITER was primarily designed to offer the user ease of use, control, management and maintenance, the layout of each component was then designed to simplify any remediation action necessary to create a comprehensive system easy and intuitive to for everyone.

It is provided with the full electrical power of an agricultural tractor, and can be used for different operations, for example as a snow remover, on gravel, on soil, or connected to a trolley or any other accessory through its posterior tow hook, positioned so as to allow the exact balance of the machine during towing, thus avoiding unwanted inclines or loss of traction. Thanks to the incredible tractive force, delivered by the powerful main engines coupled with strong torque-reducing multipliers, ATR-Orbiter is able to pull extremely heavy loads. Designed and developed to provide the best possible performance in every situation, it can move with precision in either wet or dry grounds, mud and sand minimizing slippage.

Figure 49 - UC5 D1: QTR-Orbiter during sand-removal operations

Technical details are reported in Table 76.

Features		Performances	
Equipment body	On crawlers	Dynamometer test (pull/push)	397 KG/3893N
Driving control type	Remote control	Max gradient	57 %
Accelerator	1 Joystick	Max lateral gradient	37 %
Battery Charger - Lithium	External (100A) with charge status information	Forward/Revers speed -FAST -SLOW	 3,0 Km/h 1,8 Km/h
Dashboard display	Remaining battery charge Equipment failures Hour meter	Mechanical transmission	2x Worm gear motor (i38)

Product net weight	350 Kg	Pulling capacity on flat surface	3500 Kg
Battery - Lithium	+24v (200 Ah) heated	Battery recharging time - Full charge - 50%	2 hours 30 min
Electric motor	2X 24v/1000 watt S2 30min	Operational indicator	Flashing light

Table 76 - UC5 D1: Main features and performances of ATR-Orbiter

The rover will be equipped with sensors for autonomous navigation. The minimum set of sensors integrated in COMP4DRONES is composed of an RTK GPS, an Inertial Measurement Unit (IMU), a daylight stereo-camera, and a laser scanner.

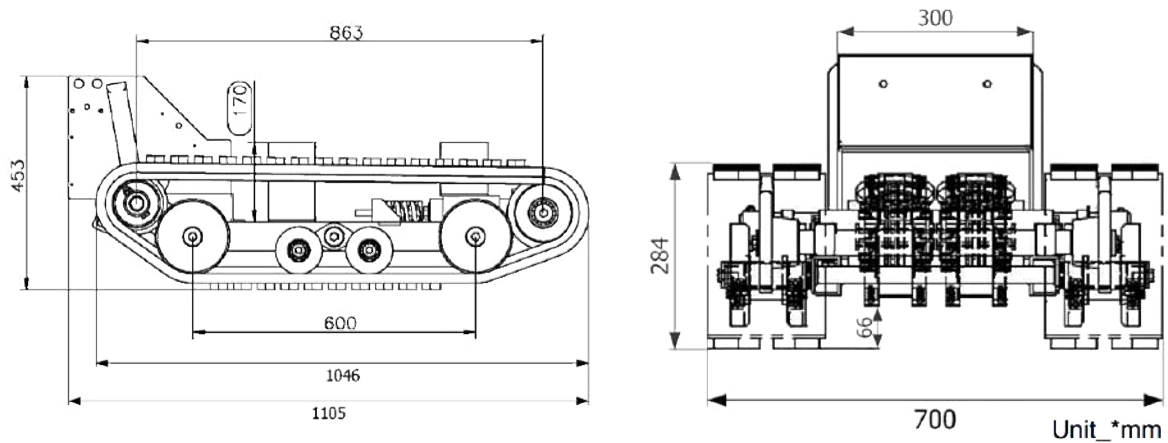


Figure 50 - UC5 D1: Dimensions of ATR-Orbiter

Specific manufacturers and models have been identified. However, they could be further replaced with other components that might enter the market and show better performances, costs, and reliability. The preliminary list of selected sensors is reported in the table below.

Sensor Type	Manufacturer	Model	Website
RTK GPS	Ublox	Ublox C94-M8P	https://www.u-blox.com/en/product/c94-m8p
Inertial Measurement Unit (IMU)	Aceinna	openIMU300RI	https://www.aceinna.com/inertial-systems/IMU
Lidar	Keyence	SZ-V	https://www.keyence.it/products/safety/laser-scanner/sz-v/index.jsp
Stereo-camera	Stereolabs	ZED	https://www.stereolabs.com/

Table 77 - UC5 D1: Preliminary list of sensors selected for the ATR-Orbiter rover

Moreover, at least one heterogeneous platform will be mounted on board the robot. Current platform candidates are Nvidia Jetson TX2, Nvidia Jetson AGX, and Xilinx Zinq Ultrascale+. Nvidia platforms have GPU on board, whereas Xilinx Zinq provides FPGA. Similar to sensors selection, final decision will be taken according to technical opportunities and challenges in COMP4DRONES.

Relating functionalities and components, the autonomous rover will implement on board advanced heterogeneous platforms (**UNISS-ENG** and **UNIMORE**) and control technologies related to ensuring drone/rover safe cooperation (**UNIVAQ**, **TEKNE** and **RO-T**) and automatic path planning (**UNISANNIO**). As every partner is responsible for its own technology, each component shall be provided to be integrated with no modification from AIK. AIK, on its turn, will provide the mechanical, electric, electronic, and software interfaces to ease the development and further integration of technologies.

Figure 51 - UC5 D1: ATR-Orbiter during a trial close to Aitronik facilities

8.2.1.5.2 The Drone

Two different drones will be available to implement the activities on-field foreseen for the agriculture use case.

1. A Commercial Off-The-Shelf (COTS) solution as operational platform to test automatic flight operations with possibility of acquisition of thermal infrared and RGB data over the crops with pre-programmed flight plan. (TRL 9)
2. An Integrated drone solution (obtained by assembling COTS parts available on the market) for testing more demanding features such as embarking required avionics for conditional decisions as well as cooperation with Rover (TRL 7).

An example of possible COTS drone is reported is the section below.

Moreover, both drones **SHALL BE** equipped with a multi-constellation GNSS Receiver (EGNOS/Galileo enabled). Indeed, GNSS is a key enabler of precision agriculture[11], allowing not only farmers to drive their tractors (and rovers) along parallel lines, but also allowing drones to fly accurate straight flight path for better performance, during the acquisition and acting stage. The involvement of EGNSS technology differentiators such as Galileo High Accuracy Service (up to 20 cm accuracy) or Multi-constellation RTK

[11] https://www.gsa.europa.eu/newsroom/news/egnss-and-agriculture-—-win-win relationship

as alternative (with local or remote reference station), will help to avoid overlaps and gaps in field cultivation during acquisition, providing superior accuracy in positioning when actions are needed (e.g. spraying).

In both cases GNSS accurate positioning will be investigated considering a possible architecture composed by a local Ground Stations and a drone (base + rover solution) in combination with Galileo High Accuracy service (if available) or other comparable techniques.

8.2.1.5.2.1 Commercial Off The Shelf Drone

Figure 52 - UC5 D1: GNSS Local station and GNSS modules in RTK/PPK Rover + Base configuration

An example of possible COTS drone to be involved during tests is hereafter reported. The drone taken into account represents the state-of-the-art solution available on the market for drones below 10 kg. In fact, the Matrice 200 is a powerful aerial imaging system with class-leading agility and speed, redundant components for maximum reliability, and smart features that make performing complex tasks easy. Gimbal cameras can be easily exchanged to suit agriculture use case needs. The added value introduced by this system is represented not only by the reliability of flight itself, but also by the possibility to program it with a powerful SDK[12] allowing many integration possibilities with additional hardware and sensors.

Figure 53 - UC5 D1: Target COTS development platform (DJI M210 with SDK, TRL 9)

A Commercial Off-The-Shelf (COTS) solution (entirely or by assembling COTS parts) is the preferred one for providing the *basic UAV* whose constitutive blocks are listed in Table 78.

[12] https://developer.dji.com/onboard-sdk/documentation/introduction/homepage.html

Blocks	Identification
Platform	DJI M210 Drone
Flight Controller	M200 series autopilot
GPS	U-blox M8N multiconstellation, single frequency
Inertial Measurement Unit (IMU)	not provided by vendor
Altimeter	not provided by vendor
Battery	2x TB55 - 7660 mAh-22.8 V

Table 78 - UC5 D1: Components of the basic COTS UAV

The M210 drone can be equipped with a large number of payloads. The payload considered for agriculture use case is the DJI FLIR XT2 Zenmuse optical/Thermal Payload.

8.2.1.5.2.2 Integrated drone solution

TOPVIEW Mantide 900[13] is a class 900 drones of 8,2 Kg that has been approved by Italian CAA for flight operations in critical scenarios. It is a general-purpose light hexcopter based on S900 frame capable of embarking a 3,3 Kg payload, very useful at first stage of testing when it is expected a heavier payload composed by different development boards not yet integrated and optimized. This platform has large space to integrate sensors, On-Board Computers and high accuracy GNSS receivers.

This drone will be equipped with a Pixhawk based open source autopilot to extend its integration capabilities with new payloads that will be developed during the project, considering the large possibilities of customization with DroneKit API[14] available for custom development.

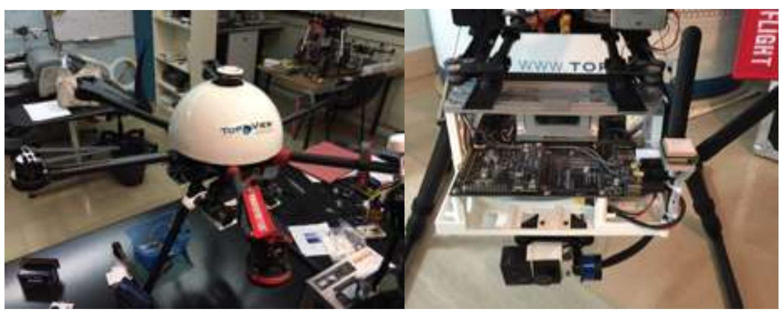


Figure 54 - UC5 D1: TopView MANTIDE 900 with no payload and with a high-performance onboard computer prototype payload based on Nvidia Jetson

Blocks	Identification
Platform	TopView Mantide 900
Flight Controller	RPI4 + Navio2 Flight Controller
GNSS receiver	U-blox ZED F9D multi constellation, L1 / L5
Inertial Measurement Unit (IMU)	not provided by vendor
Altimeter	MS5611 barometer
Battery	1x 16.000 mAh Tattoo 22.8 V

Table 79 - UC5 D1: Components of the basic Integrated UAV

[13] https://moduliweb.enac.gov.it/applicazioni/SAPR/APR_Lista_Unificata.asp?RIF_ENAC=&OPERATORE=topview
[14] https://dev.px4.io/v1.9.0/en/robotics/dronekit.html

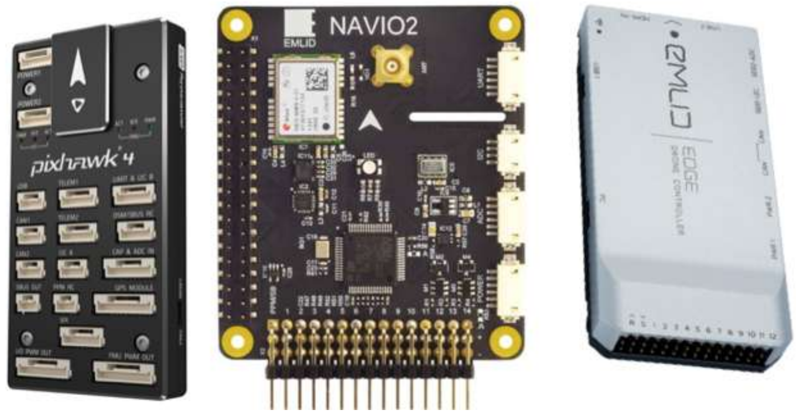


Figure 55 - UC5 D1: ROS / Ardupilot-based autopilots (candidates for the integrated drone solution)

The blocks are such that the basic UAV, in order to be used in the scenarios of the use case, possesses the characteristics (Table 80) which result from the analyses above.

