Scenarios for validation experiments

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DACUS

DEMAND AND CAPACITY OPTIMISATION IN U-SPACE

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Abstract

This document details a set of operational scenarios which will allow the team to perform a series of validation experiments aimed at testing the suitability and performance of the various prototype algorithms under nominal and sub-nominal operating conditions, as well as to support the analysis of separation intelligence balance and refinement of CNS requirements linked to separation minima criteria.

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1 Executive Summary

Due to the substantial increase expected of drone operations over the next years in Europe, the European Commission supports the development of the U-space highly automated and digitalized service framework, which will need to guarantee the safe management of the high-volume drone traffic.

U-space should also ensure airspace access availability to multiple drone operators, maximizing the number of drones flying at the same time in a certain area, especially in urban environments. To do that, U-space shall adequately balance between system capacity and demand of drone operations, considering the dynamic nature of the drone mission trajectories.

Taking into account, as the main point of reference, the work started in DACUS WP1 through the definition of the first ConOps for DCB processes in U-space [1], DACUS project will develop different prototypes to support the DCB process decision making, which will be carry out in WP2 and WP3.

These prototypes will be part of the mains services involved in DCB process such as Operational Plan Preparation service, Operational Plan Processing service, Strategic Conflict Resolution service and Dynamic Capacity Management service. In addition, DACUS will perform simulations through the Fast Time Simulation (FTS) technique, producing results that will allow the evaluation of diverse separation approaches in terms of drone performance indicators to optimise decision making between on-board capabilities and U-space separation services, among others.

Prototypes and Fast Time Simulations will provide answers to some of the Research Challenges identified during the elaboration of the DACUS DCB ConOps [1], and they will address DACUS' objectives 2 and 4 as well [2].

The prototypes' functions will address the generation of nominal and contingency-based probabilistic 4D trajectories, the calculation of foreseen demand based on AI, the calculation of demand prediction and uncertainty, the monitoring of collision and social risk indicators, and the identification of hot-spots. Thus, the main DACUS' developments will be composed by the AI Demand Prediction model, the Collision Risk model, the Societal Impact model, and the 'DroneZone' adaptation of the RAMS Plus fast-time simulation model to support drone simulation.

To address the functions mentioned above, four validation experiments will be performed, addressing strategic, pre-tactical and tactical phases. Each validation experiment will be focused on one or multiple functionalities within DACUS architecture, defining its own scope, objectives, and scenarios. In addition, each one will propose different metrics to support the DCB process decision making.

Finally, this document also presents four operational scenarios to provide a better understanding about the DCB workflow information. These operational scenarios consider both nominal and sub-nominal conditions.

2 Introduction

2.1 Purpose of the document

This document details the validation experiments that will be carried out by the prototypes developed in DACUS project in order to support the DCB process decision making. Each validation experiment presents its objectives and describes the whole range of scenarios to be tested, as well as the architecture, assumptions, and metrics.

Furthermore, this document presents a wide variety of operational scenarios to provide a better understanding on the DCB workflow information on different real situations and not only in nominal conditions but also in contingency conditions such as navigation disturbances or drone emergency.

The document follows the structure of the Validation Plan (VALP) and U-space Study Plan documents which are common to SESAR projects to maintain a high level of similarity to other projects within the SESAR domain. Nevertheless, some sections have been updated and adjusted to fit the exploratory nature of the DACUS project.

2.2 Scope

This is the Validation Plan for the DACUS project which aims to develop a service-oriented Demand and Capacity Balancing (DCB) process to facilitate drone traffic management in urban environments. The project intends to integrate relevant demand and capacity influence factors (such as CNS performances availability), definitions (such as airspace structure), processes (such as separation management), and services (such as Strategic and Tactical Conflict Resolution) into a consistent DCB solution.

This document establishes the basis to perform a series of validation experiments aimed at testing the suitability and performance of the various prototype algorithms under nominal and sub-nominal operating conditions, as well as to support the analysis of separation intelligence balance and refinement of CNS requirements linked to separation minima criteria.

2.3 Intended readership

This document is oriented towards two key audiences:

1. DACUS consortium: The experiments defined in this document should provide the baseline for designing and performing all validation experiments. This document will support the definition and planning of other tasks as well.

2. SESAR JU: This document provides the first validation experiments to be performed in the field of U-space DCB. Moreover, this document presents the DCB workflow information through a set of operational scenarios that shall be used as a primary reference to readers external to the consortium.

3. Other U-space projects that consider a high volume of drone traffic such us Very-Large Demonstration (VLDs) projects or develop U-space services.

2.4 Background

As DACUS project is a pioneer in the definition and validation of a concept for DCB within U-space, there is no previous work in the field of validation DCB experiments that can be identified as background. Nevertheless, the work conducted during DACUS WP1 through the elaboration of the deliverable D1.1 [1] is the basis for the validation experiments definition.

2.5 Structure of the document

This document is structured into seven sections, briefly described here:

- Section 1: Executive Summary.

  A quick summary of the document is provided.

- Section 2: Introduction.

  Information concerning the purpose of the document as well as means to orient the content presented within the DACUS validation experiments is provided.

- Section 3: Validation Scope.

  A brief description of the overall aim of this document as well as the architecture overview is provided.

- Section 4: Validation High Level Plan.

  This section captures a summary of the validation experiments detailed in section 6, including validation approach, objectives, and assumptions, among others.

- Section 5: Operational Scenarios.

  A wide variety of operational scenarios to provide a better understanding on the DCB workflow information under different real situations is provided.

- Section 6: Validation Experiments.

  This section is the main section of the document. It describes the validation experiments to be carried out by the prototypes developed in DACUS project in order to support the DCB process decision making, including scope, objectives and metrics of each one.

- Section 7: References.

  A list of reference material which was used to develop this document.

2.6 Glossary of terms

Term	Definition	Source of the definition
Demand and Capacity Balancing (airspace)	The ability to evaluate traffic flows and adjust airspace resources to allow airspace users to meet the needs of their operating schedules.	EATMA V12 (ATM Capability)
Separation Provision (airspace)	The ability to separate aircraft when airborne in line with the separation minima defined in the airspace design (incl. aircraft separation from incompatible airspace activity, weather hazard zones, and terrain-based obstacles).	EATMA V12 (ATM Capability)
Service	A contractual provision of something (a non-physical object), by one, for the use of one or more others. Note: Services involve interactions between providers and consumers, which may be performed in a digital form (data exchanges) or through voice communication or written processes and procedures.	SESAR Integrated Dictionary
Traffic density	The traffic density measures the (uneven) distribution of traffic throughout the airspace.	Performance Review Unit
Controlled ground area	Controlled ground areas are a way to strategically mitigate the risk on ground (like flying in segregated airspace); the assurance that there will be uninvolved persons in the area of operation is under the full responsibility of the UAS operator	Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Commission Implementing Regulation (EU) 2019/947

Table 1: Glossary of terms

2.7 List of Acronyms

Acronym	Definition
AEMET	Spanish State Meteorological Agency
AESA	Spanish Aviation Safety and Security Agency
AI	Artificial Intelligence

Acronym	Definition
AMC	Acceptable Means of Compliance
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
BADA	Base of aircraft data
BLOS	Beyond Visual Line of Site
CISP	Common Information Service Provider
CNS	Communication, Navigation and Surveillance
COM	Communication
ConOps	Concept of Operations
CORUS	Concept of Operations for EuRopean UTM Systems
DAA	Detect and Avoid
DACUS	Demand and Capacity Optimisation in U-Space
DCB	Demand and Capacity Balancing
DCM	Dynamic Capacity Management
DOP	Drone Operator Plan
EATMA	European Air Traffic Management Architecture
EGNOS	European Geostationary Navigation Overlay Service
ER	Exploratory Research
ETA	Estimated Time of Arrival ?¿?¿?
EVLOS	Extended Visual Line-Of-Sight
EXP	Validation Experiment
FP	Flight Plan
FTS	Fast Time Simulation
GM	Guidance Material
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Human-Machine Interface
INE	Spanish National Institute of Statistics

Acronym	Definition
KPA	Key Performance Area
KPI	Key Performance Indicators
MS	Microsoft
NAV	Navigation
NCAR	National Centre for Atmospheric Research
NOTAM	Notice To Airmen
OBJ	Objective
OS	Operational Scenario
PAV	Personal Aerial Vehicles
PIC	Pilot-in-command or Drone Pilot
RC	Research Challenges
RNP	Required Navigation Performance
RPAS	Remotely Piloted Aircraft System
RTTA	Reasonable Time to Act
SBAS	Satellite-Based Augmentation Systems
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
SORA	Specific Operation Risk Assessment
SUR	Surveillance
TLS	Target Level of Safety
UAS	Unmanned Aerial System
USSP	U-space Service Provider
VALP	Validation Plan
VLD	Very-Large Demonstration
VLL	Very Low-Level
VLOS	Visual Line-Of-Sight
WP	Work Package

Table 2: List of acronyms

3 Validation Scope

3.1 Validation Purpose

Following the work carried out by DACUS WP1, DACUS will develop algorithms and prototypes to address the DCB functionalities within U-space services.

In order to show these functionalities and the algorithms and prototypes performances, the aim of this document is present a wide range of validation experiments to be executed by these algorithms and prototypes, as well as a validation experiment to be performed through a Fast Time Simulation technique.

The following list presents a brief description of the main algorithms, prototypes, and simulation platform to be used in the validation activities:

- **AI demand prediction model**: generate drone operations, considering assumptions on demand and weather analysis.
- **Collision Risk model**: calculates the expected ground fatality risk and estimate the maximum capacity during a time period.
- **Societal Impact model**: evaluate the noise and visual impact of drone flights over populated areas (urban environments).
- **DroneZone fast-time simulation platform**: extension of the commercially-available RAMS Plus ATM gate-to-gate fast-time simulation model that provides micro-scale functionality for drone performance, conflict detection and zone-based functional behaviour.

3.2 Architecture overview

The CORUS ConOps [3] proposals are extended in DACUS to consider a continuous and pro-active process which starts working before the RTTA. As in ATM, U-space DCB process aims at pro-actively monitoring the traffic situation to identify and manage imbalance situations as soon as they are detected with enough certainty.

The following paragraphs provide an overview of the main DCB flow and the U-space services which participate in it. Those U-space services which have an active role in the identification of contingencies in the tactical phase are not included. The following section will provide a detailed description of the main and secondary processes which are part of the U-space DCB in all operational phases.

1. Operation Plan Preparation service facilitates the preparation and submission of the operation plans. It shall allow indicating those parameters which are critical for the fulfilment of the mission. Operation plans, which are closely linked to the business needs of the drone operators, include contingency considerations for the declared flights.

2. Operation Plan Processing Service verifies the consistency of the information submitted with the operation plans and generates probabilistic 4D trajectories. It shall also have capabilities for the storage of operation plans and make them available before and during the flight. The service should probably generate what-if" probabilistic 4D trajectories taking into consideration contingency volumes or contingency plans which will be included in the operation plans.

3. Strategic Conflict Resolution Service compares the submitted operation plan with the already approved ones and propose solutions if the risk of a conflict is higher than a certain limit. It must consider mission objectives to propose suitable solutions for the Drone operator.

4. Dynamic Capacity Management Service is key throughout the whole DCB process. It provides a prediction of the demand by combining available 4D trajectories with predictions of new ones, quantifying its level of uncertainty and characterizing them. This Demand Prediction model will take on board factors that might impact the declared demand, such as weather forecast.

   Moreover, the Dynamic Capacity Management Service calculates and monitors indicators related to safety and social impact and assesses how the proposed DCB measures will affect those indicators and the missions also. Two models will allow quantifying the collision risk and the social impact of the demand in each airspace. The Collision Risk model will consider all factors influencing the mid-air collision probability and severity, including contingency measures associated with the declared demand, as well as other influence factors impacting the capacity such as the population density in real-time. The Social Impact model will input in the picture environmental biases and social concerns related to noise, visual impact, or perceived safety, among others. The applicable airspace structure and urban rules are taken into consideration as boundary conditions in the models.

   Finally, the Dynamic Capacity Management service evaluates if demand can be executed safely and efficiently taking into consideration the existing performance thresholds in each airspace volume. In case of imbalances, DCB measures need to be proposed and sent to the Operation Plan Processing service.

The following figure provides a high-level overview of the DCB process:

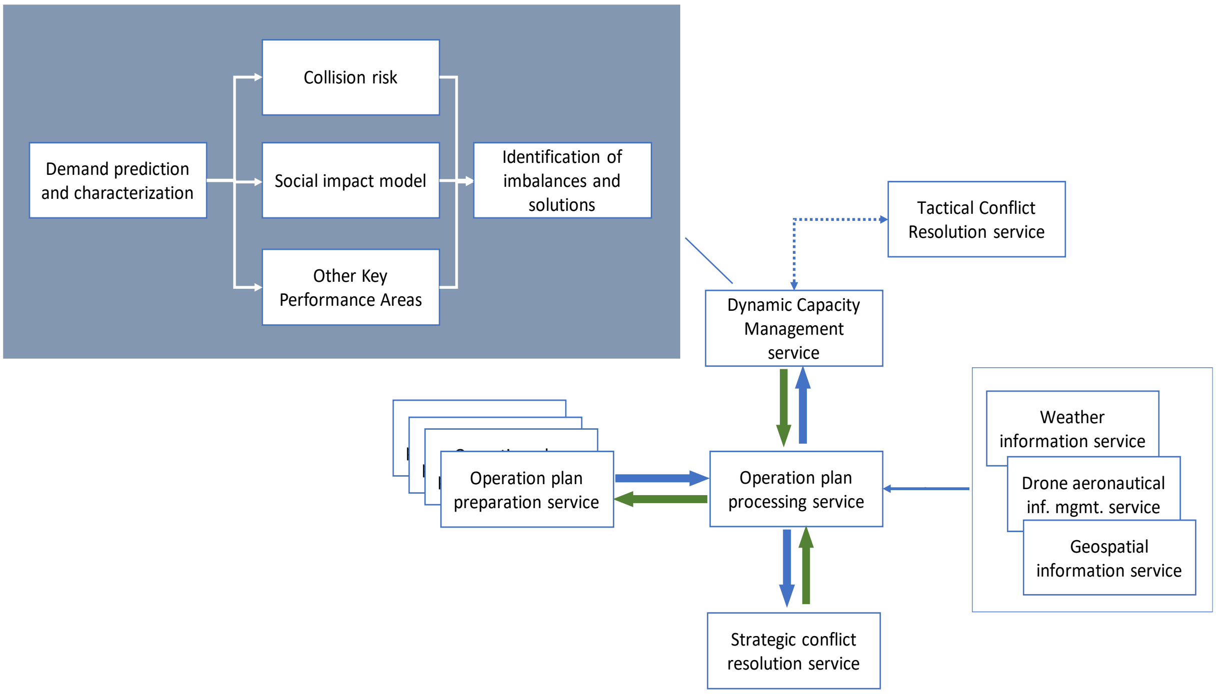


Figure 1: High-level overview of the DCB processes in U-space

Tactical Conflict Resolution Service compares existing operation plans in flight, to identify potential conflicts with other flights and propose pair wise solutions in the tactical phase. Although this is not a service with an active role in the DCB process, its performances will determine the maximum number of drones that can be safely managed in each airspace.