Characteristic	Value
Maximum operating altitude	3000 [m]
Command and control communication link	<name/part-number> <type> range = xx [km]
Autonomy	25 minutes
Payload	2 Kg (with 16 Ah battery)
Payload power	50 W

Table 80 - UC5 D1: Characteristics of the basic UAV

To be used in a given use case scenario, the basic UAV must be equipped with the components[15] that the scenarios operativity requires: these too result from the analyses above and the characteristics of the basic UAV depend on them. Table 81 gives an example of such components for the Scenario 5.1.1 and Scenario 5.1.2. Please note that the description there is not complete, e.g. the power consumption is currently missing. Nevertheless, the table is meant to provide an idea of the information that are expected to be included in future deliverables.

Components	Identification
Altimeter	<name/part-number> <type>
Gimbal	<name/part-number>
RGB camera	<name/part-number> (if any)
Multispectral camera	<name/part-number> (if any)
Thermal camera	<name/part-number> (if any)
Lidar	<name/part-number> (if any)
Video communication link	<name/part-number> <type> range = xx [km] (if any)
Data communication link	<name/part-number> <type> range = xx [km] (if any)
Mission control computer	<name/part-number> (if any)
Parallel number-crunching computer	<name/part-number> (if any)

Table 81 - UC5 D1: Example of devices which the basic UAV is equipped with for Scenario 5.1.1 and Scenario 5.1.2

[15] 'Block' and 'component' are synonyms: the two different terms are used for differentiating blocks that belong to the basic UAV from components that belong to the UAV operating in different scenarios.

Relating functionalities, components, and additional developments it must be noted that:

1. Some components may be part of the project development. For example, the parallel number-crunching computer may be the FPGA-based processing platforms that the project wants to explore.
2. Certainly, some blocks/components (even COTS) are loaded with the software that the project develops.
3. The components with which the basic UAV is equipped may be different for different scenarios. As an example, the configuration of the scenario 5.1.3 must be completed so that the UAV operates in the scenario 5.1.3.
4. This document reports of scenarios from 5.1.1 to 5.1.3, but scenarios aren't ordered linearly: for unit/component/integration/system verifications the project may define other scenarios in which the basic UAV (or even a different UAV) is equipped differently (even with components not yet considered here).

Additional components of the basic UAV for the Scenario 5.1.3 is the communication link for the identification and anti-collision that will be developed during the project.

8.2.1.6 Implementation

Figure 56 depicts this demonstrator implementation flow, which stages are better described below.

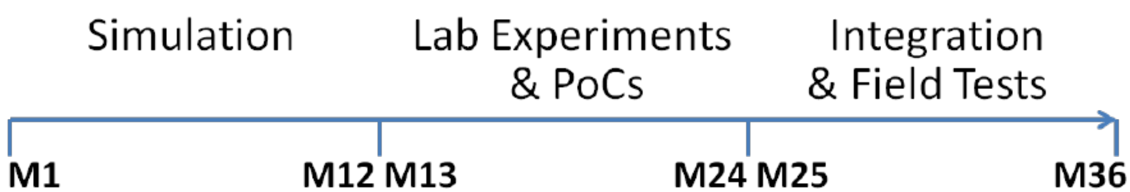


Figure 56 - UC5 D1: Demonstrator implementation flow

8.2.1.6.1 Stage 1: Technology Validation

Problem, specifications and components will be defined starting by the analysis of the user needs and, more in general, of smart and precision agricultures issues, current trends and SoA. Each partner will be involved in SoA and starting data gathering for those aspects related to their own technologies.

In parallel, UNISS-AGR team will start the sample gathering for algorithms training and evaluation (i.e. collection of leaves affected by disease or defects).

8.2.1.6.2 Stage 2: Technology Experimentation

Lab experiments of the main demonstrator components primarily in a stand-alone manner. Partial sub-system integration is also foreseen, most likely of real machineries but not to be tested in operational environments. Also, components that, due to a lower TRL, will not be included in the final demonstrator are meant to be assessed through simulation and small in lab PoCs at this stage.

In parallel, the sample gathering for algorithms training and evaluation (i.e. collection of leafs affected by disease or defects) will continue. Photo dataset are meant to be provided by the UNISS-AGR team representing plant phenology and the cluster dimensional evolution to improve detection efficiency.

8.2.1.6.3 Stage 3: Technology Implementation

Test in real operational environments of integrated technologies are expected. The scale of these tests will be highly dependent on the maturity level of the technologies after the first two years.

Field tests are expected to be carried out in UNISS facilities and in other suitable locations in contact with end users.

8.2.2 KPIs

From the user perspective the following needs will have to be satisfied to be able to produce the expected benefits:

- To be able to minimize wastewater and the costs of treatments, intended as cost of the tankers in terms of preparation and number of missions to be organized/handled, by sizing the volume of water and pesticides to be distributed upon the plant's growth volume.
- To reduce the effort of human operators in the monitoring of the field health status and in the actuation of ad-hoc spot treatments.
- To provide improved usability of advanced technologies by non-expert operators.

In the following section there is the list of the Key Performance Indicators that are preliminary considered for the UC (Section 8.2.2.1) and the technologies/components (Section 0) evaluation. The corresponding tables provide just a preliminary description since more details will become available as soon as the technical components and their requirements will be refined. Therefore, these tables will certainly be updated and integrated in the next deliverable of the project.

8.2.2.1 Business KPIs

ID	KPI	Description
UC5-D1-KPI-01	Drone mission duration % of reduction in resources consumption (i.e. water, fertilizers)	Comparison between data acquisition/post-processing executed through drone mission and actual reference values in the agricultural domain.
UC5-D1-KPI-02	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.

Table 82 - UC5 D1: Business KPIs

8.2.2.2 Technical KPIs

ID	KPI	Description
UC5-D1-KPI-03	Comparison with approaches in the State of the Art with regards to FPGA-based acceleration (e.g. Xilinx SDSoC): • Easy to design and deploy • Easy to develop applications for heterogeneous platforms (ARM GP core + FPGA acceleration blocks) • Improvements in performance and resource consumption	• Number of lines of code. • Execution time, clock cycles and energy consumption per offloading and execution.
UC5-D1-KPI-04	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.

UC5-D1-KPI-05	Accurate SLAM technique implementation / no-GPS positioning system	• Object recognition (e.g. fence, tree wall, hedges, and furrows) accuracy. • Orientation capabilities with geomagnetic field mapping.

Table 83 - UC5 D1: Technical KPIs

8.2.3 Specification Plan

8.2.3.1 Scenarios

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
5.1.1	Monitoring and post-processing	Acquisition and Storing units	H	UC5-DEM10
		Post-Processing algorithms	H	UC5-DEM10
		Secure, Safe and Energy-aware flight planning and navigation	H	UC5-DEM10
5.1.2	Monitoring, online processing and classical manual intervention	Image Campaign Acquisition - Acquisition and Storing units	H	UC5-DEM10
		Post-Processing & On-Board Algorithms	H	UC5-DEM10
		Secure, Safe and Energy-aware flight planning and navigation	H	UC5-DEM10
		On-Board computing platform customization with dedicated accelerators	M	UC5-DEM10
5.1.3	Monitoring, online processing and rover-based intervention	Image Campaign Acquisition - Acquisition and Storing units	H	UC5-DEM10
		(post-)Processing & On-Board Algorithms	H	UC5-DEM10
		Secure, Safe and Energy-aware flight planning and navigation	H	UC5-DEM10
		On-Board computing platform customization with dedicated accelerators	M	UC5-DEM10
		Drone/rover safe coordination and general functional cooperation	L	UC5-DEM10

Table 84 - UC5 D1: Scenarios description

8.2.3.2 Features and/or subsystems

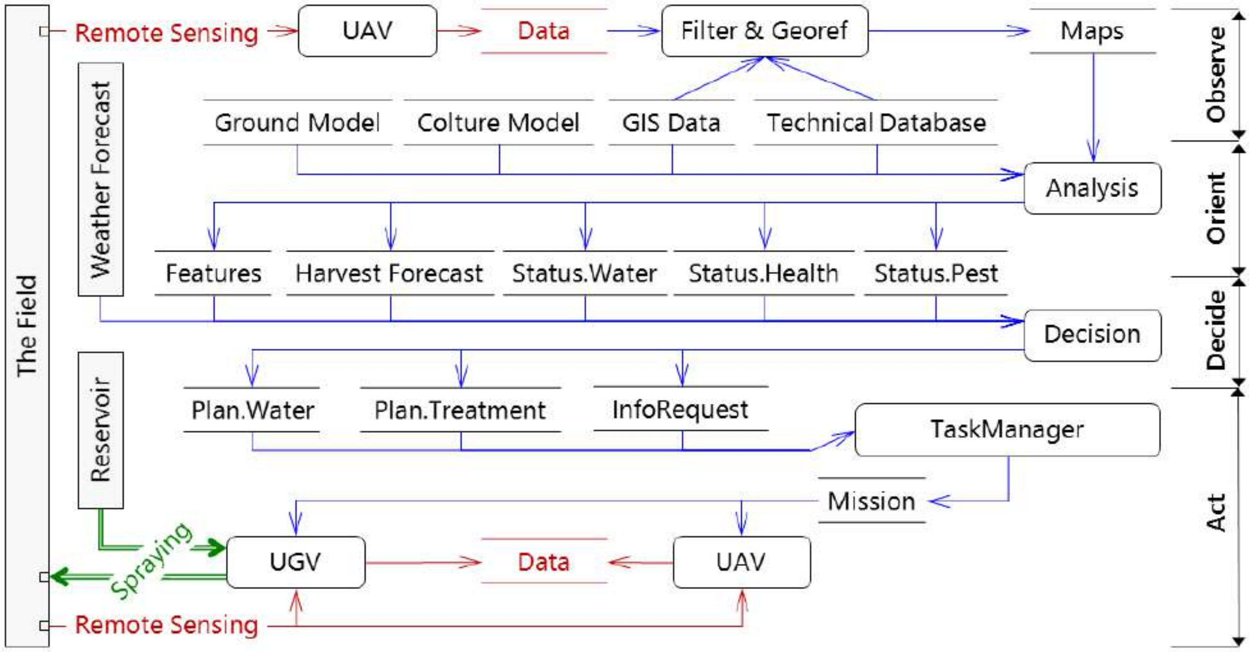


Figure 57 - UC5 D1: Composition of Scenarios 5.1.1 (Observe and Orient), 5.1.2 (Decide), and 5.1.3 (Alert)

Figure 57 summarises all the elements, including tasks and components which will implement Scenario 5.1.1, Scenario 5.1.2 and Scenario 5.1.3 of the demonstration scenario described in Section 8.2.1.1. In the following table features and requirements related to the third “all-inclusive” scenario are reported.

	WP3	WP4	WP5	WP6
Image/Video Acquisition	UC5-DEM10-INT-001 UC5-DEM10-INT-002 UC5-DEM10-INT-003 These requirements are not related to any specific component advances but to the demonstrator in general. Therefore, cannot be linked to WPs.			
Dedicated SW/HW video (Post-)Processing	UC5-DEM10-FNC-07			
Advanced onboard SW	UC5-DEM10-FNC-005			
Dedicated Computing Platforms for Drone and Rover	UC5-DEM10-FNC-004 UC5-DEM10-FNC-05 UC5-DEM10-P&C-01			
Modular System Composition	UC5-DEM10-INT-004 UC5-DEM10-OPR-001 UC5-DEM10-DSG-01	UC5-DEM10-DSG-02		UC5-DEM10-INT-004 UC5-DEM10-OPR-001 UC5-DEM10-DSG-01

Advanced Geo-Localization		UC5-DEM10-FNC-008		
Secure E-Identification			UC5-DEM10-FNC-002	
Continuous monitoring and optimization.	UC5-DEM10-PRF-01		UC5-DEM10-SEC-004	
Path Planning		UC5-DEM10-FNC-009 UC5-DEM-PRF-003		UC5-DEM10-FNC-003
Drone/rover safe coordination and general functional cooperation.		UC5-DEM10-FNC-001 UC5-DEM10-FNC-010 UC5-DEM10-OPR-002 UC5-DEM10-OPR-002 UC5-DEM10-UR-01	UC5-DEM10-SEC-001 UC5-DEM10-SEC-002 UC5-DEM10-SEC-003 UC5-DEM10-SEC-004	

Table 85 - UC5 D1: Link between features/subsystems, WP and requirements

Table below maps each Feature and Subsystem to U-Space features, but also reports on those components that are mission specific only and not related to the U-Space.

Feature/Subsystem	Description	Requirements	Demonstrator	U-Space / Mission Specific Operations
Image Campaign Acquisition	Acquisition and Storing units	UC5-DEM10-INT-001 UC5-DEM10-INT-002 UC5-DEM10-INT-003	Scenario 5.1.1 Scenario 5.1.2 Scenario 5.1.3	Remote Sensing Sensing and Actuation Remote Sensing
Image (Post-)Processing	Algorithms for post and onboard processing	UC5-DEM10-FNC-007 UC5-DEM10-FNC-005	Scenario 5.1.1 Scenario 5.1.2 Scenario 5.1.3	Remote Sensing Sensing and Actuation

Drone Flight	Secure, Safe and Energy-aware flight planning and navigation	UC5-DEM10-FNC-008 UC5-DEM10-FNC-002 UC5-DEM10-FNC-003 UC5-DEM10-FNC-009 UC5-DEM10-PRF-001 UC5-DEM10-PRF-002 UC5-DEM10-PRF-003 UC5-DEM10-SEC-004	Scenario 5.1.1 Scenario 5.1.2 Scenario 5.1.3	Flight Navigation – Obstacle detection and avoidance (KET 2.2.7) Communication - Network Centric Communications Systems (KET 2.6.1) Flight Navigation – Planning and Scheduling (KET 2.2.3) Flight Navigation (KET 2.2) Flight Control (KET 2.1) U1 –Telemetry (KET 1.1.4) Flight Navigation – Planning and Scheduling (KET 2.2.3) Communication - Network Centric Communications Systems (KET 2.6.1)
Drone Customisation	Modular system composition with dedicated HW/SW components for processing and navigation and ad-hoc communication links	UC5-DEM10-INT-004 UC5-DEM10-INT-005 UC5-DEM10-INT-006 UC5-DEM10-OPR-01 UC5-DEM10-FNC-007 UC5-DEM10-FNC-004 UC5-DEM10-FNC-005 UC5-DEM10-FNC-008 UC5-DEM10-P&C-01 UC5-DEM10-DSG-01 UC5-DEM10-DSG-02	Scenario 5.1.2 Scenario 5.1.3	Communication - Network Centric Communications Systems (KET 2.6.1) Flight Navigation (KET 2.2) Flight Navigation - Contingency Management Remote Sensing Sensing/Actuation (KET 2.2.5) Flight Navigation – Obstacle detection and avoidance (KET 2.2.7) Flight Navigation (KET 2.2)

Drone/Rover Cooperation	Drone/rover safe coordination and general functional cooperation	UC5-DEM10-OPR-02 UC5-DEM10-OPR-03 UC5-DEM10-FNC-001 UC5-DEM10-FNC-006 UC5-DEM10-FNC-010 UC5-DEM10-SEC-001 UC5-DEM10-SEC-002 UC5-DEM10-SEC-003 UC5-DEM10-SEC-004 UC5-DEM10-UR-01	Scenario 5.1.3	Flight Navigation - Contingency Management (KET 2.2.5) Power & Propulsion (KET 2.7) Coordination - Drone and Rover Actuation (KET 2.5.1) Communication - Network Centric Communications Systems (KET 2.6.1) Flight Control (KET 2.1)

Table 86 - UC5 D1: Features/Subsystems

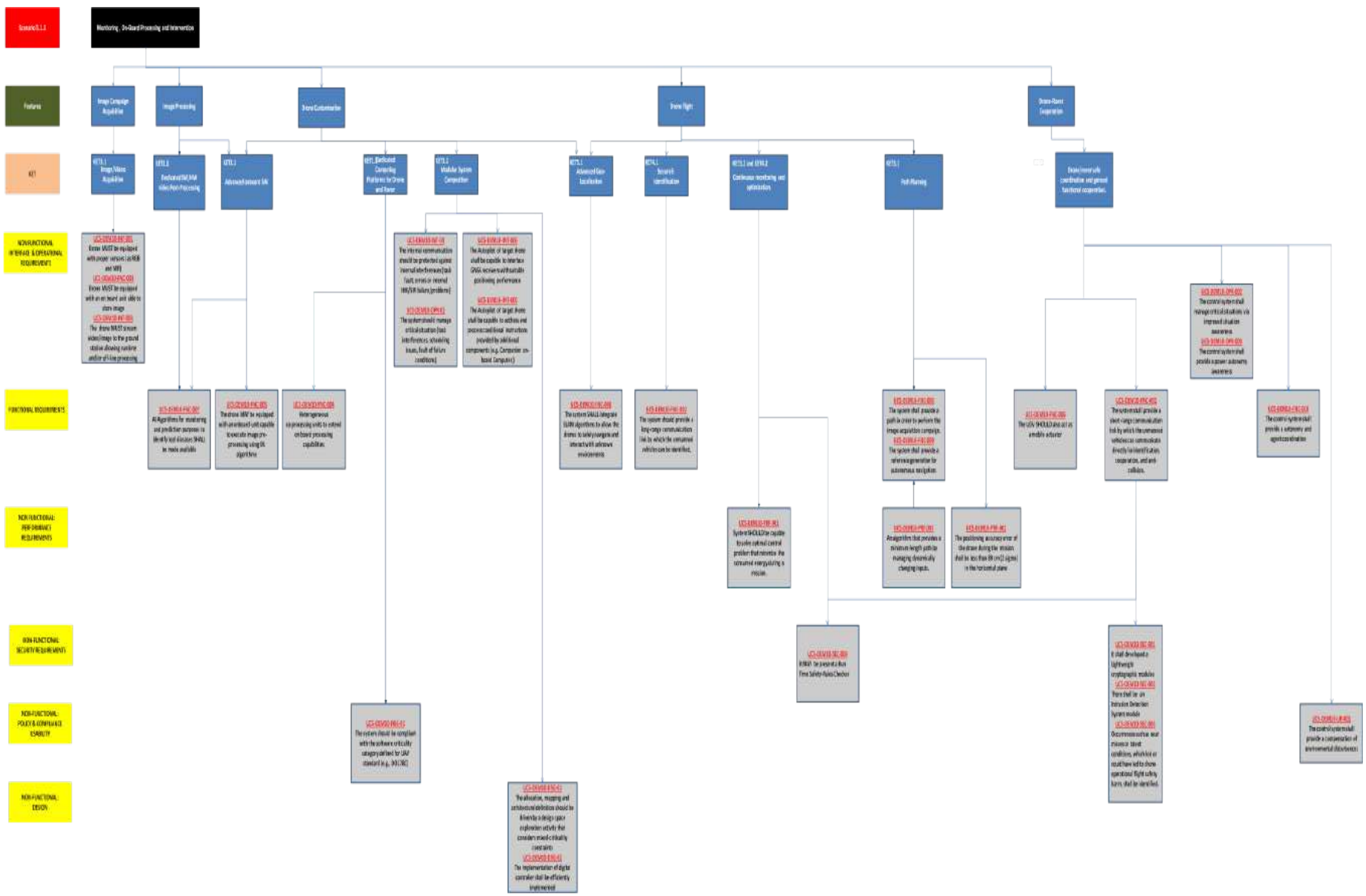


Figure 58 - UC5 D1: Relation between components and KETs

8.2.3.3 Requirements

Please note that, in all the tables below, the requirements that are not linked to a specific WP (but necessary to guarantee the correct demonstrator execution) present and empty WP column. The complete requirements list is available as an excel file and tables below represent just an excerpt including high-priority requirements only.