In contrast to ATM, this limit will not be constrained by the air traffic controller's capability to safely separate aircraft. The U-space capacity will be limited by the ability of the tactical conflict resolution process to manage the density of aircraft to keep the risk of conflict acceptably low. Drone components related to its remote control and positioning capabilities as well as navigation, communication and surveillance data provision will have an influence on this risk of conflict.

3.3 DCB processes and involved U-space services

Like processes in air traffic management, the U-space DCB process can be divided into five phases: Long-term planning, strategic, pre-tactical, tactical, and post-operational phase. The major novelty of the U-space DCB phases with respect to that of air traffic management is the inclusion of the "consolidated demand picture" as a means to separate the strategic phase from the pre-tactical phase. The time in which the demand picture is considered stable enough to take decisions on the implementation of DCB measures affecting some drone operations is named *"Reasonable Time to Act" (RTTA)*. This metric is entirely based on probabilistic estimations of traffic demand, which deviates from the predominantly deterministic and rigid approach to DCB currently employed by air traffic management.

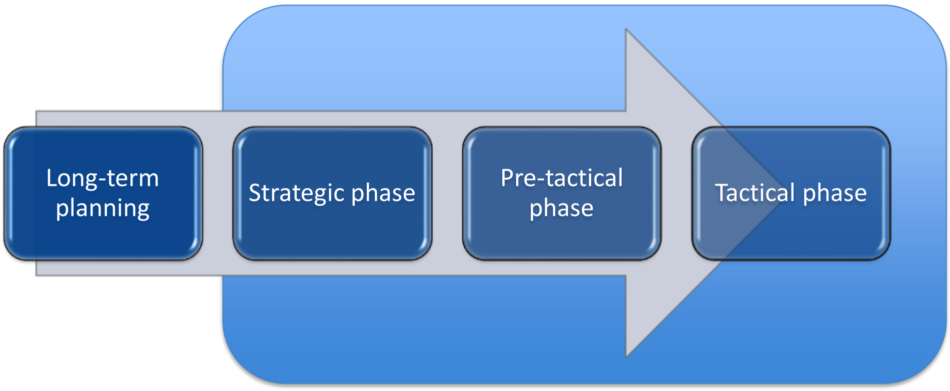


Figure 2: Overview of DCB phases and DACUS scope (in blue)

Long-term planning starts months or even years prior to the execution of operations. It is focused on the early identification of major demand and capacity imbalances. For example, air shows, major sport events, demonstrations, political rallies, military exercises are major events affecting the demand and the capacity. Planned inauguration of large drone-based distribution centres in a specific area is an example of events impacting the capacity. We are assuming that this phase is not managed through the U-space services which were defined within the CORUS ConOps [3], and it is considered out of the scope of DACUS project.

The following sections provide a detailed description of the main and secondary processes which are part of the U-space DCB in different stages of the operational phases which are within the DACUS scope - strategic, pre-tactical and tactical -.

3.3.1 Strategic phase

It starts days or even weeks prior to the execution of operations, as soon as a certain amount of drone operation plans have been submitted by the Drone Operators, and the demand can be predicted with a minimum level of confidence. The main objectives of this phase are twofold:

- To implement those DCB measures which are not imposing critical constraints to the fulfilment of the mission according to the Drone Operator’s expectations.
- To pre-define those DCB measures which impose restrictions which could put the fulfilment of the mission at risk. These types of measures will be ready for their implementation in the next phase, assuming that it is necessary to increase the level of confidence in the demand prior to the implementation of such type of measures.

The number of operation plans that will exist in a specific timeframe prior to day of operations will be determined by the diversity of business models. As an example, operation plans for last-mile delivery will only be available on short notice, however drones supporting recurrent operations, such as for instance in support of waste management in Smart Cities, could have periodical Operation Plans which are available longer time in advance.

The detailed processes are included in the following diagram. They will take place before the “Reasonable Time to Act” (RTTA).

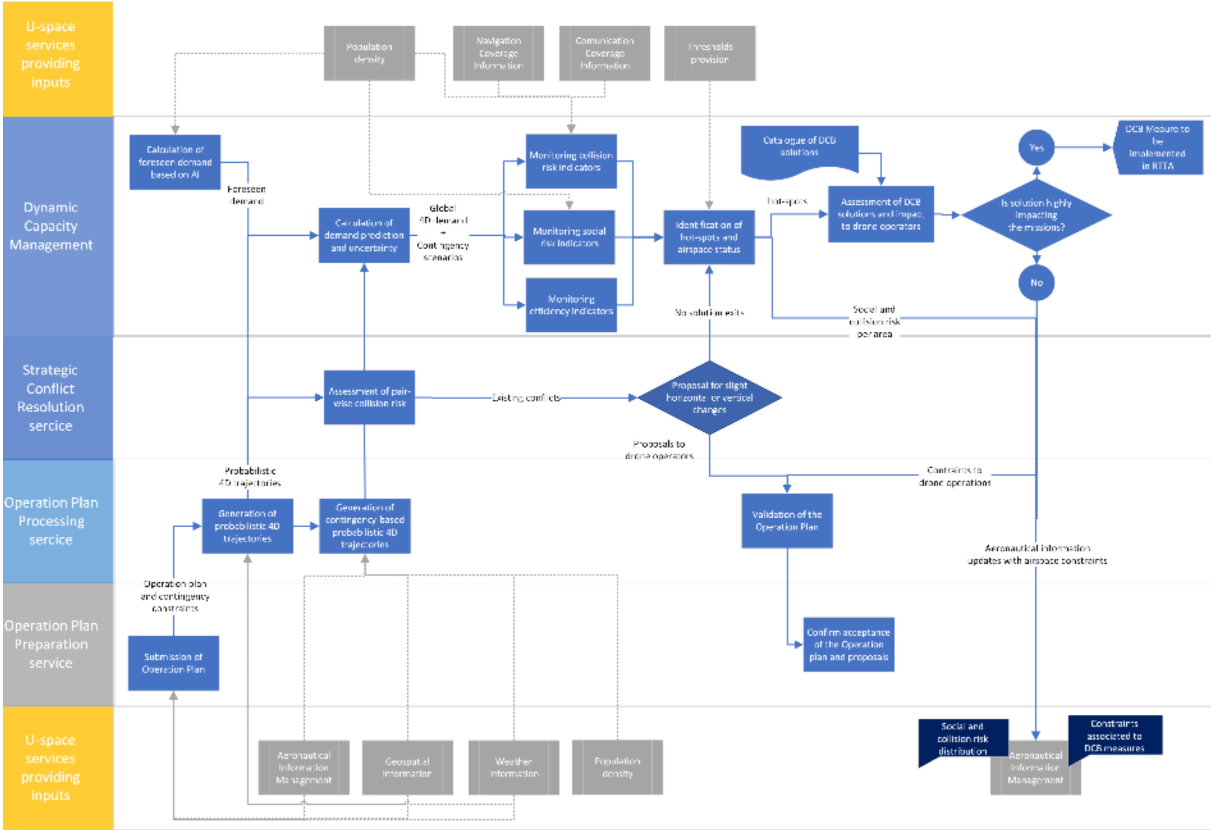


Figure 3: Detailed DCB processes in the strategic phase

3.3.2 Pre-tactical phase

It starts hours or even minutes prior to the execution of operations, at a certain time in which predictions on traffic are stable enough (based on traffic data, weather, ground risk, etc.) and the level of confidence in them is high enough to ensure the effectiveness of the DCB measures to be implemented.

The main objective of this pre-tactical phase is to consolidate the global traffic picture and implement the appropriate DCB measures if they were not implemented in the previous phase.

Starting time will depend on the trade-off between the soonest that the Drone Operators can provide operation plans according to their business characteristics, and the latest they must be made aware of the DCB measure, in order to implement it before take-off. Thus, the start of the pre-tactical phase is linked to the point in which the demand picture is consolidated enough thanks to the fact that most of the operation plans have been submitted. However, in order to be effective, the start of this phase must be far enough in advance to allow for the communication (and potential negotiation) of DCB values with the affected drone operators.

Operation plans submitted after RTTA for that flight are the first candidates to be proposed a plan change. Although there is no advantage to early operation plan submission, there is a limit in the interests of giving other operators some stability. At RTTA a flight becomes “protected” and may be considered as being in its Tactical phase. The following diagram represents a certain time after the RTTA, so that DCB measures have been already implemented. New submitted operation plans will need to comply with the constraints associated to the implemented DCB measures.

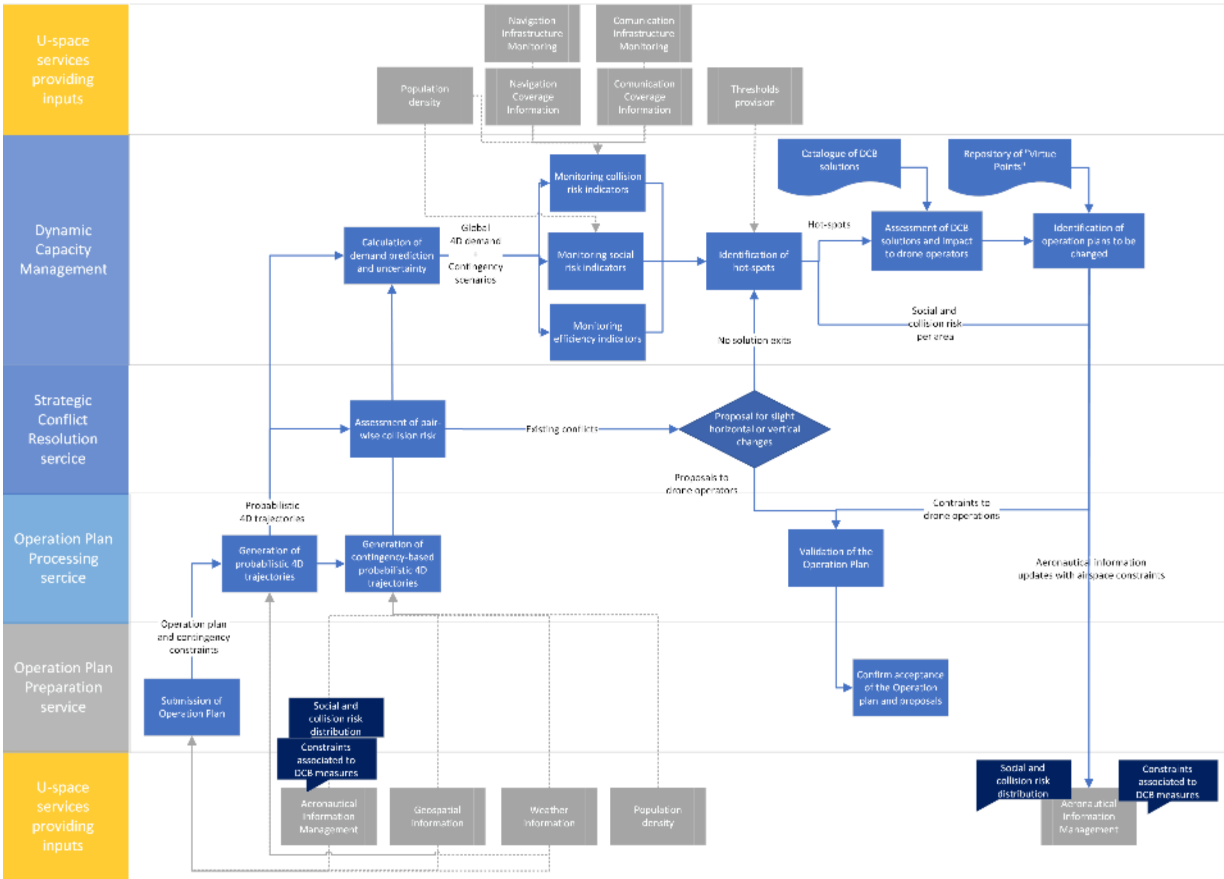


Figure 4: DCB processes in the pre-tactical phase

3.3.3 Tactical phase

It takes place during the execution of the operations. It involves considering those real-time events that affect the overall traffic picture and making the necessary modifications to it to restore the stability. The need to adjust the original traffic picture may result from disturbances such as significant meteorological phenomena, crises and special events, unexpected limitations related to ground or air infrastructure, drones’ contingencies, etc. The main objective of this phase is to monitor the overall traffic picture and to minimise the impact of any disruption.

The following diagram represents the case in which the Navigation Infrastructure Monitoring service is reporting a degradation of navigation performances. This degradation is impacting to drones which are already in the air. The degradation is declared for a long period of time. This implies that additional Operation Plans, which have not been activated, will also be impacted. Contingency plans need to be activated for those drones which are already in the air and cannot fly in the area due to the loss of navigation capabilities.

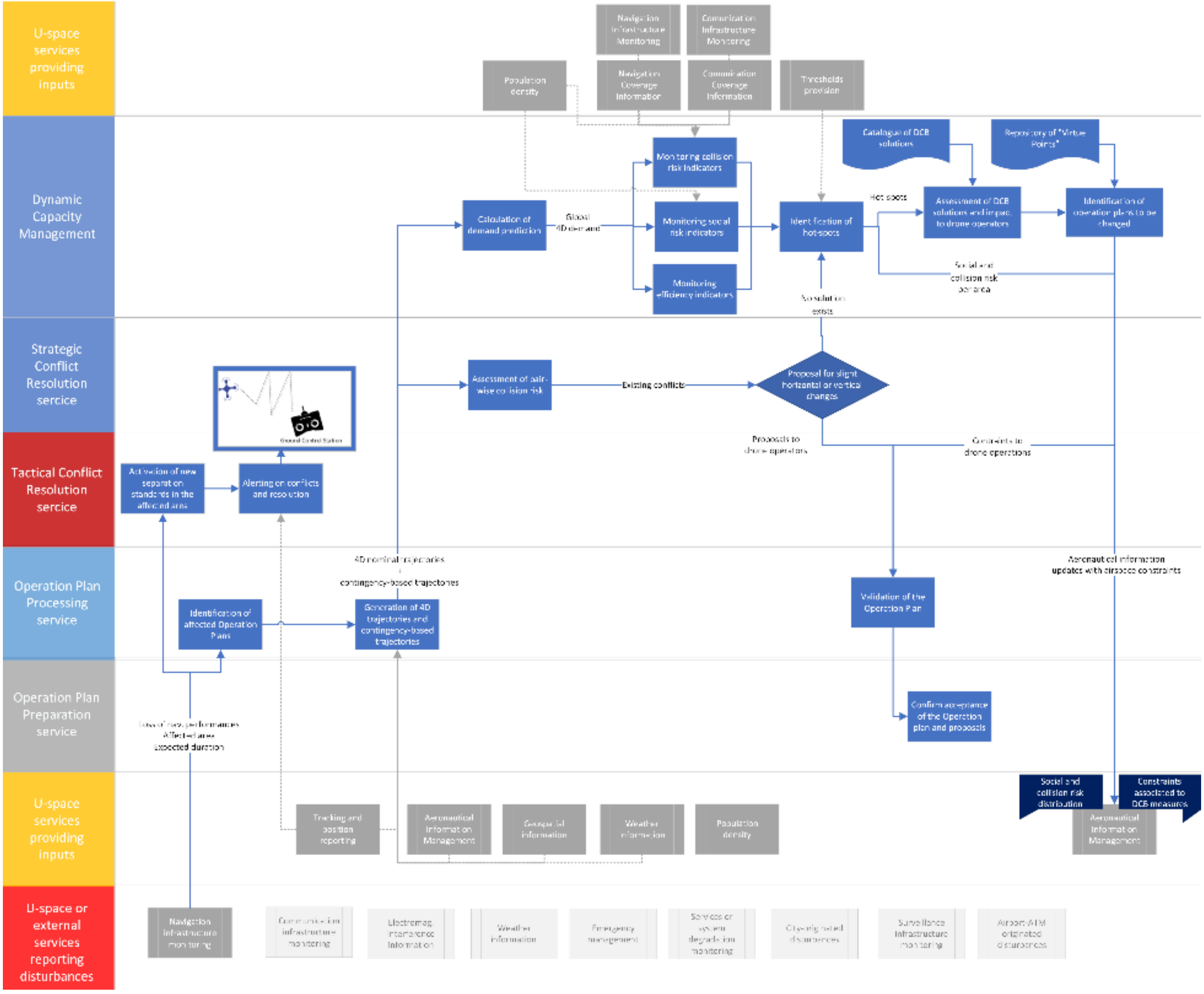


Figure 5: DCB processes in the tactical phase

4 Validation high level Plan

4.1 Validation Approach

The validation approach is focused on testing the processes which are part of the U-space DCB in different stages of the operational phases which are within the DACUS scope: strategic, pre-tactical and tactical.