Requirement Type	Requirement ID	Description	Priority (H/M/L)	WP	Source
Functional Requirement	UC5-DEM10-FNC-003	The system shall provide a path in order to perform the image acquisition campaign.	H	WP6	UNISANNIO
Functional Requirements	UC5-DEM10-FNC-004	The system should enable advanced onboard computation by means of dedicated and optimized accelerators.	M	WP3 WP4 WP6	UNISS-ENG UNIMORE
Functional Requirements	UC5-DEM10-FNC-007	AI algorithms shall be designed, trained and tested to detect and identify parasite animals and to classify leaf diseases using imaging sensor data.	H	WP3	AITEK, UDANET
Functional Requirements	UC5-DEM10-FNC-008	The system shall integrate SLAM algorithms to allow the drones to safely navigate and interact with unknown environments.	H	WP4	MODIS
Interface Requirement	UC5-DEM10-INT-001	The drone shall mount an onboard camera (the type of cameras will be defined) to acquire images.	H	---	AITEK, UDANET, MODIS
Interface Requirement	UC5-DEM10-INT-002	The drone shall be equipped with an onboard unit capable to store images.	H	---	ROT
Interface Requirement	UC5-DEM10-INT-003	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
Interface Requirement	UC5-DEM10-INT-005	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

Interface Requirement	UC5-DEM10-INT-006	The Autopilot of target drone shall be capable to interface GNSS receivers with suitable positioning performance.	H	---	TOPVIEW
Security Requirement	UC5-DEM10-SEC-002	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	WP5	ROT

Table 87 - UC5 D1: Main requirements

8.2.3.4 Methodology to follow-up requirements

The proposed methodology for Requirement Engineering definition and tracing is based on the refinement and adaptation of a standard methodology for Requirements Engineering as required by **Capability Maturity Model Integration** (CMMI) that describes the aspects of product development that are to be covered by supplier organizational processes.

The purpose of **Requirements Management** (REQM) is to manage requirements of the project's products and product components and to ensure alignment between those requirements and the project's plans and work products. Steps for implementing Requirements Management (REQM) in projects are (*Source: CMMI-DEV Model, CMMI Institute*):

1. **Requirements understanding**. First step for Requirements Management (REQM) is to develop the understanding of requirements using different techniques like surveys, study of existing system, interviews, prototyping, modelling, etc. Requirements then are documented in the form of Requirements Document. Requirements are then analysed to ensure that they met the customer needs.
2. **Take Commitment to Requirements**. Next step is to take the commitment from relevant stakeholders for the documented requirements. Generally commitment for requirements is taken in the form of approval email or signup.
3. **Requirements Change Management**. Once requirements are approved and base-lined, changes to the requirements are managed so that they do not impact the project negatively. All the change requests are logged, analysed, reviewed, approved and implemented. Different artefacts used to manage Requirements changes may include Change Log, Requirements Impact Analysis, and updated Requirements document.
4. **Update Requirements Traceability Matrix Document**. After each base-lining of the requirements document (and other engineering document) RTM (Requirements Traceability Matrix) document shall be updated with the relevant section in each engineering document. Traceability is maintained in bi-directional manner from first phase to the last phase and vice versa.
5. **Maintain alignment between Requirements and Project Work**. Project Manager shall ensure that the project work is aligned with the approved requirements of the project. Changes to the requirement are also updated to the project tasks and assigned to the team

Supporting software tools such as IBM DOORS, Sparx Enterprise Architect or an Excel file can be used to achieve our goal. In this demonstrator we will use a shared excel (*UC5_DEM10_Requirements_Tracing.xls*) file with different sheets.

In the presented case, the first two processes (Requirements understanding and Take Commitment to Requirements) have been carried out through several meetings among the Italian Partners that analysed the User and Business Needs (see Section Objectives of this demonstrator) through the active participation of the Agricultural department from UNISS and the technical partners that understood needs and have committed themselves to requirements. This led, so far, to the definition of 7 different needs. In the *UC5_DEM10_Requirements_Tracing.xls* file there is a sheet devoted to list of the User, Business and all High level needs called Stakeholder requirements (SHR), each with a unique identifier of the requirement SHR#N.

The identified attributes have the following meaning:

1. **Req. ID** - a unique identifier of the requirement
2. **Description** - a concise description of the SHR
3. **Source** - specifies a reference to the source where the SHR was originally stated, for example if it is a User need or a Business need.
4. **KPI -** related demonstrator KPI (if any)

In the following the current version of the SHR sheet is reported.

Req. ID	Description	Source	KPI
SHR#1	To gather precise knowledge and awareness of the health status and growth evolution of the crops/plants minimizing the effort for human operators, an autonomous system capable of advanced acquisition, monitoring and actuation capabilities **SHALL** be made available.	User Need	UC5-DEM10-KPI-003: Availability of cooperative smart UGV and UAV
SHR#2	The acquisition/monitoring system **SHOULD** be able to recognize nutritional deficiencies or other diseases. The objects/areas to be recognized **SHOULD** be in the range of 1-2 centimetres.	User Need	UC5-DEM10-KPI-001: Mission improvements: 1) % reduction in number of missions, and 2) in stand-alone mission duration
SHR#3	The acquisition/monitoring system **SHOULD** be able to collect and store image (RGB or NIR or thermal) up to 300 pictures per hectare to determine in post processing the crown tree volume. The number of required megapixel per picture may vary depending on the sensor used, but standard RGB pictures used for this purpose reach 21-24 megapixel.		
SHR#4	The actuator, based on the autonomous spraying system, as actuator, **SHOULD** be able to treat plants from a distance in the range of 3 to 5 meters to guarantee the effectiveness of the treatment itself.	User Need	UC5-DEM10-KPI-002: % of reduction in resources consumption (i.e. water, fertilizers)

SHR#5	Easing the integration and customization of smart drone/rover systems	Business Need	UC5-DEM10-KPI-004: Improvements wrt SoA FPGA-based acceleration (e.g. Xilinx SDSoC): 1) Easy to design and deploy; 2) Easy to develop applications for heterogeneous platforms (ARM GP core + FPGA acceleration blocks)
			Improvements in performance and resource consumption
SHR#6	Ensuring the deployment of trusted communications.	Business Need	Operational communication
SHR#7	Optimize the design and verification effort for complex drone applications	Business Need	UC5-DEM10-KPI-005: Accuracy in the prediction of the behaviour of the system through SIL/HIL methodologies

Table 88 - UC5 D1: New format for requirement following

The *Understand Requirements* and *Obtain Commitment to Requirements* are finalized to have the System Requirements baseline. In the *UC5_DEM10_Requirements_Tracing.xls* file there is a sheet reporting on the System Requirements (SYRs), i.e. functions to be implemented by the demonstrator in order to comply with the needs listed in the SHR sheet. These baseline SYR are reported in the present document in the Section Key concepts and technologies, which group them into five main categories: on-board information processing capabilities, Drone/rover safe coordination and general functional cooperation, Planning and Navigation, Secure communications and safety guarantees, Advanced geo-localization techniques.

The identified attributes used in the SYR sheet have the following meaning:

1. **Req ID** - a unique identifier of requirements
2. **Label** - a short self-explanatory name
3. **Description** - a description of the requirements
4. **Satisfy -** contains the links (i.e., the IDs) of the SHRs which are satisfied by the current SYR (note that using a database tool, these links define also "satisfied by" relationships from SHRs to SYRs; these links are useful for coverage analysis).

For the sake of brevity, please find below just an example of tracing between SYR and SHR.

Req ID	Label	Description	Satisfy
SYR#1	Advanced on-board information processing capabilities	Advances on system customization and processing platforms	SHR#5

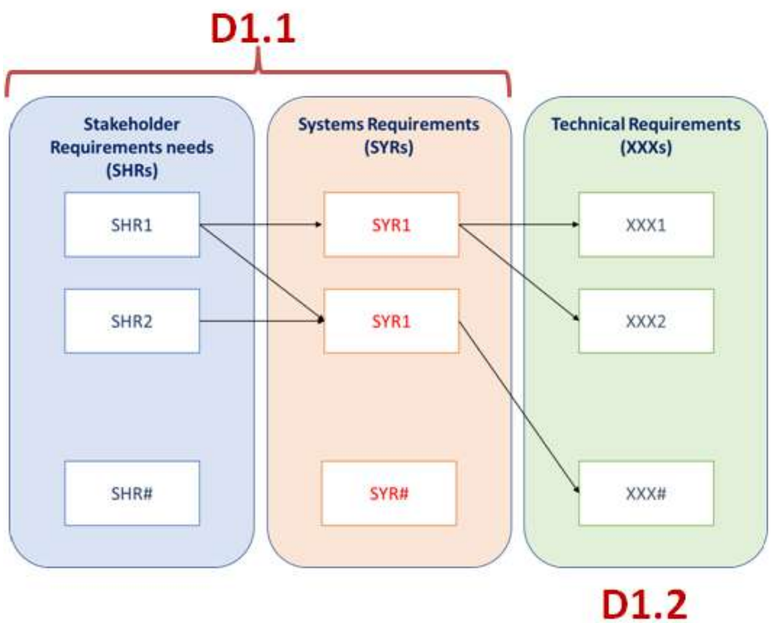
Table 89 - UC5 D1: Example of traceability between SYR and SHR.

System Requirements and associated sheet also act as the parent document for the **technical requirements** (TR) that need to be addressed in lower-level design description documents and are detailed in a separate sheet (TR) of the *UC5_DEM10_Requirements_Tracing.xls*.

The following attributes can be attached to the technical requirements:

1. **Req ID** - a unique identifier of requirements. In particular this one is assigned as specified in the Introduction of the present deliverable, i.e., UC5-DEM10-FNC-005 is the ID of the fifth (005) functional (FNC) requirement of UC5 demonstrator 10 (which is demo 1 within UC5).
2. **Label** - a short self-explanatory name
3. **Description** - a description of the requirements
4. **Requirement Type** – identify the type of requirement, i.e. Functional, Security, Interface, etc.
5. **Priority** – identify the priority level.
6. **WP** – identify the project WP it is connected to
7. **Source** – identify the partner responsible for the correspondent technology/components
8. **Satisfy -** contains the links (i.e., the IDs) of the SYRs which are satisfied by the current TR (note that using a database tool, these links define also "satisfied by" relationships from SYRs to TRs; these links are useful for coverage analysis).

The process and links at the different level are presented below:



As you can see the present document as dealt mainly with the first two steps, whether the technical requirement will be detailed and provided in the following deliverable.

8.3 Demonstrator 2

8.3.1 Justification Plan

8.3.1.1 Demonstrator overview and Key concepts

This demonstrator is designed to assist the winemaker in his work and to minimize the workload and the travel time to remote and poorly connected to the infrastructure vineyards. Collecting data by flying autonomous over the vineyards, saves considerable time, otherwise the assessment and evaluation of the plants and the soil needs to be done locally. This will be faced through two key approaches: i) Using the drone as gateway, and ii) using the drone as an earth-observation platform.

Weinbau Martin Moravitz, an Austrian SME wine producer from Burgenland with around 6 hectares of vineyards, will be the major stakeholder in this use case and will provide two of his vineyards with around 3.3 hectares for field tests and drone flights.

8.3.1.1.1 Drone as gateway

A drone will fly over the vineyard to collect sensor readings of land bound sensors and visual and multispectral images of the grapevines (see Figure 59). This data will be sent to a base station for offline analysis.