In order to validate the models, capabilities and prototypes developed in DACUS, the following validation experiments are envisioned:

- **Validation Experiment #01:** This validation experiment will be focused on the strategic and pre-tactical phases, with the main focus being on the application of the DCB services related to the management of noise and social impact due to drone operations in urban environments. Thus, the main objective of this experiment is to test the feasibility and the reliability of the use of noise and visual impact metrics for the DCM service.

- **Validation Experiment #02:** During the second validation experiment the nominal processes of flight plan processing, contingency planning and the resulting demand and uncertainty predictions will be validated. Furthermore, the influence of the demand and uncertainty predictions on the collision risk and efficiency will be tested, as well as the feedback loop of additional information such as collision risk and efficiency indicators into the flight plan processing.

- **Validation Experiment #03:** The third validation experiment will apply the collision risk model in the strategic phase in order to test the effect of considering different CNS performances and defining different airspace structures on the maximum acceptable capacity in a certain scenario.

- **Validation Experiment #04:** This validation experiment will use a fast-time simulator to validate the DCB process in diverse scenarios and conditions. Thus, it will be focused on tactical phase and the main objective is to analyse the effect on DCB process when a perturbation is activated, as well as the effectiveness of different DCB measures. Then, each DCB measure will be assessed by considering the performance areas included in the DACUS Performance Framework [4].

Each validation experiment is designed to test a key part of the DCB process, as well as to understand the functionalities of the models involved. Depending on the validation experiment, one or more developments are involved in it.

Thus, each validation experiments have designed its own scenarios, and have defined its own low-level objectives, assumptions, and limitations. With the aim of monitor the results, a set of metrics has been defined as well, taking as reference the DACUS' Performance Framework [4].

The following table shows the relationship between the developments, main functions, involvement in the validation experiments and the U-space services concerned:

Development	Main Functions	Involved in	U-space service
AI demand prediction model	Calculation of foreseen demand prediction and uncertainty based on AI	Validation Experiment #01 and #02	Dynamic Capacity Management
Collision Risk model	Monitoring collision risk indicators Identification of hot-spots and airspace status	Validation Experiment #02 and #03	Dynamic Capacity Management
Societal Impact model	Monitoring social risk indicators Identification of hot-spots and airspace status	Validation Experiment #01	Dynamic Capacity Management
Trajectory Planning capability	Generation of 4D probabilistic trajectories with uncertainty	Validation Experiment #02	Operational Plan Preparation & Processing
Contingency Planning capability	Generation of contingency-based 4D probabilistic trajectories with uncertainty	Validation Experiment #02	Operational Plan Preparation & Processing
Micro-Weather prototype	Supportive functions for large number of simultaneous operations	Validation Experiment #02	Feeder service

Table 3: Link between developments, functions, validation experiments and U-space services.

Furthermore, as it is indicated previously, the Validation Experiment #04 will use a commercial ATM fast-time simulator to test a wide range of scenarios focused on tactical phase. In order to tackle the micro-scale functionality for drone performance and conflict detection, the model DroneZone will be used as an extension of the simulator. Its main functions are 4D profile calculation and insertion, separation priorities, and 4D conflict detection and resolution.

The following figure shows a summary of the main figures of the DACUS' validation experiments:

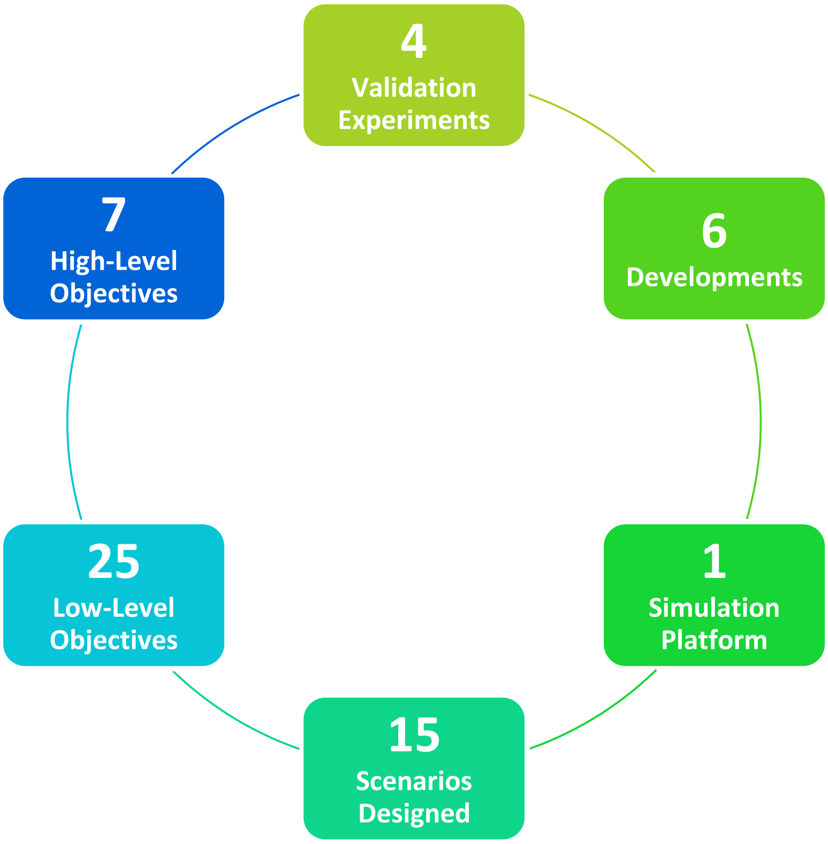


Figure 6. Main figures of the validation experiments.

4.2 Stakeholder's expectations

Stakeholder	KPA affected	Why it matters to stakeholder
Drone operator	Capacity Predictability Environment Safety	Drone operator will be the first one to be impacted by any DCB measure(s) applied to his operation. They will be allowed or not to fly depending on the traffic conditions, exclusive areas, preferences, restrictions… Drone Operator Plans (DOPs) will be able to be automatically accepted and authorised for execution with little or no risk of encountering separation issues, provided that the execution conforms with the proposed plan -some flexibility is built into the authorised trajectory which can account for a limited variability during execution (e.g. due to navigational accuracy, slight weather effects, etc.)-.

Stakeholder	KPA affected	Why it matters to stakeholder
		In the event of unexpected issues during the execution phase, sufficient available contingency options will be shown to allow operators to perform contingency action in a safe and efficient manner. These unexpected events could result in a loss of predictability impacting the effectiveness of the operation, in particular for operators that have multiple 'linked' missions using the same vehicles. Additionally, operators will plan to specifically avoid areas where constraints (such as noise or visual constrains, CNS performances…) are present, and could adapt their plans to flight over other regions where the issues are less constrained. Furthermore, based on recurring hot-spots location identification, drone operator could try to avoid them by changing the filed Drone Operator Plan (DOP) before submitting.
U-space Service Provider (USSP)	Efficiency Resilience Safety	DACUS' models will allow the USSP to manage the required demand in line with the available capacity, in order to reduce the risk of separation issues and possible collisions between vehicles during the execution phase, so that operations are able to conform closely to the proposed/authorised operational profiles, calculating and monitoring at any time the appropriate metrics related to capacity, efficiency or resilience, among others. In addition, identification of hot-spots and appropriate DCB measures related to its nature may increase DCM efficiency through the choice of appropriate measures that help to mitigate noise/visual impact. Also the fact that some drone operators modify their plan to avoid being impacted by DCB measures is likely to increase the capacity, as the operators would use other volumes where the traffic density is lower, releasing space in the hot-spot areas. On the other hand, contingency plans included in the pre-tactical planning phase are able to be evaluated to confirm that vehicles are able to respond safely to unanticipated issues (e.g. CNS degradation/loss, vehicle technical failures…) during the execution.

Stakeholder	KPA affected	Why it matters to stakeholder
		USSP should guarantee that sufficient contingency has been built into the pre-tactical planning and mission authorisation phase to ensure that all vehicles that are operating in the region have multiple options available in response to an unforeseen critical event. Emergency 'landing' locations are included in the planning to offer sufficient locations that are within the operating range of each vehicle as well as alternatives that can be used in the case that any of those locations are not available (e.g. are closed due to high wind issues).
Regulators	Environment Capacity	In close relation with USSP to foster drone market, the regulator may propose some specific regulation(s) (e.g., airspace structures) provided that the identification of hot-spots reveals that some changings could make the traffic flow smoother and increase the number of drone operations. Specific regulatory constraints may be introduced to help protect regions of high noise sensitivity (e.g. hospitals, schools, residential areas at night etc.).
Public, citizen	Environment	The results of the experiment may provide the citizens with an assessment of drone operations impact in the future. It is likely that such results push citizens to influence the regulators (positively or negatively for drone operations). Indicators such as the number of inhabitants that might be exposed to noise/visual impact of varying levels (e.g. population density within noise contours) can be used to evaluate the potential impacts.
Drone manufacturers	Environment	Hot-spots identification in the field of social impact can influence drone manufacturers in producing drone with lower noise emissions in case the issue of hot-spots reduces the market (the demand).

Table 4: Stakeholder's expectations

4.3 Validation high level Objectives

During the DACUS proposal's preparation, five specific objectives were set [2]. One of them (**Objective 4**) aims to **find the optimal balance between on-board separation intelligence and U-space separation service intelligence in tactical separation** depending on the type of airspace (with or without conflict resolution in strategic and/or tactical phases), type of separation (drone-drone or drone-manned aviation), CNS performances and the separation process that applies in each type of airspace area. This objective will be covered by the Validation Experiments' results, which will allow the evaluation of diverse separation approaches in terms of drone performance indicators as defined in DACUS Performance Framework.

In addition, during the elaboration of the first ConOps for DCB processes in U-space [1] performed in DACUS WP1, different Research Challenges are identified as a next step in the DCB research activities, taking some of them as a Validation Experiments' High-Level Objectives. In particular, the following Research Challenges will be covered by the Validation Experiments:

Research Challenge 1 - Contingency plans as part of the Collision Risk Model
The inclusion of contingency plans within the scope of the Collision Risk Model for UAS operations, which is the main model to determine the maximum number of drone operations in a certain urban area, is subject to further research. Drone operation plans will contain the volumes of airspaces in which the UAS operator plans to conduct the operation under normal procedures and also those volumes of airspace outside the flight trajectory where contingency procedures are applied. The Collision Risk Model could use both of them, in the form of 4D trajectories, to calculate not only the envisioned level of risk under nominal circumstances but also how risk can change if contingency plans need to be implemented. Research on how to deal with these multiple sets of trajectories and the impact on the level of risk should be conducted.

Research Challenge 2 - Consistency of the Collision Risk and Societal Impact Models
Given the close proximity of drone operations to the general public as well as ground infrastructure, a special emphasis was placed on including both risk and social indicators as an integral part of the DCB process. The Collision Risk Model will assure that overall flight safety and the safety of third-parties remains acceptably high; the Societal Impact Model will assure that social impact factors (such as noise, pollution and visual impact) will remain below an acceptable threshold. Both models could have different spatial and temporal variability (e.g., the Societal Impact Model could capture citizens' movement patterns or real-time citizens' positions which could be particularly complex). However, the two models should be combined to determine the maximum number of drones which are acceptable in a given airspace. This final target makes it necessary to ensure that the outcomes of both models can be consistently integrated both in spatial and time domains.

Research Challenge 3 - Consolidation of metrics to determine the maximum number of UAS operations
Several challenges related to the need of evolving from traditional capacity indicators to risk and societal indicators are subject to further research. Indicators that reflect how citizens are affected by drone operations should be investigated. The need of defining what is considered as a "populated area" was identified as part of the DCB concept. This notion should not be simplified to indicators such as population density. An example illustrating this idea: Urban areas such as residential suburbs could have high population densities, but residents are not very impacted by the drone operations as they stay most of the time inside buildings. Additionally, trade-off between acceptable risk and societal thresholds and other indicators related to how mission efficiency is impacted by the increase in the number of operations needs to be further investigated. Previous research projects showed that there is a threshold in which the average mission efficiency starts to decrease as the number of drone flights are increased within a defined area. Thus, some drone operations would no longer be feasible based on this drop in efficiency.

Research Challenge 4 - Applicable DCB measures and their effectiveness
This U-space DCB concept redefines the set of DCB measures which are applicable in urban environments. Although previous research initiatives have analysed some of these measures and their expected benefits, there is a need of assessing consistently their effectiveness not only from the perspective of the network performances but also by assessing how each measure will impact the diverse business models that will coexist in the cities. This needs to be tested in a context in which "free-route" operations should be facilitated as a general principle. As an example, one of the measures consists of allowing operations above VLL airspace (and below minimum operating altitudes for manned aircraft) in those areas where demand exceeds the capacity. However, we have identified that cellular network coverage decreases dramatically above VLL because network antennas are tilted down. Thus, this could be a limiting factor which constraints the effectiveness of the measure.