Here, attention is paid to secure communications, as the increased use of drones and the spread of sensors in the coming years' data and C2 links need to be protected from misuse and attackers.

Trustworthy and reliable communication of the drone with the sensors and base station guarantees that only valid data is retrieved, defective sensors are detected and only authorized partners (drones, sensors, base stations) participate in the communication. As a result, all communication partners are in a valid state, the sensor data cannot be manipulated and retrieved by any foreign drones.

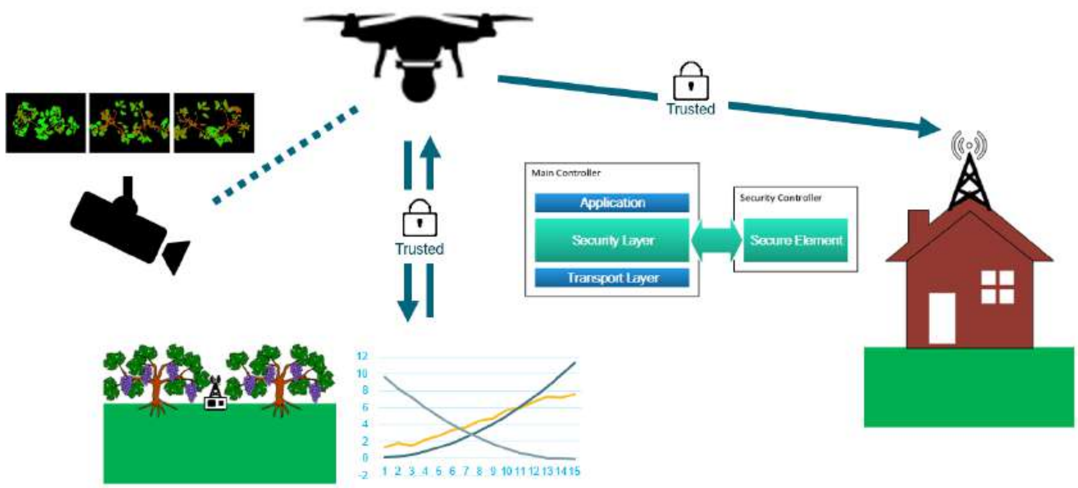


Figure 59 - UC5 D2: Use case concept

8.3.1.1.2 Drone as EO platform

For a profitable harvest, the state of health of the vines and the soil is of great importance. To recognize the health of soil and crops by eye is limited. Modern sensor technology and data analysis is used to provide the winegrower with the necessary information. By fusing the measurements of land-bound sensors and visual and multispectral images from a drone, the winegrower can monitor the condition of the soil and the single vine. This makes it possible to effectively manage plants, soil, fertilization and irrigation and respond to shortages, diseases or pests in a timely, targeted and local manner. For the farmer and the environment this is advantageous because the use of pesticides, fertilizers and water is reduced to a minimum and at the same time the yield is increased. For the data processing, study and application, LAYERS®[16] AI Agro platform will be used. Additionally, periodical satellite and meteorological information will be monitored on the platform.

Visual and multispectral images are a very effective tool for evaluating soil productivity and analysing plant health. By analysing the different color and spectral bands pests, disease and weeds can be identified, nutrient deficiencies can be detected. In addition, drone information can be used to optimize the land-bound sensor distributor considering areas with similar behaviour in terms of vegetation growth and hydric-stress response.

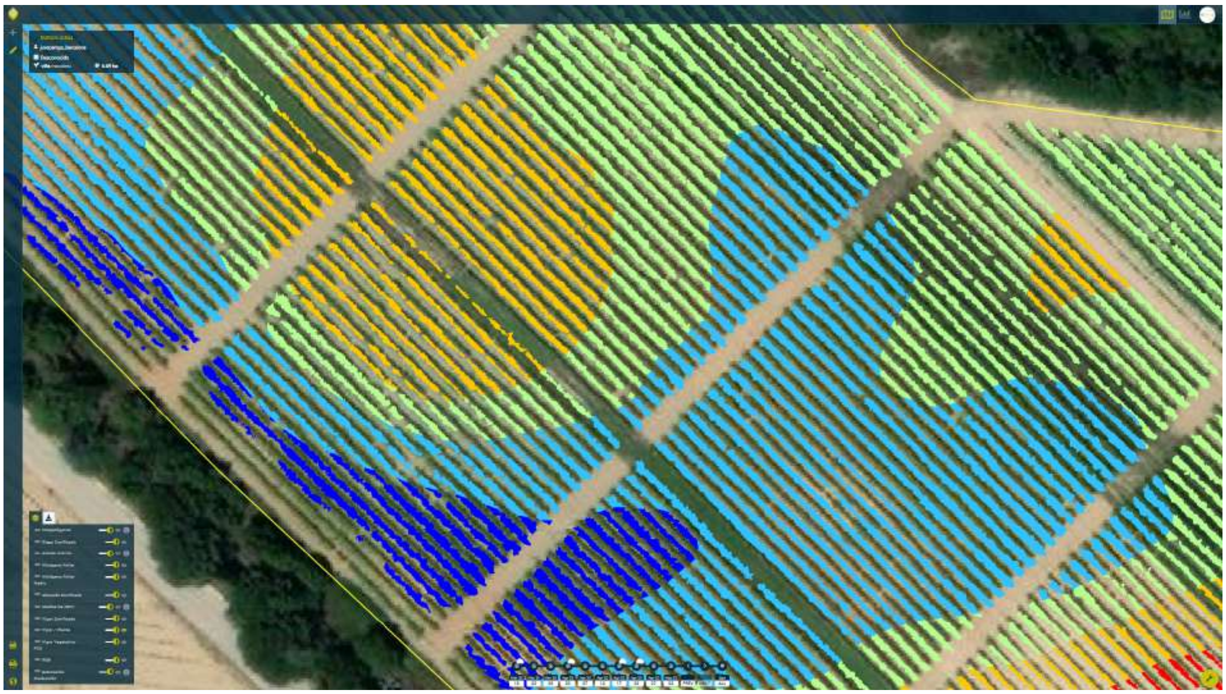


Figure 60 - UC5 D2: LAYERS Interpolated NDVI in vineyard field. 2019

[16] 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.

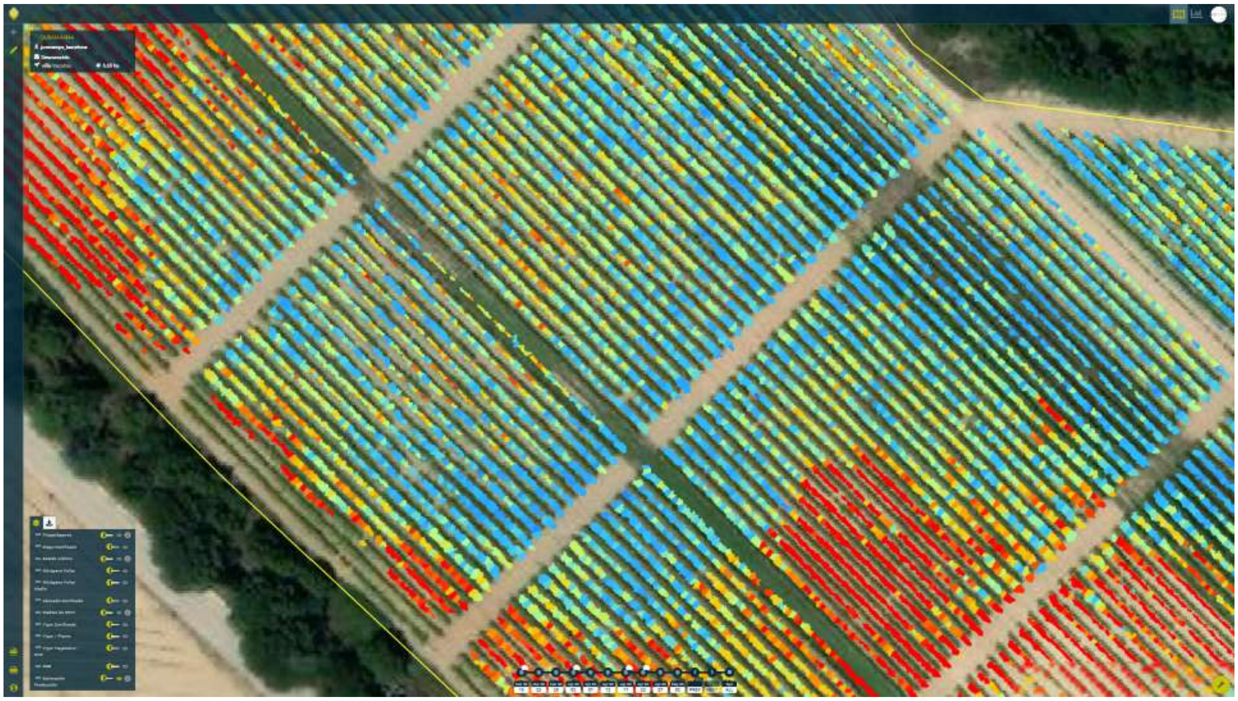


Figure 61 - UC5 D2: Per-plant yield in vineyard field. 2019

Since the sensor data and images are captured automatically by a drone and sent to a base station, there is also impressive time savings. After the data analysis, the winegrower knows exactly where he has to perform which treatment (e.g. fertilize, spraying).

8.3.1.2 Infrastructure and drones

8.3.1.2.1 Test Sites

The test environment is provided by Winery company “Weinbau Moravitz”. Two vineyards in Burgenland are available for field tests and test flights.

In the first vineyard (Figure 62) with a size of 1.7ha, the wine varieties Blaufränkisch, Merlot, Rösler, Blauburger are grown and located in Gemeinde Zemendorf, Ried Haidäcker (47.751675, 16.463349). The other vineyard is located in Gemeinde Marz, Ried Granberger (47.727791, 16.434175), where Blauer Zweigelt, Pinot Noir, Grüner Veltliner, Welschriesling and Gelber Muskateller is grown on an area of 1.63 ha.

Figure 62 - UC5 D2: Test environment: vineyard

8.3.1.2.2 Drones

A modified DJI M600P (Figure 63) is used to capture the multispectral and daylight images and to collect the measured values of the land-bound sensors, whose operational limitations are listed in Table .

In accordance with the legal regulations in Austria, the UAV has a second flight controller. DJI A3Pro flight controllers with autonomous flight operation mode are used, which offers special hardware interfaces and flight data can be made accessible with onboard and mobile SDKs.

In order to be able to use drones as flexibly as possible for a large number of operations, a modular design is used and, depending on the task, equipped with the necessary hardware.

Figure 63 - UC5 D2: DJI M600P

Operational Limitations

Max. flight time	16 minutes
Max. Windspeed	10 m/s
Payload	~4 kg
Altitude	60 m
Weather condition	dry (no rain, no snow)

Table 90 - UC5 D2: Operational limitations

8.3.1.2.3 Aerial Sensors

For the multispectral imaging a MicaSense Redge MX will be used to capture images of the blue, green, red, red edge and near-IR spectral bands, with a Ground Sample Distance (GSD) of 8 cm per pixel (per band) at 120 m Above Ground Level (AGL).