Research Challenge 7 - Prioritization of drone operations within the DCB process
The thinking in the U-space ConOps is that within any priority level, the selection of flights to act on for DCB or strategic conflict resolution, and how to act on them, should be driven by minimizing overall impact when all flights are considered. However, this raises the possibility that a particular flight is always considered the best target for change. Hence a draft of the ConOps proposed "Virtue Points" which would be awarded to operators whose flights were selected to be delayed or

rerouted. These points would in future be used to raise the priority of a flight. The idea was explored further, and the proposal made that Virtue Points should also be awarded for other actions that maximise capacity – a very controversial question.

This notion of "Virtue Points" was included in this DCB ConOps. However, it is still to be defined whether or not to include this concept within the process, or another method to maintain equity among operations needs to be found. And, if this concept is considered feasible, investigate how to manage its impact on capacity.

Research Challenge 8 - Operation Plan as up-to-date information for the entire DCB process

This U-space DCB concept recognizes the Operation Plan as the "single point of truth" which keeps continuous up-to-date information about the situation and expected evolution of the drone operation. However, the document also highlights the difficulties for the Drone Operator to participate in a continuous process to keep the Operation Plan updated during the flight execution, or to receive requests to change the Operation Plan in different timeframes along the process. To address this issue, DACUS proposes to reduce up to the minimum the interactions with the drone operator to request these updates.

The reconciliation between this idea of the Operation Plan as "single point of truth" of the drone operation and entirely managed by the drone operator and the need to reduce the interactions up to the minimum is subject to further research.

Research Challenge 12 - Impact of weather conditions in the DCB process [1]

The analysis up to what point the weather conditions could affect the decisions taken on the DCB process is subject to further research.

As an example, the impact of weather conditions in the urban environments' infrastructure could allow (or not) to make available certain take-off and landing locations (vertiports) in urban areas.

[1] Research Challenge identified during the elaboration of this deliverable.

The next table shows the relationship between validation experiments, high-level objectives, and low-level objectives, which are presented in section 6.X.2 of each validation experiment:

	OBJ 4	RC 1	RC 2	RC 3	RC 4	RC 7	RC 8	RC 12
EXP#01			EXP1-OBJ2	EXP1-OBJ1	EXP1-OBJ3			
EXP#02		EXP2-OBJ1	EXP2-OBJ3 EXP2-OBJ6				EXP2-OBJ2	EXP2-OBJ4 EXP2-OBJ5 EXP2-OBJ7
EXP#03			EXP3-OBJ1 EXP3-OBJ4	EXP3-OBJ2 EXP3-OBJ3	EXP3-OBJ2 EXP3-OBJ3			
EXP#04	EXP4-OBJ2			EXP4-OBJ3 EXP4-OBJ4 EXP4-OBJ5	EXP4-OBJ1 EXP4-OBJ6 EXP4-OBJ7 EXP4-OBJ8	EXP4-OBJ9 EXP4-OBJ10		EXP4-OBJ11

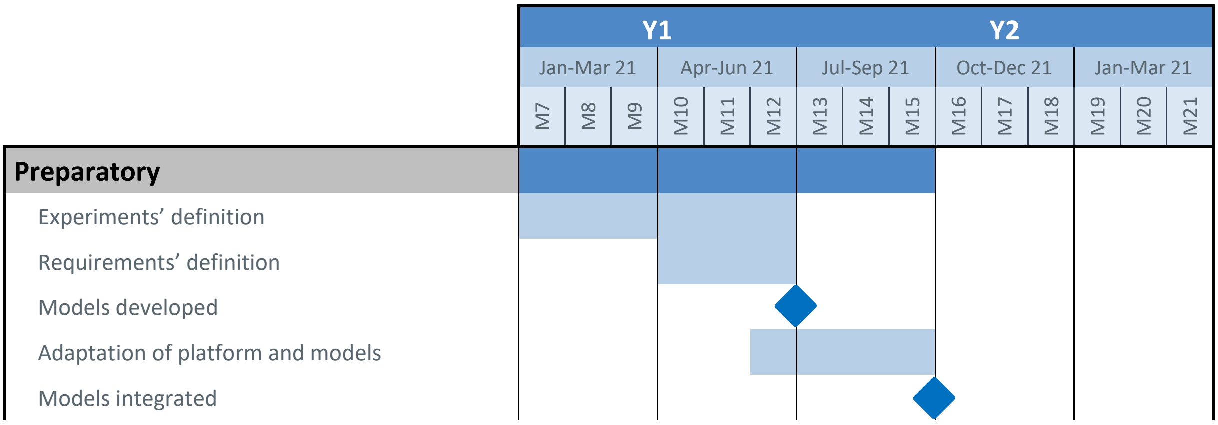
Table 5. Objectives – Validation Experiments relationship.

4.4 Validation Assumptions & Limitations

Although some DACUS Validation Experiments pursue the same high-level objectives, each one of them is designed to test different functions of the DCB process. Thus, the nature of the algorithms, prototypes, platform, and scenarios designed makes that each validation experiment has their own assumptions and limitations, presented in section 6.X.5 of each experiment.

4.5 Validation Experiments Planning

The following table shows the Validation Experiments' planning:



	Y1						Y2								
	Jan-Mar 21			Apr-Jun 21			Jul-Sep 21			Oct-Dec 21			Jan-Mar 21		
	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21
Execution							■	■	■	■	■				
Exercises' preparation (traffic & scenarios)							■	■	■						
Experiments' execution										■	■				
Post-Experiment										■	■	■	■	■	
Output data collection										■	■				
Results analysis											■	■	■	■	
Initial version D4.2 Validation test results												◆			
Final version D4.2 Validation test results														◆	

Table 6. Validation Experiments' planning.

5 Operational scenarios

5.1 Summary

In order to provide a better understanding about the DCB workflow information presented in section 3.2, this section presents four operational scenarios in which workflow information and actors could be identified easily on different real situation.

The operational scenarios consider both nominal and sub-nominal conditions. A summary of each one is follows:

- **OS #01 - Navigation disturbances reported by the Navigation Infrastructure Monitoring service**: Describe how disturbances in navigation integrity might affect DCB processes.
- **OS #02 - Drone emergency reported by the Emergency Management service**: Describe how to deal with a drone emergency reported by the Emergency Management service, distinguishing between the situations in which a contingency plan exists and those cases in which the emergency is declared, and it is so severe that no contingency plan exists.
- **OS #03 - DCB workflow information under nominal conditions**: Describe how information flow between services and functions under nominal condition for both strategic and pre-tactical phases.
- **OS #04 – Weather impacting vertiports capacity:** Describe how risks can be mitigated pre- and in-flight using services that anticipate off-nominal conditions in the traffic system, taking as use case a future drone operation related with air transportation service for passengers using semi-autonomous vehicles.

The common actors involved in the operational scenarios are the following:

- **End user:** the end user is the person who receives the service from the drone operator. For instance, in operational scenario #03 the end-user is the customer that has instigated the request for delivery, thus the delivery location's specifics must be known in advance. In operational scenario #04 the end users are the passengers, who choose to travel by air taxi inside a point-to-point station network.
- **Pilot-in-command:** Drone Pilot or Pilot-in-command (PIC) is in charge of managing the operation of at least one vehicle in the fleet on behalf of the operator. He/she is personally monitoring if the vehicle is operating nominally or is in an abnormal state (operation plan deviations, unforeseen events), which cannot be handled by the semi-autonomous systems on-board. The PIC is tasked in resolving such abnormal situations and notifying the U-space Service Provider (which subsequently informs the CISP in the city) if need be and to confirm safety critical decisions made by the on-board systems.
- **Drone Operators**: the drone operators are certified U-space Operators and operates a fleet of UAS for different types of missions. For instance, in operational scenario #04 are commercial

companies that are certified to fly passengers in semi-autonomous vehicles to a set of pre-defined destinations in urban and sub-urban environments. For the purpose of this scenario the non-control related vehicle logic will be considered part of the operator for simplicity.

- **Base Operator:** One or more companies that maintain, operate and administer the safe and efficient utilization of available take-off and landing sites under the guidance of the local authorities.
- **U-space Service Providers (USSP)**: the USSP are licensed entities which gathers data from the CISP and the subscribed drone operators and provides U-space services to drone operators (including assistance for flight planning as well as additional DTM supporting services) to ensure a safe, efficient, and secure conduct of UAS operations.
- **Common Information Service Provider**: CISP ensures that the airspace users have an equitable access to U-space information. It assumes a centralized role, as it provides the same safety-relevant information to all users, such as geo-awareness, traffic information and conformance monitoring.
- **U-space Authority:** Authority gives the operators their permissions to operate and use a specific category of aerial vehicles for a specific business. It has centralized registries about all actors involved.

5.2 OS #01 - Navigation disturbances reported by the Navigation Infrastructure Monitoring service

5.2.1 Scope of the scenario

The aim of this scenario is to describe how disturbances in navigation performances might affect DCB processes.

The scenario considers two drones flying within a U-Space designated airspace with a high level of navigation performance requirement. Both drones use GNSS as their primary source of navigation. However, a GNSS jammer from an unknown source is inhibiting proper GNSS signal reception by the drones (a very likely scenario) and as such they need to rely on secondary navigation sources to navigate.

This navigation disturbance is identified by Navigation Infrastructure Monitoring service, which detects a GNSS performance degradation below an admissible threshold in the area in question. The service subsequently sends an alert to the Operation Plan Processing service.

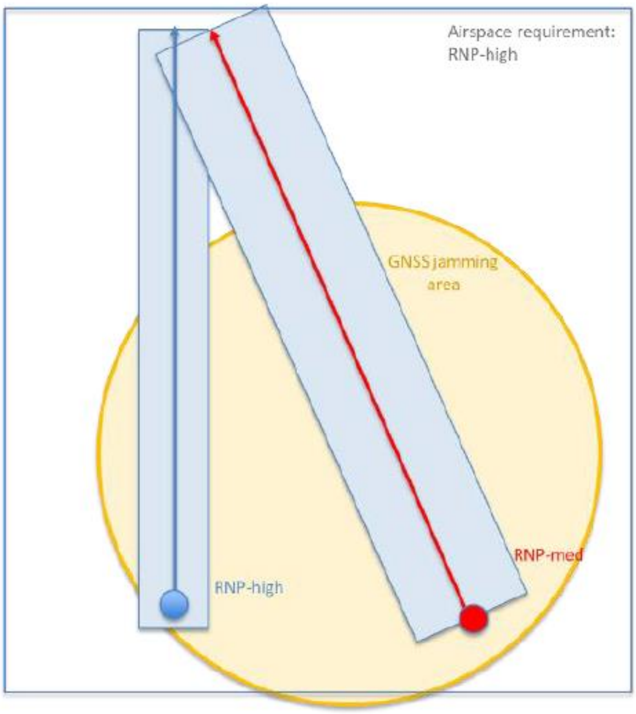


Figure 7. Operational Scenario #01.

The DCB workflow information would be: (1) generation of contingency-based 4D trajectories, (2) calculation of demand prediction, (3) monitoring of risk-based and social indicators, (4) assessment of predefined DCB measures and (5) prioritisation of operation plans.

5.2.2 Assumptions

- Both drones use GNSS as their primary source of navigation.
- Secondary navigation sources will likely be utilized as well, which include technologies such as visual navigation, signals of opportunity and infrared.
- In order to be technology agnostic with regard to U-space, it would make sense to apply Required Navigation Performance (RNP) standards for specific routes or sections of airspace.
- The “blue drone” is capable of falling back to a highly capable visual navigation technology which is able to maintain the RNP-high requirement.
- The “red drone” does not have such a capable secondary navigation means available and is only able to maintain a medium level of navigation performance (“RNP-med”).

5.2.3 Pre-conditions

- All operations of flight vehicles are nominal.

- The meteorological conditions (forecast/observed as appropriate) are within the specified operational limits of the drones.

5.2.4 Trigger

The use case starts with a degradation in CNS performance due to a GNSS jammer from an unknown source which inhibits proper GNSS signal reception by drones.

5.2.5 Post-conditions

5.2.5.1 Success end-state

A success end state is when:

- Drones in flight are rerouted safely.
- Drones on ground are successfully rerouted or delayed so that they can achieve their operations efficiently and safely.

5.2.5.2 Failed end-state

A failed end state is when:

- Drones in the affected area collide as a consequence of inadequate or lack of rerouting; or
- Drones on ground take off in the affected area putting themselves and other aircrafts at risk (they may collide); or
- Drones on ground cannot be rerouted or delayed safely so they cannot achieve their operations on time.

5.2.6 Scenario description

This scenario is divided in six steps:

Generation of 4D trajectories

The **Operation Plan Processing service** receives the alert reported by the Navigation Infrastructure Monitoring service and identifies that the red and blue drones are affected by it. The Operation Plan Processing service requests an update on the status of the operation plans of the red and blue drones. The red drone informs the service that it is no longer capable of maintaining RNP-high and has resorted to RNP-med for the time being. The Operation Plan Processing service recalculates a **new 4D trajectory for the red drone based on its the reduced navigation capability**.

Calculation of demand prediction

This process is **performed by the Dynamic Capacity Management service**. It receives the updated 4D trajectory of the red drone as well as other Operation Plan updates caused by DCB actions to resolve the imbalance.

The outcome of the process will be:

- **Prediction of the overall demand** – based on existing operation plans and the contingency-based 4D trajectory - associated to predefined volumes of the airspace.
- **Characterization of the demand** – The outcome will not be only the number of drone operations but also those characteristics which are relevant to understand the demand picture such as drone type (fixed wing, rotary), level of autonomy (from fully autonomous to human-controlled drones), type of operation (VLOS, EVLOS, BLOS), % of flights with high-priority missions and % of manned aviation operating in proximity.

Monitoring of risk-based and social indicators

This process is **performed by the Dynamic Capacity Management service**. The demand provided by the previous process will be used for the calculation and monitoring several indicators which will allow understanding the safety and social impact of the envisioned demand. The indicators will be calculated in pre-defined volumes of the airspace.

The monitorization of indicators will be done by comparing their value with certain safety and social thresholds for each pre-defined volume of airspace. This process identifies volumes of the airspace where acceptable safety and social thresholds are exceeded. The city councils or other representative entities will be able to set the admissible thresholds in each area.

Assessment of pre-defined DCB measures

This process is performed by **the Dynamic Capacity Management service**. First, it will assess whether the airspace requirements can be reduced to RNP-med to continue accommodating planned operations. If this is not possible, the capacity in the affected area must be reduced. As a consequence, drones that will enter this airspace will likely be subject to DCB measures such as rerouting or delays on ground. The assessment of adequate measures is up to the **Dynamic Capacity Management service.**

Drones that are already captured within the affected area (in this case the red and blue drone) might need to be rerouted in order to maintain safe separation due to the larger uncertainty area of the red drone. This process is performed by the **Tactical Conflict Resolution service.**

Prioritisation of Operation Plans

This process is performed by **the Dynamic Capacity Management service** in combination with the assessment of pre-defined DCB measures and will identify which drones to apply these measures on. Drones are selected regardless of their RNP capabilities, but rather based on their flight priority and "virtue" - Drone Operators with behaviour that increases the efficiency of the overall process, such as submitting the operational plan in due time and format, will be awarded with "virtue points".

The concerned operation plans will take part in a process that proposes changes to those with the least virtue until the problem is solved. The operations are examined to find those with higher impact on the airspace in question.

Towards the implementation

At this stage, as in the previous phases, two approaches are envisioned which are characterised by:

- Option A: Drone Operators will provide new Operation Plans complying with the re-routing. These Operation Plans will be verified by the Operation Plan Processing service and slight horizontal/vertical changes could be proposed by the Tactical Conflict Resolution service.
- Option B: The Operation Plan Processing service integrates the constraints from the Dynamic Capacity Management service and the Tactical Conflict Resolution service and proposes alternative Operation Plans to the Drone Operators.

5.2.6.1 Main flow of events

Step	Actor(s) Involved	Actor(s) Action	System Response
1	U-space Service Provider	**Navigation Infrastructure Monitoring service** sends an alert regarding the degradation of signal GNSS	The **Operation Plan Processing service** receives the alert reported by the Navigation Infrastructure Monitoring service and identifies that the red and blue drones are affected by it.
2	Operator U-Space Service Provider	**The red drone** informs the service that it is no longer capable of maintaining RNP-high and has resorted to RNP-med for the time being.	**The Operation Plan Processing service** recalculates a new 4D trajectory for the red drone based on its the reduced navigation capability.
3	U-Space Service Provider	**Operation Plan Processing service** sends update 4D trajectory to Dynamic Capacity Management service.	**Dynamic Capacity Management service** receives the updated 4D trajectory of the red drone as well as other Operation Plan updates caused by DCB actions to resolve the imbalance.
4	U-Space Service Provider	**Dynamic Capacity Management service** predicts the overall demand and the characteristics	-
5	U-Space Service Provider	**Dynamic Capacity Management service** will calculate and monitor several indicators which will allow understanding the safety and social impact of the envisioned demand in pre-defined volumes of the airspace by **comparing their value with certain safety and social thresholds**.	-

Step	Actor(s) Involved	Actor(s) Action	System Response
6	U-Space Service Provider	**Dynamic Capacity Management service** assesses whether the airspace requirements can be reduced to RNP-med to continue accommodating planned operations. If this is not possible, capacity will be reduced.	-
7	U-Space Service Providers	**Dynamic Capacity Management service** assesses adequate DCB measures such as rerouting or delays on ground.	-
8	U-Space Service Providers	**Tactical Conflict Resolution service** applies adequate measures such as rerouting. to drones already captured within the affected area.	-
9	U-Space Service Provider	**Dynamic Capacity Management service applies** DCB measures to drones regardless of their RNP capabilities, but rather based on their flight priority and "virtue".	-
At this stage, two approaches are envisioned which are characterised by:			
10a	Operators U-Space Service Provider	**Drone Operators** will provide new Operation Plans complying with the re-routing.	**Operation Plan Processing service** verifies the new Operation Plans. **Tactical Conflict Resolution service** could propose slight horizontal/vertical changes.
10b	Operators U-Space Service Providers	**Operation Plan Processing service** integrates the constraints from the **Dynamic Capacity Management service** and the **Tactical Conflict Resolution service** and proposes alternative Operation Plans to the Drone Operators.	

Table 7: OS #01 Main flow of events.

5.3 OS #02 - Drone emergency reported by the Emergency Management

5.3.1 Scope of the scenario

This operational scenario is focused on how a **drone emergency reported by the Emergency Management** service could affect the DCB process, and which actions might be performed to deal with, distinguishing between the situations in which a contingency plan exists and those cases in which the emergency is declared and it is so severe that no contingency plan exists. Thus, it is focused on tactical phase.

The main services involved in this DCB process are the Operational Plan Processing, the Strategic Conflict Resolution and the Dynamic Capacity Management. The DCB workflow information consist of (1) generation of 4D trajectories and contingency-based trajectories, (2) calculation of demand prediction, (3) monitoring of risk-based and social indicators, and (4) submission of alternative operation plans.

5.3.2 Assumptions

The following assumptions about the DCB workflow information apply to this operational scenario:

- DCB functionalities/services are established and accessible.
- The flow of information has little or no time latency between requesting and receiving information.
- Drone operators have an intuitive and friendly HMI connected to the U-space Service Providers, where they can receive any information such as alerts or proposal of changes for their flight plans.
- DCB measures are pre-defined and can be calculated within a reasonable time.
- CISP is responsible to provide the Tactical Conflict Resolution service. The detection and resolution of the conflicts are sent to the USSP.
- U-space autonomy and decision-making capabilities are also considered high, which will automatically plan (and replan) drone routes using path-planning to avoid conflicts among vehicles and adhere to clearances.
- The airspace is considered “open” for all drone operations which meet minimum operating requirements.
- Drones have the ability to request, receive and use geo-fencing data.

5.3.3 Pre-conditions

- All operations of flight vehicles are nominal.
- The meteorological conditions (forecast/observed as appropriate) are within the specified operational limits of the drones.

5.3.4 Trigger

The use case starts with a drone emergency, specifically when the Operation Plan Processing service receives the alert reported by the Emergency Management service.

5.3.5 Post-conditions

5.3.5.1 Success end-state

A success end-state is when:

- Drone re-routings are implemented in an efficient and safe manner.
- Drones avoid the area where the emergency has been declared.

5.3.5.2 Failed end-state

A failed end-state is when:

- Drone contingency plan has not been activated.
- Drone endangers other airspace users, persons or animals, airborne or on the ground.
- Drone causes damage to property or itself.

5.3.6 Scenario description

This scenario is divided in four steps:

Generation of 4D trajectories and contingency-based trajectories

As an example, the 4D trajectory will be calculated taking into consideration the starting point of the emergency and the dedicated landing area in case of an emergency of that specific drone operation. The process is similar to the one performed in the pre-tactical phase, i.e., uncertainties are considered as negligible.

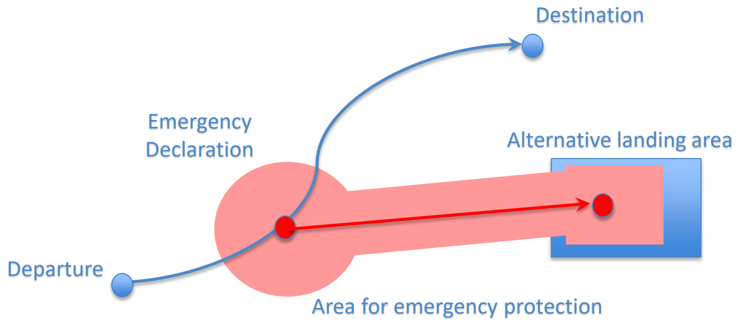


Figure 8: Visualization of the activation of an emergency with contingency plan to land in an alternative drone port.

If contingency plan cannot be implemented due to external circumstances, it is mandatory the declaration of a no-fly zone in the area impacted by the emergency. The following figure shows the visualization of a new flight airspace restriction and four airborne drones within this region exiting the restricted zone:

Figure 9: New flight airspace restriction and drones within this region exiting the restricted zone

Calculation of demand prediction

This process is performed by the Dynamic Capacity Management service. The outcome is the update of the following information:

- Prediction of the overall demand – based on existing operation plans and the contingency-based 4D trajectory - associated to predefined volumes of the airspace.
- Characterization of the demand – the outcome will not be only the number of drone operations but also those characteristics which are relevant to understand the demand picture such as drone type (fixed wing, rotary), level of autonomy (from fully autonomous to human-controlled drones), type of operation (VLOS, EVLOS, BLOS), % of flights with high-priority missions and % of manned aviation operating in proximity.

Monitoring of risk-based and social indicators

This process is performed by the Dynamic Capacity Management service. The monitoring of indicators will be done by comparing their value with certain safety and social thresholds for each pre-defined volume of airspace.

The city councils or other representative entities will be able to set the admissible thresholds in each area. **Different thresholds can be declared in an area where an emergency is in place**. This implies that airspace volumes with an active emergency could see their capacity reduced.

Submission of alternative operation plans

This step is composed of the assessment of pre-defined DCB measures, the prioritizations of Operation Plans through the awarded with "virtue points", and the implementation.

5.3.6.1 Main flow of events

For workflow information, the flow of events follows the trigger events described above. This section outlines the proposed content of the information contained in the information flow.

Step	Actor(s) Involved	Actor(s) Action	System Response
1	U-space Service Provider	The Operation Plan Processing service receives the alert reported by the Emergency Management service and acknowledges the initiation of the contingency plan.	The Operation Plan Processing service **recalculates the new 4D trajectory based on the description of the contingency plan** which was part of the approved operation plan.
1 bis	U-space Service Provider	If contingency plan cannot be implemented, Geo-fence Provision service declares a no-fly zone in the area impacted by the emergency and facilitates ad-hoc geo-fence changes to be sent to drones immediately.	Affected Operation Plans are updated taking into consideration this new constraint.
2	Drone Operators	Other drone operations in the surrounding should avoid the area for emergency protection.	
3	U-space Service Provider	Dynamic Capacity Management service receives the contingency-based 4D trajectory from the Operation Plan Preparation service or the newly activated no-fly zone. The rest of the operations plans, including those affected by the emergency area around the contingency-based trajectory or by the no-fly zone, are received in the form of 4D trajectories in a continuous process.	**Calculation of demand prediction:** prediction of the overall demand and characterization of the demand
4	U-space Service Provider	DCM service calculates (in pre-defined volumes of the airspace) and monitors of several indicators which will allow understanding the safety and social impact of the envisioned demand.	**Monitoring of risk-based and social indicators**: identification of volumes of the airspace where acceptable safety thresholds are exceeded.
5	U-space Service Provider	DCM service assesses if the previously identified safety and social hotspots could be solved through some of the pre-defined DCB measures. As most of the drones are already flying, the most probable DCB measure to be applied in	Assessment of pre-defined DCB measures. A prioritization process will be launched.

Step	Actor(s) Involved	Actor(s) Action	System Response
		this phase is the re-routing away from the affected volumes of the airspace. Delays on ground is the other measure that can be implemented for those flights whose operations cannot take place due to the new restrictions.	
6	U-space Service Provider	Drone Operators with behaviour that increases the efficiency of the overall process, such as submitting the operation plan in due time and format, will be awarded with “virtue points”.	DCM service proposes changes to the operation plans of the Drone Operators with the least virtue points until the problem is solved. The operations are examined to find those with higher impact on safety and social indicators, hence whose removal would cause the largest overall reduction in risk or social impact.
At this stage, two approaches are envisioned which are characterised by:			
7.a	Drone Operators	Option A: Drone Operators provide new operation plans complying with the re-routing.	Operation Plan Processing service verifies the new operations plans. Slight horizontal/vertical changes to solve potential encounters should be solved by the Strategic Conflict Resolution service[2].
7.b	U-space Service Provider	Option B: The Operation Plan Processing service integrates the constraints from the Dynamic Capacity Management service and the Strategic Conflict Resolution service[2].	Operation Plan Preparation service confirms acceptance of the operation plans and proposals.

[2] Further discussion about which service should address this function is needed.

Step	Actor(s) Involved	Actor(s) Action	System Response
		Operation Plan Processing service proposes alternative operation plans to the Drone Operators.	

Table 8: OS #02 Main flow of events.

5.4 OS #03 - DCB workflow information under nominal conditions

5.4.1 Scope of the scenario

This operational scenario focuses on DCB workflow under nominal conditions i.e., no anomalous conditions such as emergencies, adverse weather or prioritized delivery are included. It describes the information flow between services and functions under nominal conditions for the strategic phase.

This operational scenario considers drone delivery services in an urban environment. The drone deliveries can include both packages and food. The delivery region is made up of a combination of urban and nearby suburban areas. Package delivery is assumed to originate in one or more distribution centres and the delivery schedule is well known in advance of the operation. Food delivery, however, is assumed to have a much shorter planning time, since typically food orders would be received and processed in a very short time period prior to being delivered to the consumer location.

A commercial company A provides food deliveries using semi-autonomous vehicles. The food delivery company receives a food order which should be delivered in 45 minutes. Its planning software makes an estimation for the preparation of the package of around 30 minutes. Company A has a contract with one of the U-space service providers in the area, USSP1, which facilitates the access to the U-space airspace by managing Operation Plans authorisations.

The pre-tactical phase in the area starts in a frozen time horizon which is 10 minutes[3] before the execution. Then, the pre-tactical phase has not yet started at the time of requesting the authorisation of the new food delivery.

High density of operations in western area of the downtown is expected at the foreseen time of execution. The distribution of the collision risk and social impact in the area is visualized by all USSPs through the Aeronautical Information Management service. DCB measures should be implemented when *Reasonable Time to Act* (RTTA) will be reached i.e., 10 minutes before the execution. However,

[3] Note that the starting time of the pre-tactical phase is under discussion in DACUS. It should be a time before the execution in which the demand is stable enough to be able to implement effective DCB measures.

foreseen measures can be visualized prior to the implementation through the Aeronautical Information Management service.

The U-space services involved and DCB workflow information for the strategic phase is described according to the Figure 3.

5.4.2 Assumptions

The most relevant assumptions for the flow of DCB information are presented in the following list:

- Protocols for the flow of information are established and accessible;
- The flow of information has little or no time latency between requesting and receiving information;
- Reactive latency, to respond to information or a situation whether it is a human or decision support response, is negligible. Certainly, the time to react is relevant for safety, risk, conformance monitoring, etc. however this is not the focus of the scenario;
- The review of the types and domains of available information, or information that should be available, is not the focus of this scenario;
- The architecture and platform performing the flow of information exists and can handle the flow and magnitude of information;
- All services identified in U-space U1 and other specific U2 and U3 services which are part of the DCB process -see Figure 3 -, are available. This includes real-time distribution of information to drone operators as geofence changes, collision risk and social impact evolution or existing airspace situation;
- Those U-space services that imply to take decisions based on overall demand or capacity figures and affecting to operation plans of diverse USSPs are provided by a unique entity in the airspace. In particular, we are assuming that Dynamic Capacity Management service and Strategic Conflict Resolution[4] will be provided by the CISP;
- DCB measures are pre-defined and can be calculated within a reasonable time, however the DCB measures are defined elsewhere within the DACUS project therefore not specifically identified here for purposes of this scenario.

[4] Although Strategic Conflict Resolution service could be easily de-centralized and provided by each USSP, for the sake of simplicity, we are assuming that it is also provided by the CISP as one of the services involved in the process of operation plan's approval.