A Sony A7R2 with a 42MP full frame sensor and a 5-axis image stabilization will be used as a visual camera. The weight of the multispectral camera and the mount is about 1kg, if the RGB camera is also installed, about 2kg will be added. This setup in combination with the Air-Sensor is also not a problem, the complete system is below the maximum take-off weight of the UAV.

An Air-Sensor is also mounted on the drone, which collects the measurement data from the land-bound sensors and sends it to the base station via Wi-Fi. All communication partners must authenticate themselves to ensure that only authorized partners have access to the data. Additionally, trustworthy and reliable data collection makes sure that all communication partners are in a valid state and the data are not manipulated.

8.3.1.2.4 Land-bound Sensors

Real-time weather measurements are important for decision-making regarding the activities in the vineyard at a given moment. E.g. spraying with certain plant products works best in a certain temperature range. Thus, air temperature/ humidity/ pressure sensors will be used to monitor the temperature, humidity and pressure.

Rainfall sensors will be used to monitor the amount of precipitation, which is important to calculate the condition of the plant with other environmental parameters.

The speed of the wind is important to predict the weather. The direction from which the wind comes is important to get a complete picture of the weather situation. Also, a change of the wind direction can be an early warning for a change of the weather. Wind helps to dry the plant faster and helps with disease control. To monitor this, wind speed/direction sensors will be used.

Soil moisture sensors will be used to monitor the humidity of the soil, which is important to know if the vines have enough water. Soil temperature sensors will be used to monitor the temperature of the soil, which makes it possible to calculate when and if it is necessary to irrigate the vines.

Sunlight has a direct influence on the growth of the grapes and their sugar content. Sunlight is also important for calculating the evaporation of water in the soil. Thus, a sunlight sensor will be used to monitor the sunlight.

The wetness of the plant is important for disease management. Fungus can grow better on wet leaves. To monitor this, a leaf wetness sensor will be used.

8.3.1.2.5 Data processing and delivery

LAYERS platform will be used for the drone data process and deliver. In order to do so, up to five tools will be used:

1. **AgroMOM** is a web tool used for flight management. It serves to create the flight date and link it to a certain user in LAYERS.

2. **HLINK** is the desktop tool for drone data upload. This tool verifies that the flight has covered at least 80% of the objective area and uploads to a folder in AWS the information gathered during the flight.
3. **Layers Processing** is the data processing tool that if everything followed the *happy flow* processes all the flight data automatically but has the possibility to easily verify and address the most common issues.
4. **Layers Map & Dashboard** is the user interface where all the agronomical information is gathered. Map shows the geographical information and Dashboard (see image below) shows the analytical information related to the flights. iOS & Android LAYERS APP is also available with off-line capabilities for remote areas.
5. **Sampling APP** helps the user to take notes and samples from the fields.

Figure 64 - UC5 D2: LAYERS Dashboard

8.3.1.3 Implementation

8.3.1.3.1 Stage 1: Technology Validation

This Demonstrator will focus on the secure communication and protection of on-board data by Hardware supported security solutions. The first step is therefore to validate core technologies like secure element, usable crypto approaches, identify suitable key distribution approaches and develop a concept of how drone and the modular secure element can interact. In addition, one of the goals is to improve the weather-based planning of drone missions / data transmission of ground sensors to the drone and communicate such data securely.

8.3.1.3.2 Stage 2: Technology Experimentation

Core technologies are developed and tested in controlled environments. First integration of core technologies without drones to verify security and self-adaptability.

8.3.1.3.3 Stage 3: Technology Implementation

Secure communication and weather-based mission planning are integrated into drone platforms and evaluated in real mission scenarios. The drone operator SkyA will execute drone flights in the selected evaluation environment.

In this third stage, drone data transmission to the cloud and data delivery after cloud processing to the user will be used. Economic impact for the end-user will be estimated with the aim of enhancing the introduction of drones in the agriculture sector.

8.3.2 KPIs

8.3.2.1 Business KPIs

ID	KPI	Description
UC5-D2-KPI-01	Time saving in data collection and evaluation of growth, health and overall plant status. Based on data analysis performed by the overall drone-based application. KPI_UC5_DEM2_1	Full coverage of vineyard in less time than walkthrough. Time savings per observation phase and condition of at least 50% is expected to be observed in the execution of a demonstrator.
UC5-D2-KPI-02	Resources saving (time, fertilizer, water, etc.) – work on demand and optimized to the specific areas incl. early warnings for detection of unsatisfactory conditions such as diseases and water stress. KPI_UC5_DEM2_2	Remote data analysis enables the necessary work steps (spraying, fertilizing, irrigation) to be specifically prepared and directed to the specific areas. A resource saving for the given situations of at least 20% is expected.

Table 91 - UC5 D2: Business KPIs

8.3.2.2 Technical KPIs

ID	KPI	Description
UC5-D2-KPI-03	Trusted communication and data collection from land-bound sensors to the drone bound sensor on hardware security IC.	Both communication partners need to authenticate to ensure that monitoring data is not manipulated – intentionally or unintentionally. Data tampering must be detected by the platform when analysing the collected data.
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.

Table 92 - UC5 D2: Technical KPIs

8.3.3 Specification Plan

8.3.3.1 Scenarios

The components and features developed and researched in this use case are demonstrated in a single scenario (see Table 93), where a drone flies over the vineyard collecting sensor readings of land bound sensors and visual and multispectral images. For this purpose, the drone will operate on an autonomy level of 2-3 (partial/conditional automation) and will not be improved in the course of the project.

The actual legal situation in Austria requires a pilot operating the drone (Drone Class 1). The operation must be in line of sight what makes a full autonomous flight currently impossible. In Semi-autonomous operations the drone takes off after a pilot input and lands after autonomous mission fully autonomous. The pilot must have the possibility to react on unexpected situations. Line of sight operations allow a flight radius of about 500m around the pilot location.

Scenario ID	Scenario	Features	Priority (H/M/L)	Demonstrator
UC5-SCN-0x	Sensor and images collection	• Self-adaptability framework • Secure Element (SE) • Crypto Libraries	H	DEM9

Table 93 - UC5 D2: Scenario descpription

8.3.3.2 Features and/or subsystems

The features and subsystems developed for this demonstrator do not focus on access of the drone to the airspace and are therefore not related to U-Space services.

Feature/Subsystem	Description
Self-Adaptability Framework	Self-adaptability framework for drone systems, allowing to adapt and shift focus and computation power based on measured parameters and flight situation.
Secure Element	Reusable secure element which can be used for different levels of security from secure communication inside and outside the vehicle to protection against loss of drone (e.g. protect data on drone).
Crypto Libraries	Crypto Libraries for secure element which ease the challenge to implement own crypto (one of the main causes for security weaknesses) to support communication inside and outside vehicle.
Data analysis	Desktop application for drone data uploading, cloud-based infrastructure for data processing and Web and mobile APP elements that will be used for drone data delivery to final user. Satellite information will be delivered as well.

Table 94 - UC5 D2: Features/Subsystems

In addition to the main features and subsystem listed in Table 94, a more detailed description of the components developed in the UC follows.

8.3.3.2.1 Self-Adaptability Framework

The Generic Autonomic Management Framework (GAMF) architecture is a Java-based framework used to develop autonomic managers for any target system without having to (re)implement the generic control mechanisms. GAMF provides generic control mechanisms based on the autonomic control loop (MAPE-K) and a set of interfaces to allow the interaction between control mechanism and system specific management components, the system adapters. System adapters include event generators and effectors, which allow interaction of the control mechanism with the target system, as well as metric extractors and policy evaluators, which provide the means for computing a specific response determined by policies to an observed situation modelled by metrics. The information about how a specific system adapter is triggered is held in the system adapters' registry.

From a Service Oriented Architecture perspective, Generic Autonomic Management is designed as a component-based REST service (GAMS) that can be invoked by different SOA-based frameworks without requiring a high adjustment effort. Additionally, given its generic property, each component of the autonomic control loop has abstract interfaces that can be used by a number of application systems. This would reduce the software engineering effort since there is no need to (re)implement the generic control mechanisms for different application systems, only to properly define events, metrics and adaptation policies. E.g. limiting factors for the mission duration are the weight of the payload and available battery capacity, as well as the energy consumption for example computer or cameras or weather conditions such as high winds (because more energy is needed for the engines). Through the use of a policy based Self-Adaptability Framework, it is possible to react to these conditions. This makes it possible 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.

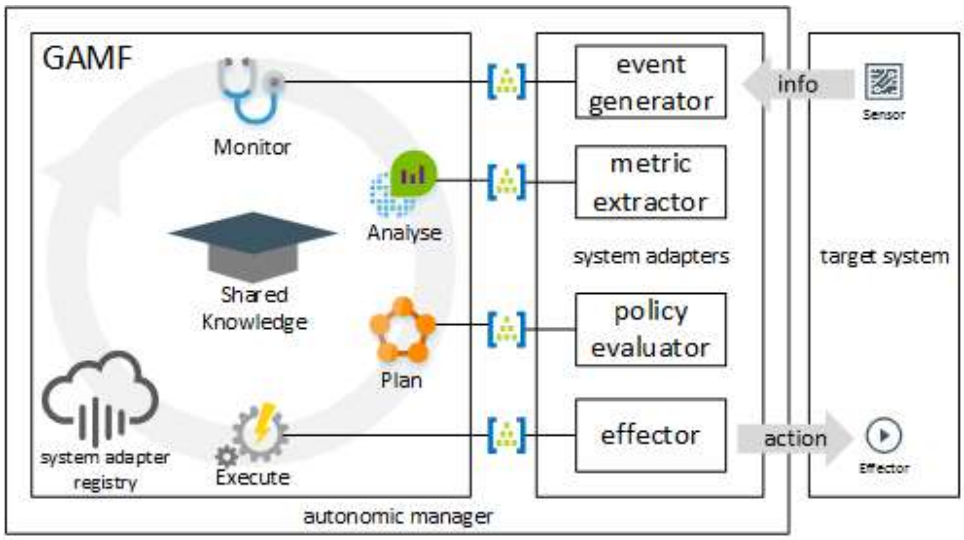


Table 95 - UC5 D2: Software architecture

8.3.3.2.2 Secure Element

The Secure Elements are hardware security components, comprising hardware, firmware and software, which can be used for trusted communication in drones.

Therefore, RaspPis equipped with Infineon secure element, e.g. Infineon OPTIGA TPM (Trusted Platform Module) and/or related OPTIGA Trust will be used to establish secure TLS channel and support mutual authentication (via TLS) to the land-bound sensor nodes and base station.