5.4.3 Pre-conditions

- U-space Authority:
    - Provides centralized registries about UAVs, drone owners, drone operators, drone pilots, U-space authorized service providers;
    - Provides specific centralized registries that will depend on the agreed Spanish operating methods (e.g. list of authorized landing pads in urban areas).
- CISP:
    - Has direct access to all registry information managed by the U-space Authority.
    - Manages centralized drone aeronautical information databases (including geographical information) for drone operations;
    - Provides the status of the collision risk and social impact distribution in the city according to the existing demand as part of the Aeronautical Information Management service;
    - Provides the foreseen DCB measures to be implemented when starting the pre-tactical phase;
    - It is responsible of the interface with ATC:
    - Provides the unique dynamic capacity management and strategic conflict resolution service in the city;
    - Approves operation plans' requests electronically.
- Drone delivery company A:
    - Provides food delivery services with drones for customers;
    - Operates within or near the city's urban boundaries;
    - Has a contract with USSP1 to be able to access U-space airspace;
    - Defines its *mission goal* based on requests by the End Customer and in line with the topical conditions and regulations.
    - Has a defined origination point, for example a distribution centre or restaurant/supermarket location;
    - Has a valid operating license registered by the U-space Authority as an Operator;
    - Has vehicles that are capable of fulfilling the mission goal and are available at the time the service is requested.

- USSP1:
    - Has a valid U-space service provision license for the provision of services within the city boundary and its immediate surroundings;
    - Provides select U2 and U3 services to its customers;
    - Has direct connection to CISP;
    - Can calculate tentative operation plans based on the mission plan requirements completed by the Drone Operator and the registry information provided by the Authority (drone, drone operator and drone pilot databases);
    - Has information about the capabilities, equipment, optimal operating method and specific emergency procedures of all of the drones of the Drone Operator;
    - Provides optimized operation plans in matter of seconds for any given mission within its area of effect;
    - Is connected to other supplementary services provided by other USSPs such as weather service;
    - Has all the relevant Aeronautical Information updated, including the collision risk and social impact distribution, and the foreseen DCB measures which could be implemented in the tactical phase.
- End-customer:
    - End-users have basic understanding, acceptance, and expectation of drone delivery services in terms of safety, risk, delays, receiving goods, theft, etc.
    - End-users have a protocol to request and pay for goods and accept the delivery terms and conditions.

5.4.4 Triggers

The operational scenario starts when the End-Customer makes an order for food delivery with the APP of Company A, and it is waiting for the acceptance of the order. The planning software of the company A sends to USSP1 its *mission goal* based on the food delivery requested by the End-Customer. Mission requirements include the need of departing in 30 minutes.

5.4.5 Post-conditions

5.4.5.1 Success end-state

A success end-state is when:

- End-user receives confirmation of acceptance of his food delivery request and the expected delivery time.

5.4.5.2 Failed end-state

A failed end-state is:

- End-user receives an alert from Company A informing that its request cannot be satisfied.

5.4.6 Scenario description

5.4.6.1 Main flow of events

For workflow information, the flow of events follows the trigger events described above. This section outlines the proposed content of the information contained in the information flow.

Step	Actor(s) Involved	Actor(s) Action	System Response
0	End-Customer Company A	End-Customer makes a request for food delivery to Company A to be delivered to a given address/location. Company A makes an estimation of the time to prepare the food to determine the departure time of the drone. Its planning software performs an internal process to select the vehicle in its fleet in order to carry the mission taking into account departure time, weight of the package, etc.	Company A assimilates delivery requests based on their operating procedures and fleet, and forward them in the form of mission requirements to the USSP1.
1	USSP1 CISP	Mission requirements are received by the Operation Plan Preparation service of USSP1 which details an Operation Plans fulfilling those requirements. Two operation plans[5], from the distribution centre to the end-user location and return to base, are sent to the CISP for validation and approval. Operation plans' uncertainties, and contingency plans are part of the information included in the operation plans. The risk of the operations is also quantified by taking into consideration the population density.	USSP1 assimilates mission requirements based on the aeronautical, geospatial and weather information, and forward the information in the form of operations plans to the CISP.

[5] Other internal processes such as the coordination with the base operators at origin and destination are not described in this scenario for the sake of simplicity. They can be found in Scenario 4.

Step	Actor(s) Involved	Actor(s) Action	System Response
2	CISP	CISP acknowledges the reception of the operation plans and check consistency with registry information and aeronautical and geospatial information. CISP launches two internal processes: the assessment of pair-wise collision risk and the assessment of overall remaining risk in the airspace.	CISP activates the strategic conflict resolution service and the dynamic capacity management service.
3	CISP	Strategic conflict resolution service identifies two potential conflicts with pre-existing operation plans, one in the suburban area and other in the western area of the downtown. The service checks for slight changes in the horizontal and vertical profile to solve these two conflicts. Different alternative are found for the conflict in the suburban area. However, the alternatives to solve the conflict in the western area are very limited as possible alternatives are generating new conflicts with other operation plans.	Strategic Conflict Resolution service informs Dynamic Capacity Management service about the difficulties to find alternatives to resolve conflicts in the western area.
4	CISP	Dynamic Conflict Resolution service is monitoring the potential hot-spot in the western area due to the high collision risk associated to the foreseen demand. It receives the alert from the Strategic Conflict Resolution service and activates an advisory about the potential implementation of one of the pre-defined DCB measures in the western area, the organization of flows per layers	CISP sends advisories to the USSPs about the potential organization of flows per layers in the western area.
5	USSP1	USSP1 checks how its operation plans are affected by the DCB measure. In particular, it checks that the two operation plans of Company A should fly on specific flight levels if the DCB measure is implemented. Flight levels are not rigid mission requirements for Company A as they are interested in flying the shortest distance at maximum speed.	

Step	Actor(s) Involved	Actor(s) Action	System Response
6	USSP1 CISP	USSP1 refines the operation plans maintaining the trajectory over the western area but flying at a flight level which is fulfilling the pre-designed DCB measure. USSP1 sends the new Operation Plans which are approved by the CISP.	
7	USSP1 Company A	Operation plan preparation service has fully defined the operations plans in line with mission requirements.	USSP1 passes this result to the Company A planning software.
8	Company A End-Customer	Company A does a final validation of the mission and sends confirmation to the End-Customer.	Company A sends the relevant details to the client app.

Table 9: OS #03 Main flow of events.

5.5 OS #04 – Weather impacting vertiports capacity

5.5.1 Scope of the scenario

A commercial company provides an air transportation service for passengers using semi-autonomous vehicles, able to carry up to 4 persons with no pilot on-board. The possible routes span inside an urban and sub-urban environment, connecting the nodes of a vertiport network.

The vertiports are situated in locations that naturally attract a high demand for quick, safe and uncomplicated travel: airports, intermodal hubs, city centres, public and governmental facilities and mercantile clusters.

The use case demonstrates the interaction between the drone operator, the responsible pilot-in-command, the USSPs and CISP and the base operators (aka take-off and landing site management). Furthermore, a U-space service provider enables flight planning, processing of hyperlocal weather information, risk assessment and contingency management.

The envisioned operational scenario is expected to take place between 2025 and 2030, either in a model like sand box environment or as part of the regular development of urban air mobility in greater Europe. Advanced U-space services (U3) allow for dynamic capacity management, tactical conflict resolution and provide the collaborative interfaces with ATC that enable regular operation close to or inside of traditional airspaces.

The objective of this use-case is to show how DCB processes will benefit from additional services that anticipate off-nominal conditions in the traffic system, such as non-ideal weather, availability of landing sites (final destination and contingency) and/or high-density operations.

In the case of drones used for human transport, a secondary objective of predicting off-nominal conditions in order to avoid them is to increase the comfort and perceived safeness. Avoiding turbulence and varying high winds, even areas that would not pose any real danger, could accelerate public acceptance and the early adoption of these technologies.

The operational scenario introduces a sudden change in the predicted weather. This is not to say that such a change is necessary for the weather prediction to have an impact on the DCB processes, and it is simply a resource to highlight some of these processes.

The scenario describes a situation in the strategic phase, in the sense that it happens before RTTA i.e. time wise starts 30 minutes before take-off and pre-tactical phase is assumed to start 10 minutes before the execution. Weather predictions should be mostly settled by this time.

5.5.2 Actors involved

In addition to the actors mentioned in section 5.1, the following actors are also involved in the operational scenario #04:

- **U-space Service Provider 1:** This is an implementation of the Operation Plan Preparation Service. USSP 1 provides assistance for mission planning and flight authorizations as well as additional DTM supporting services to ensure a safe, efficient and secure conduct of drone operations. These supporting services include the risk assessment as well as the planning of contingency management. It also includes a module for the computation of efficient operation plans given two ending points, vehicle characteristics and mission parameters.
- **U-space Service Provider 2:** USSP 2 provides hyperlocal weather data for the strategic & pre-tactical phases with an accuracy of about 2 x 2 meters to be utilized by the flight planning USSP 1.

5.5.3 Assumptions

The most relevant assumptions for drone operations within the timeframe 2025-2030 are included in the following list:

- PAVs and UAVs are operating in Beyond Visual Line of Site (BVLOS).
- Although PAVs are required to have collaborative detect & avoid systems on-board, the BVLOS flights rely heavily on the operational plan created prior to the execution of the mission, including detailed flight management procedures, for both nominal and off-nominal circumstances.
- All services identified in U-space U1 and other specific U2 and U3 services which are part of the DCB process -see Figure 3 -, are available, with real-time distribution of information to drone operators and/or drone pilots including traffic advisories, geofence change advisories

and emergency alerts. In particular, the Collaborative Interface with ATC service is available and it is used when the vertiports are inside / in the vicinity of airports, or when the PAVs are operating in controlled airspace.

- Those U-space services that imply to take decisions based on overall demand or capacity figures and affecting to operation plans of diverse USSPs are provided by a unique entity in the airspace. In particular, we are assuming that Dynamic Capacity Management service and Strategic Conflict Resolution[6] will be provided by the CISP.
- The uncertainty associated to the initial operation plan varies from low to medium. It is assumed that primarily a pre-defined route network is established by the taxi operator to make its operations simpler and more predictable, even while traversing free route airspace. This will lead to low uncertainties during the execution of the operations in general. However, it will be also assumed that some users are able to request unscheduled flights, leading to requests sent at short notice and therefore a medium uncertainty.
- The scenario focuses on 30 minutes prior to take-off and mostly on the steps and interactions that are impacted by weather information.

5.5.4 Pre-conditions

- Drone Operator:
  - Provides an air transportation service for private customers.
  - Has a local operation centre which serves a hub and maintenance platform.
  - Defines its *mission goal* based on agreements with the End Customer and in line with the topical conditions and regulations.
  - Has a valid operating license registered by the Authority as an Operator.
  - Has a vehicle that is capable of fulfilling the mission goal and is available at the time the service is requested.
- End User:
  - Private customers.
  - Requesting ad-hoc or pre-planned air transportation from A to B.

[6] Although Strategic Conflict Resolution service could be easily de-centralized and provided by each USSP, for the sake of simplicity, we are assuming that it is also provided by the CISP as one of the services involved in the process of operation plan's approval.

  - Expects a safe and timely carriage.
  - Uses a mobile app to order, negotiate and purchase the flight.
- Personal Air Vehicles:
  - Multirotor Aircraft.
  - Up to four passengers capacity.
  - Semi-autonomous: abnormal situations need human interventions as well as safety critical decisions need to be confirmed.
  - Specifications and limitations are well known and available in U-space information systems.
  - Vehicles need to be available at the starting point 30 minutes after the order has been placed by the customer.
- Base Operator:
  - Owns / manages network or single take-off and landing areas.
  - Provides Information on availability of those areas at request.
  - Has direct connection to USSP 1 and USSP 2.
- U-space Authority:
  - Provides centralized registries about UAVs, drone owners, drone operators, drone pilots, U-space authorized service providers.
  - Provides specific registries that will depend on the agreed Spanish operating methods (e.g. list of authorized landing pads in urban areas).
- Common Information Service Provider:
  - Has direct access to all registry information managed by the Authority.
  - Manages centralized drone aeronautical information databases (including geographical information) for drone operations.
  - Provides the status of the collision risk and social impact distribution in the city according to the existing demand as part of the Aeronautical Information Management service.
  - Manages operation plan receptions and approvals electronically.
  - Manages services related to geo-awareness and tactical geofencing as a mechanism to define geo-cages.

  - It is responsible of the interface with ATC.
  - During the execution of the flight, captures position reports submitted by the USSPs to monitor geo-cages and manage unexpected events during the execution of flight that might impact ATS provision.
  - Provides the foreseen DCB measures to be implemented when starting the pre-tactical phase.
  - Provides the unique dynamic capacity management and strategic conflict resolution service in the area.
- USSP 1:
  - Has a valid U-space service provision license for the provision of services within the city boundary and its immediate surroundings.
  - Provides select U2 services to its customers.
  - Has direct connection to CISP.
  - Can calculate tentative operation plans based on the mission plan requirements completed by the Drone Operator and the registry information provided by the Authority (drone, drone operator and drone pilot databases).
  - Has information about the capabilities, equipment, optimal operating method and specific emergency procedures of all of the drones of the Drone Operator.
  - Provides optimized operation plans in matter of seconds for any given mission within its area of effect.
  - Is connected to the hyperlocal weather service.
  - Has all the relevant Aeronautical Information updated.
  - Receives any regulation or information published by the U-space Authority that can impact drone operations and uses them to compute the trajectories requested.
- USSP 2:
  - Has a valid U-space service provision license for the provision of supportive services within the concerned operating area.
  - Provides sophisticated, hyperlocal weather information to its customers e.g. other USSPs, Ecosystem Management, Base Operators or private customers.
  - Information includes post-processed observation and prediction of local conditions relevant for safe flights in the VLL airspace.

5.5.5 Trigger

The trigger of the scenario was selected before the actual events that affect the DCB process to provide context which helps understand the scenario.

The operational scenario starts when the end customer requests the transportation service via the mobile app provided by the operator. This can either be planned in advance e.g., as a connecting flight after landing on a regional airport, or ad-hoc, which means the time between order and take-off is less than 30 minutes.

As this scenario involves weather information distribution, some of its steps are triggered by a new update to the weather predictions being published by the weather service. The distribution of weather information is asynchronous with the rest of the flow of events so the actions they trigger might happen at many different moments.

5.5.6 Post-conditions

5.5.6.1 Success end-state

The operational scenario is considered a success when the following conditions apply:

- Efficient and safe conduction of the mission.
- Transport of the passengers from point A to point B.
- Possible contingencies have been handled as predetermined.
- Re-routing, even not leading to destination B, is considered as inevitable if it leads to the following prioritized goals:
  - Risk levels throughout the flight within tolerable limits.
  - Perceived comfort and safety are within acceptable margins.
  - No other airspace users or persons on the ground have been endangered.
  - The air vehicle has not caused damage to property, itself or passengers onboard.
- Successful return of vehicle to its hub and availability for the preparation of the next operation.
- The CISP has kept track of all relevant events for safety, flow & DCB porpoises, making sure all relevant information in the system was properly updated and distributed.
- In case of requiring adaptation to changes, such as a change in weather prediction, involved actors have been given the chance to adapt to them as early as possible.
- Relevant information (tracking, pilot, drone operator, etc.) of the mission is properly recorded for any future legal purpose.