8.3.3.2.3 Crypto Libraries

This Crypto Libraries represents a collection of cryptographic primitives and protocols whose characteristics are tailored to the use within drone environments, taking resource consumption and latency into account. Especially, the cryptographic protocols while providing means to satisfy low latency requirements will at the same time provide strong security guarantees.

8.3.3.2.4 Data Analysis

The state of health of the vines and the soil are of great importance for the winegrowers. The drone collects the measurements of land-bound sensors, RGB and multispectral images from each vineyard. By fusing all these data, the condition of the soil and the single vine can be analysed, to effectively manage plants, soil, fertilization and irrigation and respond to shortages, diseases or pests in a timely, targeted and local manner.

Therefore, HEMAV's Layers for agriculture will be used. This a unique system based on Artificial Intelligence combining calibrated precision multispectral and RGB images and agronomic data, creating prediction capabilities.

This tool is used to determine the optimal positions of the land-bound sensors in the vineyard.

8.3.3.2.5 Air-Sensor

This sensor is mounted on the drone as a payload and is responsible for collecting the data and transmitting them to the base station. Figure 65 describes the structure of the system. The computation unit holds the Self-Adaptability Framework which will adapt the computation power based on measured parameters and flight situation. This requires parameters such as the battery capacity, the power consumption of the motors or to assess the flight situation such as the pose, which can be requested from the flight controller via the drone interface. The Secure Element will use the developed Crypto Libraries to protect the communication inside the vehicle and to the land-bound sensors and the base station.

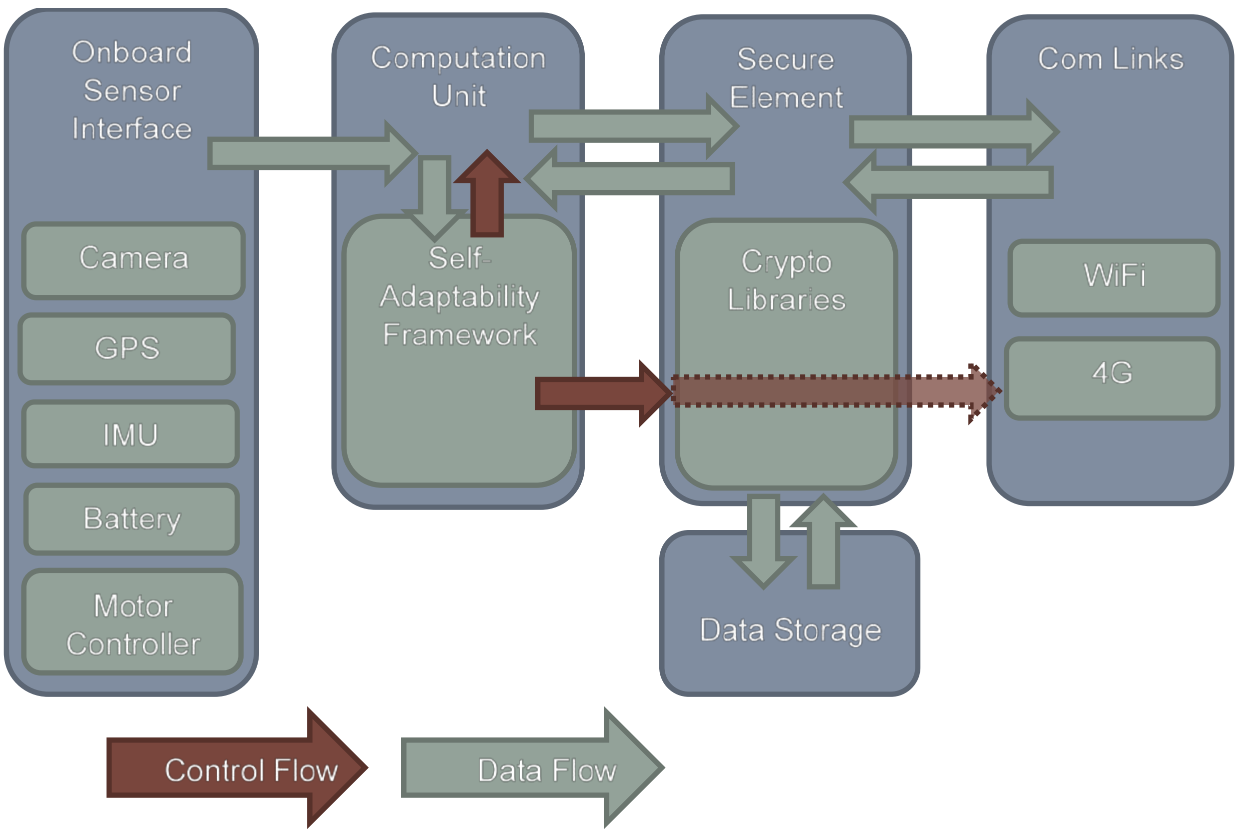


Figure 65 - UC5 D2: Air-Sensor components

8.3.3.2.6 Land-bound Sensors

The structure of the land-bound sensors is similar to that of the Air-Sensor see. As can be seen in the figure, different transducers are combined to form one sensor. This makes it possible to collect several measurement data (like air temperature, humidity, pressure, rainfall, wind Speed and direction) in one place and thereby reduce the number of sensors in the vineyard. The sensor data is regularly recorded and transmitted to the drone when it overflows the vineyard. Trustworthy communication guarantees that only approved partners receive the data and the sensors work. Since the data is only sent on request, energy consumption is reduced, and the lifetime of the sensors increases. The Secure Element will be used to protect the communication inside the land-bound sensor and communication to the drone.

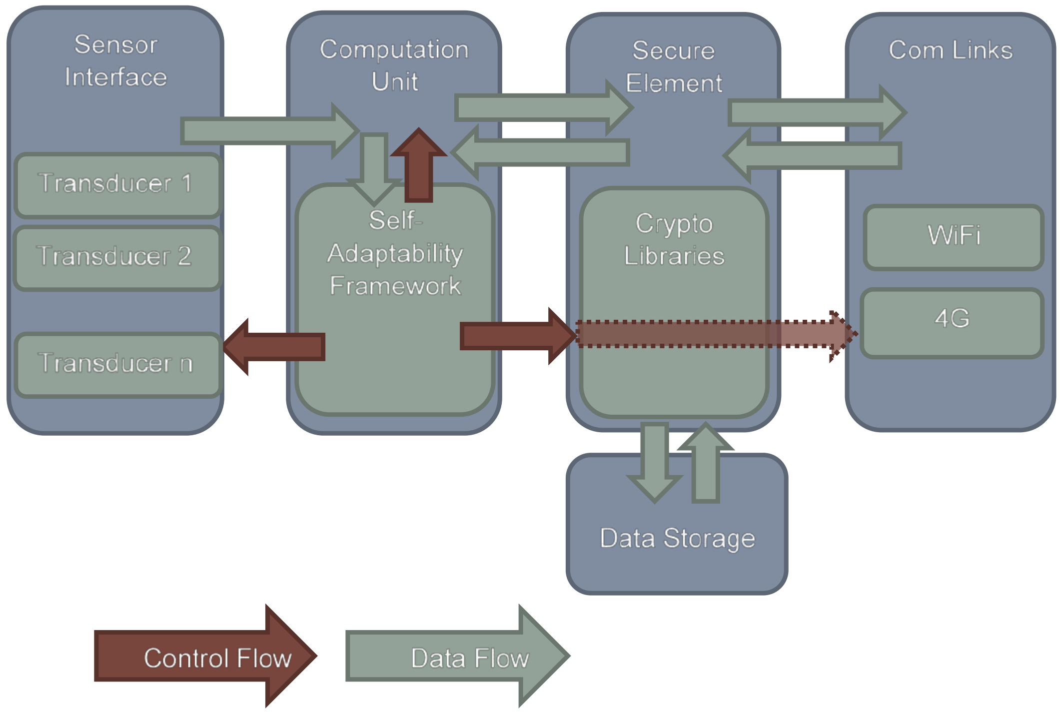


Figure 66 - UC5 D2: Land-bound sensor components

In addition, tools are developed in this use case to support the development process of drones and components:

- A standards-compliant drone-development-specific workflow.
- Tool-based safety-security co-analysis to avoid mission safety being affected by security threats.
- Model-based testing tool will be used to develop and explore new approaches for performance-sensitive security protocol testing for drone communication.

Figure 67 shows the relation of the features and subsystems used in the scenario with the corresponding KETs that were defined in this use case.

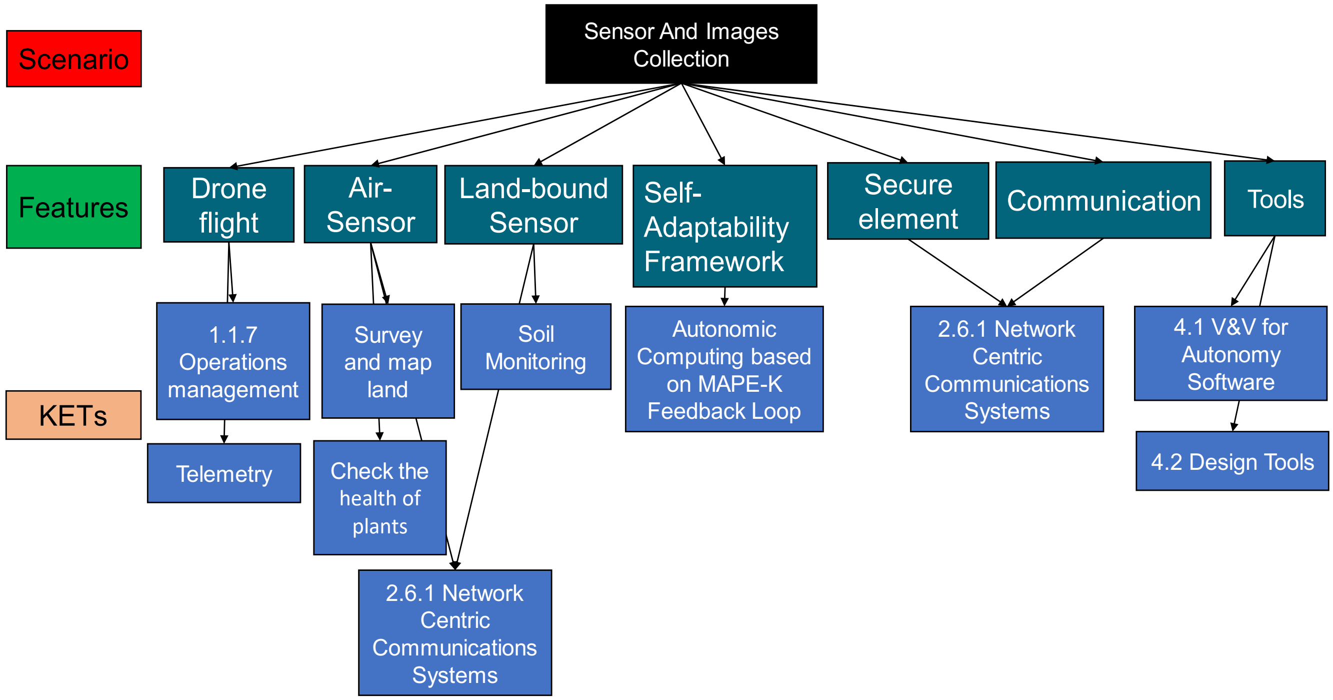


Figure 67 - UC5 D2: Relation between features and KETs

Table 96 shows the requirements for the features and subsystems that are developed in this UC.

Feature/Subsystem	Requirements	Constraints	Demonstrator	KPIS
Self-Adaptability Framework	DEM9-FUN-04 DEM9-INT-05 DEM9-INT-05 DEM9-USB-01		DEM9	UC5-D2-KPI-4
Secure Element (SE)	DEM9-INT-03 DEM9-INT-04 DEM9-SEC-01 DEM9-SEC-02		DEM9	UC5-D2-KPI-3
Crypto Libraries	DEM9-SEC-09 DEM9-SEC-10		DEM9	UC5-D2-KPI-3
Data analysis	DEM9-FUN-01 DEM9-FUN-02 DEM9-FUN-05	DEM9-DSG-04	DEM9	UC5-D2-KPI-1 UC5-D2-KPI-2

Table 96 - UC5 D2: Features/Subsystems Requirements mapping

8.3.3.3 Requirements

The following procedure is defined for the management and traceability of the requirements during the systems engineering and development processes of the components and subsystems. Traceability is achieved by capturing traces that are mapped manually using spreadsheets. All requirements are managed in the table with their ID, type, description, priority, source and version.

For this purpose, application-specific requirements are linked to the technical requirements as well as the work packages and deliverables. An initial version of the spreadsheet is shown in the Figure 68. At regular intervals (probably every two months) it is checked with the owner of the requirements whether they are still up-to-date or whether they need to be updated. The required changes of the requirements and their effects on the application are analysed and versioned in a table.

The validation relationships are also checked regularly to demonstrate that a requirement is validated by a specific test, defined at use case level and also managed in a table, and that all requirements have been met at the end of the project. If errors occur on the demonstrator during validation, these are documented and used to adapt the components and subsystems.

The traceability can document the relationships between the high-level requirements and the components to be developed and reflect any iterations in a project phase, as well as monitor their effects on applicative requirements and specifications.

REQUIREMENTS TRACEABILITY MATRIX											
Applicative requirements		Technical requirements							Validation		
Applicative Requirement ID	Applicative Requirement	Technical Requirement ID	Technical Requirement	Priority	Version	WP	Component ID	Deliverable	Test Case	Execution Status	Issue
AR_1	Applicative requirement 1	SEC_1	Security requirement 1	High	1	5	Comp 1	5.1, 5.2	Test Case_1	pass	
		SEC_2	Security requirement 2	Low	1	5	Comp 1	5.1, 5.2	Test Case_2	pass	
		INT_2	Interface requirement 2	High	1	5	Comp 1	5.1, 5.2	Test Case_4 Test Case_5	Fail	Issue 1
AR_2	Applicative requirement 2	INT_4	Interface requirement 4	High	2	3	Comp 3	3.3	Test Case_3	pass	
		DSG_2	Design Technology 6	Medium	1	3	Comp 3	3.3	Test Case_6	pass	
		DTC_6	Security requirement 1	Medium	1	6	Comp 5	6.2	Test Case_7	pass	

Figure 68 - UC5 D2: Initial requirements traceability matrix

Below is the list of main requirements, the complete list can be found in the confidential requirement Excel delivered with this document.

Requirement Type	Requirement ID	Description	Priority (H/M/L)	Source	KPI
Functional Requirement	DEM9-FUN-01	The Air-Sensor shall be able to relay sensor data from local sensors to the farmhouse.	H	WBM/AIT	UC5-D2-KPI-1

Functional Requirement	DEM9-FUN-02	The drone shall be able to transfer image data to the Air-Sensor and via this to the farmhouse.	H	WBM/AIT	UC5-D2-KPI-1
Functional Requirement	DEM9-FUN-03	The drone shall be able to return home autonomously based on geo-positioning data (e.g. in case of loss of communication).	H	WBM/AIT	
Functional Requirement	DEM9-FUN-04	The sensor data transmission frequency shall be configurable (e.g. “on demand”, “defined intervals”, “defined times”).	H	WBM/AIT	UC5-D2-KPI-4
Functional Requirement	DEM9-FUN-05	The drone shall perform the prior defined flight pattern autonomously.	H	SkyA	UC5-D2-KPI-2
Functional Requirement	DEM9-FUN-06	The Air-Sensor shall be able to act without being influenced by the drone.	H	SkyA/FB	
Interface Requirement	DEM9-INT-01	The interface between the drone and the local sensors should follow a standard protocol.	M	WBM/AIT	UC5-D2-KPI-3
Interface Requirement	DEM9-INT-02	The interface between the drone and the farmhouse should follow a standard protocol.	M	WBM/AIT	UC5-D2-KPI-3
Interface Requirement	DEM9-INT-03	Application developers shall be able to easily access the security functionality of the SE.	H	IFAT	UC5-D2-KPI-3
Interface Requirement	DEM9-INT-04	The SE shall be accessible via standard contact-based interfaces and support fast prototyping using single-board computers like Raspberry Pis.	H	IFAT	UC5-D2-KPI-3
Interface Requirement	DEM9-INT-05	The Self-Adaptability Framework shall be used by any target system without requiring a high adjustment effort.	H	FB	UC5-D2-KPI-4
Interface Requirement	DEM9-INT-06	The Self-Adaptability Framework shall provide generic control mechanisms based on the autonomic control loop.	H	FB	UC5-D2-KPI-4
Performance Requirements	DEM9-PRF-05	Drone system with Air-Sensors shall be able to perform flights in different areas with low effort.	H	SkyA	
Security Requirement	DEM9-SEC-01	The SE shall be protected against tampering attacks (such as fault and side-channel attacks).	H	IFAT	UC5-D2-KPI-3
Security Requirement	DEM9-SEC-02	For drone authentication, the SE shall support TLS client authentication (implying mutual authentication). It shall support the establishment of a secure TLS channel based on long-term key material and certificates stored securely on the SE.	H	IFAT	UC5-D2-KPI-3

Security Requirement	DEM9-SEC-03	Authentication and authorization mechanisms shall support the communication between land-bound sensors and drones (the payload).	H	FB	UC5-D2-KPI-3
Security Requirement	DEM9-SEC-04	Authentication and authorization mechanisms shall support the communication between drones (the payload) and base station.	H	FB	UC5-D2-KPI-3
Security Requirement	DEM9-SEC-05	Security measurable metrics should be extracted for each component involved in the end-to-end communication from a defined set of standards and an automatic assessment should be demonstrated in a set of representative components.	M	FB	UC5-D2-KPI-3
Security Requirement	DEM9-SEC-06	Any failures on drone like connectivity losses, system failures, and battery status shall be highlighted on ground station.	H	SkyA	
Security Requirement	DEM9-SEC-09	Methods to secure the communication should be future proof. Using beyond state of the art cryptographic algorithms (e.g. post-quantum) for authentication, message integrity and confidentiality.	M	AIT	UC5-D2-KPI-3
Security Requirement	DEM9-SEC-10	Strong privacy properties should be provided for communication content and metadata (e.g. external observers cannot track communication paths).	M	AIT	UC5-D2-KPI-3
Operational Requirement	DEM9-OPR-01	Sensors shall withstand the forces/water applied to the vineyard during the year (strong airflow and water from all sides during pesticides spraying or storms).	H	WBM	
Operational Requirement	DEM9-OPR-03	Flight boundaries shall be within the airspace authorities' law (flight height, distance to home point, etc.).	H	SkyA	
Operational Requirement	DEM9-OPR-04	The whole system shall be designed such that a single person can operate the complete process of data acquisition and transmission.	H	SkyA/WBM	

Operational Requirement	DEM9-OPR-05	For Austro Control[17] a pilot shall operate the drone to be able to oversteer autonomous operation in case of need.	H	SkyA	
Usability Requirement	DEM9-USB-01	The Self-Adaptability Framework should be accessible, this will ensure that relevant research outputs are available to industry.	M	FB	UC5-D2-KPI-4
Usability Requirement	DEM9-USB-02	All data collected and calculated should be presented at a single easy to use point (Website, App) for the end user.	M	WBM	UC5-D2-KPI-2
Policies Requirement	DEM9-P&C-01	Drones in Austria shall only be operated with pilots mentioned in the aircraft notification.	H	SkyA	
Design Requirement	DEM9-DSG-04	Weather Conditions shall be taken under account with respect to the boundaries according to specific drone manual.	H	SkyA	

Table 97 - UC5 D2: Main requirements

[17] https://www.austrocontrol.at/en

9 Conclusion

This deliverable describes all the demonstrators of the COMP4DRONES project, it gives their context and highlight their objectives and contribution to the C4D goals.

Each demonstrator also provides a set of business and technical Key Performance Indicators. These KPIs shall be further decomposed, they are at use-case level and shall de refined at system level KPIs then reach technical KPIs at component level.

Provided requirements in this doc are at use-case level, this document is accompanied by documents that gather more for each use case. However, they still need to be completed, tools will be used to gather them and track them. This tracking will allow to determine, as the project progresses, the coverage (number of requirements covered by the design) and compliance (number of fulfilled requirements).

10 Annex: Amendment to previous version 1.0

The current document is a revised version of a previously delivered D1.1 v.10. This version addresses notes and remarks provided by the European-commission reviewers. The main changes are the following:

- Clearer definition of the method to define KPIs in order to have more significant measurement, see Section 2.2.
- Introduction of the document focused on the boundary conditions that apply to the different use cases, see Section 2.3.
- Justification of the non-uniformity in the requirements names and presentation of the traceability methodology, see Section 3.5.
- Definition of a common basis to compare the uses-cases level of autonomy for the drones. See below for the impact on the uses-cases and see Section 3.6 for the common definition.
- Improvement of the uses-cases description, more precisely each uses cases has done the following:
    - Identification the major stakeholder, representing the interest for the demo result on the business perspective.
    - Description of the autonomy level aimed at by the drones, according to the frame of reference from Section 3.6.
    - Clarification of the boundary conditions: both on regulatory and system-limits aspects.
    - First introduction to the traceability methodology, will be further detailed in D1.2.
    - Refinement of the KPIs to be conform to the SMART criteria.
    - Improvement of the requirements: keep high-level requirement (business and system) corresponding to stakeholder needs, extraction of technological requirements to be moved to D1.2, identification of the link between the top-level requirements and the KPIs.
    - Finally, the features and subsystems have been linked to Key Enabling Technologies as defined in D2.1 including U-Space services.