5.5.6.2 Failed end-state

The operational scenario is considered failed when one or more of the following scenarios apply:

- Aerial vehicle unable to reach mission goal or abort of operation.
- Drone endangers other airspace users, persons or animals, airborne or on the ground.
- Drone causes damage to property, itself or the passengers onboard.
- Drone contingency provisions fail.
- Perceived comfort and safety are insufficient.
- Risk levels exceed given limits.
- Relevant information was not properly recorded.
- Unfair decisions were made to accommodate changes, and actors were not given the option to participate in the decision-making process as much as possible.

5.5.7 Scenario description

The next scenario starts with a user requesting a taxi service through an app, indicating at least number of people, desired take-off and landing spots and desired take-off time.

5.5.7.1 Main flow of events

Step	Actor(s) Involved	Actor(s) Action	System Response (optional)
1	End User Operator	Client requests service through mobile app.	
2	Operator End User	Operator does quick estimation based on Machine Learning Model	Offer is sent to the End User which agrees.
3	Operator USSP1	Now there is an internal process at the operator systems: Selecting the vehicle in its fleet that will carry the mission taking into account user preference, number of passengers, schedule & plan of each tail in the fleet, etc. The Human to monitor the operation and the emergency pilot (could be the same person of different ones	

Step	Actor(s) Involved	Actor(s) Action	System Response (optional)
		depending on fleet size and business model) are also pre-allocated internally. Operator asks Operation Plan Preparation service to plan the first leg (empty cab to closest possible take-off spot to user preference).	
4	USSP 1 Base Operator	Operation Plan Preparation service requests for the expected status of the requested landing spot for pickup and alternative landing spots that are close. It sends the type of vehicle and mission, including details such as the cab being empty during the landing.	
5	Base Operator USSP 2	Base operator uses the latest information coming from the micro-weather service subscription with USSP2. In particular it uses the predictions about high wind areas and high turbulence intensity areas around the different vertiports. It uses its own internal modelling to assign the maximum rate of movements to each of them for each operation type. Some of them might be even close due to weather conditions. The Base operator keeps on monitoring all variables to set the planned capacity of the vertiport accordingly and allocate requests.	Base operator informs to USSP1 that the requested vertiport is expected to be close due to weather and provide three alternatives in the area.
6	USSP 1 Base Operator	Operation Plan Preparation service selects one vertiport and now has all details to calculate the first leg of the service.	Return selection to Base operator.
7	USSP 1 USSP 2 Base Operator	Operation Plan Preparation service takes into account weather information coming from its subscriptions to USSP2 service to calculate the optimal trajectory. As the vehicle is empty in this leg, it is instructed to not avoid turbulence and varying lateral wind areas due to comfort reasons. Operation Plan Preparation service uses an internal contingency planning tool to add	Operation plan preparation service has fully defined the first leg of the mission.

Step	Actor(s) Involved	Actor(s) Action	System Response (optional)
		contingency information to the Operation Plan. One of the things to add is the emergency landing spots for each segment of the Operation Plan with information provided by the Base Operator.	
8	Operator USSP 1	The operator now knows the take-off spot for the second leg of the mission (with passengers) and with all parameters asks the Operation Plan Preparation service to generate it.	
9	USSP 1 Base Operator	Operation Plan Preparation service requests for the expected status of the requested landing spot for destination of the passengers and alternative landing spots. It specifies that humans are inside the vehicle.	
10	Base Operator USSP2	Base operator informs that the requested vertiport is expected to be operative and have no turbulence nor high winds above it thanks to the weather subscription to USSP2.	USSP1 Operation Plan Preparation service has now all the information needed to compute the second leg.
11	USSP 1 USSP 2 Base Operator	Operation Plan Preparation service takes into account weather information coming from its subscriptions to calculate the optimal trajectory. As the vehicle is not empty in this leg, it is instructed to avoid turbulence and varying lateral wind areas due to comfort reasons. Operation Plan Preparation service uses an internal contingency planning tool to add contingency information to the Operation Plan. One of the things to add is the emergency landing spots for each segment of the Operation Plan with information provided by the Base Operator.	Operation plan preparation service has fully defined the second leg of the mission.
12	USSP1	USSP1 files the two operation plans, adding some time uncertainty based on Machine	Operation Plans including uncertainty and contingency plans are sent to the CISP.

Step	Actor(s) Involved	Actor(s) Action	System Response (optional)
		Learning and past data (in the order of single digit minutes).	
13	CISP	CISP receives the Operation Plans and check for validity of information and against existing restrictions through the Strategic Conflict Resolution and the Dynamic Capacity Management services.	
14	CISP USSP1	Dynamic Capacity Management service is quantifying low collision risk and social impact in the area where the PAV is operating. Strategic Conflict Resolution identifies a potential conflict with the Operation Plan of a small drone doing a package delivery.	A proposal for a slight horizontal change in the second Operation Plan is sent to the USSP1.
15	USSP1 Operator	USSP1 acknowledges the proposal and check the validity against operator' mission requirements. The proposal is accepted and the results are sent to the operator planning software.	
16	Operator End User	The operator does a final validation of the mission and sends the relevant details to the client app, giving the user a cancellation dead-line (with only a partial cost).	

Table 10. OS#04 Main flow of events

6 Validation Experiments

6.1 Validation Experiment #01 Plan

6.1.1 Description and scope

The initial scope of Validation Experiment #01 will focus on the strategic and pre-tactical phases, with the main focus being on the pre-tactical application of the DCB services related to the management of noise and social impact due to Drone operations in urban environments. Prediction and analysis methods will be slightly different in each phase.

At the strategic level, predictions will be based on estimated capacity and the potential numbers of Drone operations in various cells – this would be used to estimate when and where hotspots may occur but not based on trajectory information.

In the Pre-Tactical phase, initial trajectories will be included by the prediction model to generate more realistic demand profiles. In particular, the analysis will consider how these services may perform at different time steps ahead of the proposed operations, and with the reliability or uncertainty of the information used to support demand prediction at different stages of the DCM process.

The main objective of this experiment is to test the feasibility and the reliability of the use of noise and visual impact metrics for the DCM service. This objective is subdivided into two experimental objectives. Objective EXP1-OBJ1 is to determine if the noise and visual impact of drone operations metrics are able to detect hotspots. In this context, objective EXP1-OBJ2 is to assess the reliability of this detection, regarding timeframe length and portion of airspace size. Another objective is to measure the effectiveness of DCB measures to reduce the noise and visual impact. Moreover, objective EXP1-OBJ3 is to identify which of the DCB measures are more effective from the perspective of this reduction. The selection of these measures are also consider in the effectiveness study.

Regarding the scope of the experiment, it will use the capacity and demand prediction model at the strategic phase to predict hotspots, based on the social impact measures (noise and visual impacts). This prediction will feed the contingency scenarios used in the pre-tactical phase to take early DCB measures in order to avoid hotspots. The DCM service, during pre-tactical phase, will calculate hotspots each time a new operation plan is submitted. When a new operation plan raise one or more hotspots, a DCB measure is taken to remove the hotspots. For cells (areas) where hotspots has been predicted during strategic phase, those DCB measures will be taken before the hotspot appearance, referring to a threshold on the social impact.

6.1.2 Validation Objectives

Validation Objective Id	EXP1-OBJ1
Description	Assess the feasibility of using **metrics related to the noise and visual impact of drone operations** to determine the urban areas in which the demand should be limited, i.e. metrics for the identification of social impact hot-spots.
Success Criteria 1	Proposed metrics (parameters selected) allow the identification of (localisation and measures) hot-spots based on the 4D trajectories, where the identification of any one hot-spot encompasses: • It's localisation. It's duration, and • A measure of the impact.

Validation Objective Id	EXP1-OBJ2 [7]
Description	Assess the **consistency of the process to identify social impact hot-spots and risk-related hot-spots** in terms of consistent timeframes and portions of airspace.
Success Criteria 1	The size of cells for noise and visual impact allows us to propose DCB measures with regards to the hot-spots identified.
Success Criteria 2	Cadence of measurements is relevant to capture all the hot-spots (e.g., every minute, every 5 minutes).

Validation Objective Id	EXP1-OBJ3
Description	Identify those **DCB measures which are more effective from the perspective of the reduction of noise and visual impact** of drone operations, i.e. assess the applicability of DCB measures for the resolution of social impact hot-spots.
Success Criteria 1	Application of different DCB measures (e.g., drone flight height, change of trajectory reduces the number of hot-spots or moves them.
Success Criteria 2	To be able to propose a ranking in the DCB measures efficiency. At long term, the chosen DCB measure always reduce the number of hotspots.

[7] This objective will be addressed by Validation Experiments #01 and #02: EXP1-OBJ2 will address the social impact hot-spots, and the EXP2-OBJ6 will address the risk-related hot-spots.

6.1.3 Validation Scenarios

For this experiment, a single operating environment will be chosen which will be the Toulouse metropole region. This environment scenario has been determined to specifically analyse noise and visual impacts from the social aspect.

From this scenario, two levels of Drone mission demands will be considered:

- Nominal traffic load.
- High traffic load.

Traffic will include all types of RPAS vehicle including a variety of rotorcraft and fixed wing aircraft with varying size, performance and equipage. The scenario is limited however to the subset of mission types proposed earlier in this section.

For each of the projected traffic demand levels, scenarios in both optimal and sub-optimal conditions will be considered.

This will result in a set of four distinct analysis scenarios.

6.1.3.1 Scenario #1

As indicated previously, the chosen region will be the Toulouse, metropole region.

The scenario includes two types of traffic samples as described below:

- Nominal traffic load – defined as the predicted daily traffic taking into account the various demand predictions for different types of Drone service (e.g. medical, package delivery, food delivery, other types of delivery mission). Under these levels of traffic load some hotspots are expected, in particular during the busier periods of the day (e.g. when many food orders are made) and in certain parts of the city. However, the frequency, severity and duration of these hotspots are still expected to be low.
- High traffic load - the levels of traffic will be increased compared to the nominal scenario to produce periods where the demand is significantly higher that the predicted capacity in order to support the evaluation of how severe hotspots with potentially long durations can be addressed using the available noise and social impact services.

In addition, two types of operating condition will be assessed:

- Nominal operation scenarios assume that all of the available airspace is open for operations, that weather conditions are favourable and that no other event or situation will be encountered that might affect the levels of service available to support the proposed Drone missions.

- Sun-nominal including will include constraints or events that may result in a reduction in the levels of service such as:
  - Bad weather conditions in some parts of the region.
  - Degraded CNS performance requiring a reduction in the number of operating vehicles in a given part or parts of the regions.
  - Social or sporting events which may result in reduced access to parts of the airspace of prohibited areas for Drone missions.
  - Unanticipated emergency events (e.g. a police, fire or security related issue).

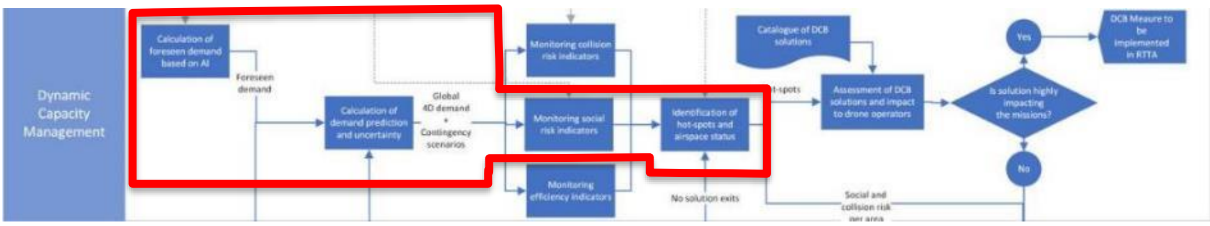
6.1.4 Description of the architecture

In this version of the document, the architecture and platform that will be used to support the scenarios are still being reviewed and have not been decided/developed.

The workflow diagrams are shown below along with a short description of the models/functions we may use in the experiments for strategic and for pre-tactical scenarios.

The DCM service for the strategic phase consists of (1) the prediction/creation of traffic demand forecasts, (2) use of this demand forecast to assess DCB indicators for risk and efficiency hot-spots, and (3) reporting hot-spot forecasted situations such that either additional capacity could be planned or the demand can be adjusted such that DCB hotspot measures are reduced.

The Validation Experiment #01 will be focused on the red box for the strategic phase:



This box is composed of the capacity/demand predictor, the social impact model and the hotspots identifier. The capacity/demand predictor will provide capacity prediction of every cell, every minute, to the social impact model. From these previsions, social impact model can compute social impact measures (noise and visual impacts). Finally, the hotspot identifier save the predicted hotspots to be used during pre-tactical phase.

The DCM service for the pre-tactical phase is mostly the same as the strategic phase.

The Validation Experiment #01 will be focused on the green box for the pre-tactical phase:

This box is composed of the 4D trajectory calculator, the social impact model, the hotspots identifier and the DCB measure selector. During pre-tactical phase, real world flight plans start to be submitted. The 4D trajectory calculator will compute the trajectory based on these plans. Then, the hotspots identifier trigger the DCB measure selector if at least one hotspot is identified from the social impact model. The DCB measure selector will simulate DCB measures on one or more flight and verify that it avoid hotspot. If all hotspots are avoided, the DCM service can finally propose the measure to the drone operator. In the case where a hotspot has been predicted during strategic phase, the DCB measure selector can have an early trigger, in order to have time to take decision, find the best measure and smoother traffic flow.

6.1.5 Validation Assumptions & Limitations

In the current planning for the proposed experiments, the following assumptions have been made:

- Mission types will be limited to those supporting deliveries.
- Some other types of mission (e.g. inspection or aerial photography) may be included, but these will not usually be included in the DCB services related to noise and social impact due to their limited operational zone and short operating times.
- Modelling of sub-nominal operating conditions will be captured through abstracted models (e.g. the definition of zones/areas where restriction apply to proposed operations) – no specific modelling of such operations is planned (i.e. a police/fire/medical/security issue will be represented by a region with restricted or no access, but the detail of those missions will not form a part of the scenario).
- Suitable noise models are available or can be adapted for each of the vehicle types used in the scenarios.
- Access to population information is available to support the noise/social impact services. A possible limitation is that the data that will be used is a statistical estimation coming from the local telecoms network but is not empirical counts.
- An acceptable measure / definition of 'visual impacts' has been agreed by the team.

6.1.6 Choice of experiment's metrics

An initial set of metrics for both the strategic and pre-tactical phases will include[8]:

- Number, location and distribution of hotspots for each type of metric (noise, visual) and the relationship between the occurrence of hotspots for different levels of traffic load.
- Hotspot severity and duration of those hotspots.
- Noise distribution/contours and exposure on population/wildlife [SOC1, SOC2, SOC3, SOC4…].
- Visual impact exposure on population/wildlife [SOC5, SOC6, SOC7, SOC8…].
- Sliding Demand/Occupancy counts for a user specified time period and slider
- Number and type of impacted operations (including average, maximum per specific time period and zone) [EFF1, EFF2, EFF3, EFF4…].
- Additional impacts resulting from sub-nominal or unanticipated reduction in available services.

Other metrics are currently being considered and will be included in this section at a later date.

6.2 Validation Experiment #02 Plan

6.2.1 Description and scope

The focus of Validation Experiment #02 lies on the pre-tactical phase. The nominal processes of flight plan processing, contingency planning and the resulting demand and uncertainty predictions are validated. Furthermore, the influence of the demand and uncertainty predictions on the collision risk and efficiency is tested. Lastly the feedback loop of additional information like collision risk and efficiency indicators into the flight plan processing is tested.

This is done through 5 validation objectives (EXP2_OBJX). EXP2-OBJ2 is to identify the influence of uncertainty in the planning phase on the demand and capacity modelling. EXP2-OBJ1 is similarly to analyse the influence of contingency situations on the demand and capacity modelling. EXP2-OBJ3 aims to analyse the effect of navigation accuracy and communication update rate on the DCB process. EXP2-OBJ4 is to identify the influence the weather impacts on infrastructure in urban environments and EXP2-OBJ5 is to analyse the effect of turbulences on especially light weight drones.

[8] References to DACUS Performance Framework metrics [4] are included in brackets.

As scenario location the city of Frankfurt am Main, Germany was chosen. Based on that location 4 scenarios will be validated where parameters like mission type, airspace, weather or demand (number of processed flight plans) are varied.

6.2.2 Validation Objectives

Validation Objective Id	EXP2-OBJ1
Description	Analyse up to what point the **inclusion of contingencies in the planning processes** could change the overall demand versus capacity situation, and the existing hot spots in the pre-tactical phase.
Success Criteria 1	The changes in the demand vs. capacity situation can be quantitatively measured based on the activation of contingencies per hazard type: • (partial) loss of autonomy level due to degradation in CNS infrastructure performance; • loss of landing location (meaning zero capacity) due to weather events and using dedicated emergency vertiports; • reduction in nominal vertiport capacity due to weather events.
Success Criteria 2	The impact of the inclusion of contingencies in the planning processes on existing hot spots can be quantitatively measured.

Validation Objective Id	EXP2-OBJ2
Description	Analyse up to what point the **uncertainty or lack of information** provided by the drone operator in the initial submission of the Operation Plans could change the overall demand versus capacity situation, and the existing hot spots.
Success Criteria 1	Definition of baseline demand & capacity situation for the experimental scenario
Success Criteria 2	Implementation of uncertainties to the experiment and definition of the minimum required information input needed by the operator to be able to create a reliable DCB analysis

Validation Objective Id	EXP2-OBJ3
Description	Analyse the effects of CNS performances such as navigation accuracy and communication update rate in the risk (both in air and ground) for the given scenario considering the 4D nominal trajectories provided by the demand model
Success Criteria 1	Estimate the collision risks for the given scenario (considering 4D nominal trajectories from demand model) depending on Navigation accuracy and communications update rate.
Success Criteria 2	Estimate the effect on false conflict alert rate of the safety margin to minimise the collisions risk, which would be set based on navigation accuracy.

Validation Objective Id	EXP2-OBJ4
Description	Analyse up to what point weather conditions affect the infrastructure in urban environments and therefore the capacity. Especially, the impact of weather forecasts will be assessed.
Success Criteria 1	The quality of the weather forecast allows to characterize the availability of the take-off and landing locations (vertiports) in urban areas.
Success Criteria 2	The impact of weather conditions can be assessed in relation to different vehicle types and performances.

Validation Objective Id	EXP2-OBJ5
Description	Analyse up to what point high turbulences / high winds affect low weight drones, in order to identify the areas to be avoided by this type of drones.
Success Criteria 1	The weather forecast allows to mark high turbulences / high wind areas for all relevant airspace levels in low weight drone operations.
Success Criteria 2	Availability to plan the avoidance of high wind areas without overloading the neighbouring areas / zones. Here, the residual areas will be used adequately to distribute the load.

Validation Objective Id	EXP2-OBJ6 [9]
Description	Assess the **consistency of the process to identify social impact hot-spots and risk-related hot-spots** in terms of consistent timeframes and portions of airspace.
Success Criteria 1	The size of cells for risk-related hot-spots allows us to propose DCB measures with regards to the hot-spots identified.
Success Criteria 2	Cadence of measurements is relevant to capture all the hot-spots (e.g., every minute, every 5 minutes).

Validation Objective Id	EXP2-OBJ7
Description	Assess the **relevance of weather information as part of the DCB process in terms of its impact on operations and planning of capacity** related measures e.g., scarcity of TOLAs and contingency sites, emergence of new hot spots or weather-related delays, which offsetting demand.
Success Criteria 1	Quantify the improvement of demand forecasts by taking into account weather information.
Success Criteria 2	Identify the general uncertainty of operations, caused by weather information, depending on the different operational phases before the actual flight.

6.2.3 Validation Scenarios

For the experiment the location of Frankfurt am Main, Germany was chosen. It is a city with a large international airport in close proximity and thus complex airspace structure and a distinct skyline significantly influencing weather factors. Based on this location different scenarios are defined where parameters like capacity, airspace, flight restrictions, weather or mission types are varied:

- Urban area.
- Location: Frankfurt am Main, Germany.
- Airspace: E, D as layers.
- Proximity <20km of EDDF, Frankfurt international airport.

[9] This objective will be addressed by Validation Experiments #01 and #02: EXP1-OBJ2 will address the social impact hot-spots, and the EXP2-OBJ6 will address the risk-related hot-spots.

- Small and large rotary wing (delivery, agriculture...).
- Combined high-res/low-res weather model.
- Airspace restrictions: NOTAM/TFR, UAV specific restrictions (large crowd of people, concerts, etc.) restricted airspace D.

	Mission types	Weather	Demand	Airspace	Uncertainty
Scenario 1	Mixed	Nominal	Normal	No restrictions	1st iteration: introducing time uncertainty with a spatial deterministic trajectory 2nd iteration introducing time uncertainty and vertical uncertainty with a 2D (lateral) deterministic trajectory Optional: 3rd iteration introducing uncertainty in all spatial and time dimensions
Scenario 2	Mixed	Off-nominal	High	No restrictions	Deterministic trajectory Optional: 1st iteration
Scenario 3	Mixed	Nominal	High	Restrictions	Deterministic trajectory Optional: 1st iteration
Scenario 4	Single	Off-nominal	High	Restrictions	Deterministic trajectory Optional: 1st iteration

Table 11. Summary of the Validation Experiment #02 scenarios.

6.2.4 Description of the architecture

The technical framework that shall facilitate this experiment integrates the implementation of models as presented in D3.1 and D3.2, as well as the prototype of service functionalities to be developed in the remaining course of the project. Specifically, the AI Demand Prediction Model [8] will help to calculate the demand prediction and Capacity Models in support of DCB [9] will allow to estimate the collision risk. The generation of both nominal and contingency-based 4D trajectories are part of the Drone trajectory Management Framework [6] and the weather service prototype together with risk map and the population density map are the expected functionalities from the development of supportive functions for large number of simultaneous operations [7]. The interaction of the aforementioned components is shown in the following high-level architecture diagram. The architecture is aligned with the defined DCB processes (see §3.2).

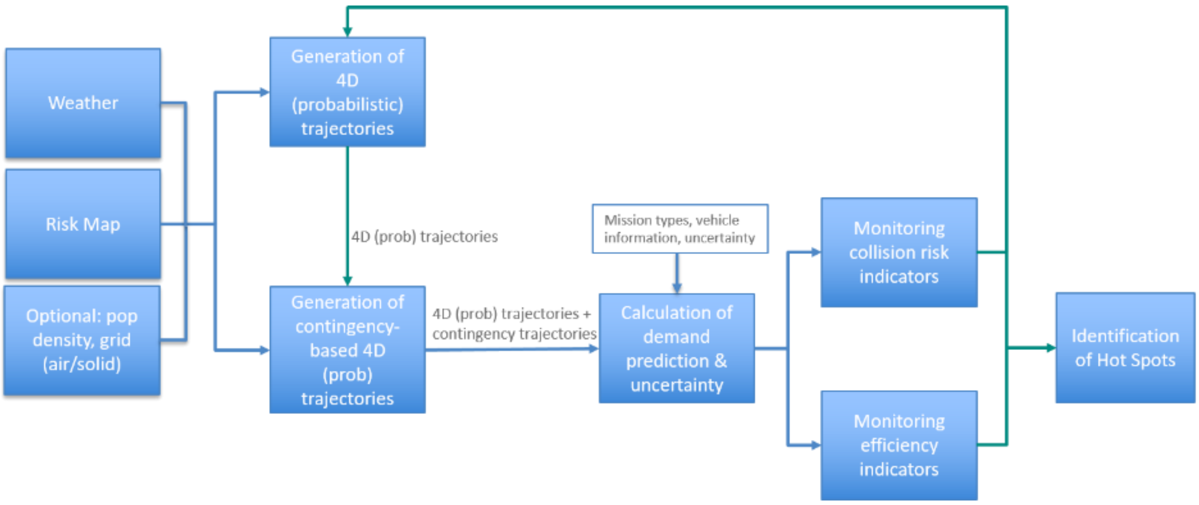


Figure 10. High-level service and capability component architecture for the experiments

The sequence order of the data can be understood as the following: with the support of weather information, static population density map and a derived risk map, nominal 4D trajectories will be modelled. In the scope of the experiments, different levels of uncertainty will be explored and tested. After this modelling, contingency trajectories will complement the drone trajectory modelling. To ensure that the same boundary conditions apply for the contingency trajectories as for the nominal trajectories, the supportive functions also feed this part of the process. Next, both datasets are forwarded to the calculation of demand prediction part, which adds information related to the technical characteristics of drone in order to generate an enhanced representation of the trajectories. Consequently, this data is passed to the monitoring functionalities which serve to the estimation of indicators for the dynamic capacity management. Finally, it is intended to feed the estimation of risk and efficiency indicators back to the flight planning process with the objective to improve this process and identify relevant hot spots. The Table 12 summarize the data types and formats that are handled by the service functionalities.

Regarding the Collision and Conflicts Risk Model, it calculates the fatality ground risk derived from collisions and failures, as well as the false alarm rate (conflicts detected which would not derive into a collision). On the one hand, collisions between drones will depend on number and performance of drones, time to react, capability of detection, CNS performances, etc. On the other hand, failures while flying will only depend on flight time. From collisions and failures, probability of fatality on the ground can be calculated. It will also depend on the size of the drones, population density and sheltering factor (if people are protected by buildings, trees or anything that could reduce the lethality).

To estimate fatality ground risk, simulations are carried out considering the 4D nominal trajectories provided by the demand model. The trajectories defined by the demand model are deterministic, however, the real execution will present uncertainties both in time (delay or advance with regard to the nominal case) and in position/heading (navigation system error, i.e., difference between the position calculated and the real position of the drone); therefore, different uncertainties in terms of time, position and headings must be introduced to assess the real ground risk associated with the foreseen operations. To that end, given the scheduled trajectories in a period of time (t_initial,t_final), N different iterations introducing errors are generated for each t_i and the risk of each of these iterations is calculated and then averaged, to obtain the expected ground risk, in the considered time period.

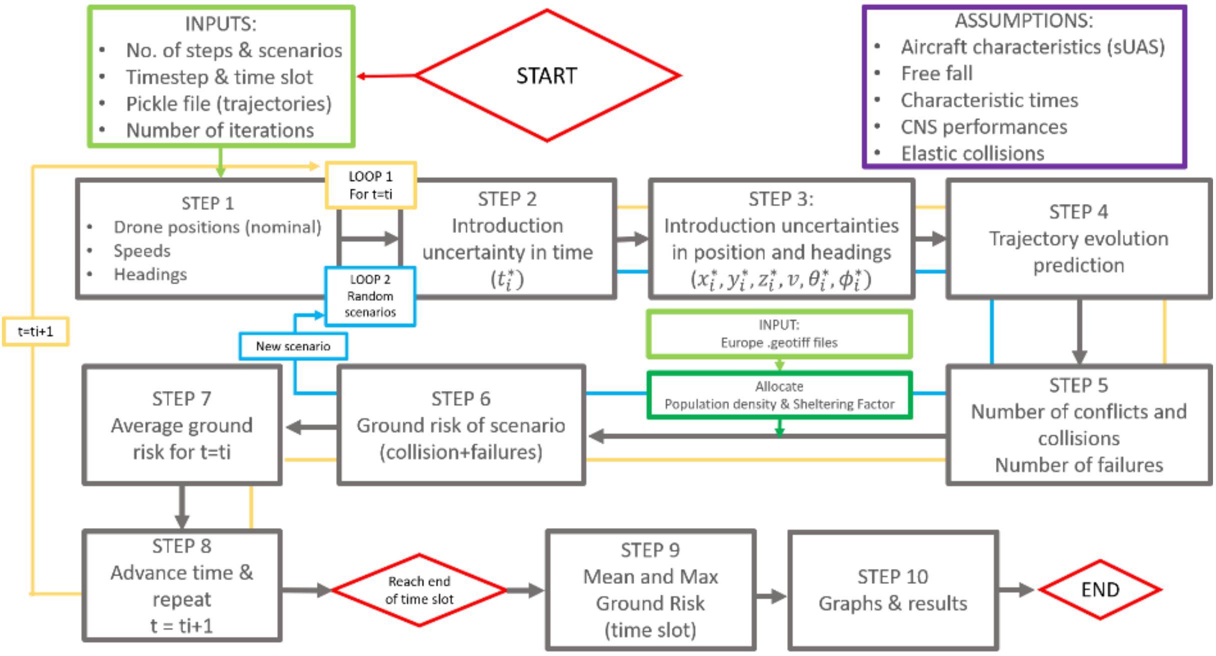


Figure 11. Overview of the Collision and Conflicts risk model process

For more details, please see D3.2 [9] where collision risk model is described.

Service Functionality	Data type	Data Format	Details	Provided to
Generation of 4D trajectories	4D trajectory with uncertainty	GeoJson		Generation of contingency-based 4D trajectories
Generation of contingency-based 4D trajectories	4D trajectories (nominal + contingency) with uncertainty	GeoJson	The output is merely an expansion of the nominal input trajectory	Calculation of demand prediction
Weather	Weather data	Raw data (xyzt, wind vector…)	Option of providing uncertainty of scenario	Generation of nominal and contingency-based 4D trajectories

Risk Map	Risk Map data	GeoJson? (X, Y, Z, Wx related Risk?)		Generation of nominal and contingency-based 4D trajectories
Static Population Density Map	Static population density map data			Generation of 4D trajectories
Calculation of demand prediction	Nominal input trajectory from prev processes including contingency components and potential uncertainty (time and /or positional) Drone vehicle 'meta data' indicating vehicle type and preferred operation (e.g. flight level, direct, structured route etc.)	GeoJson (note we would probably extend the data from prev steps to include additional Json fields if required)	The updated Json profiles including enhanced vertical performance, vehicle types, capabilities and range plus (1..n) contingencies	Monitoring of Collision Risk and Efficiency Indicators
Monitoring of Collision Risk Indicators	Collision risk	Array of data	Centre (and size) of each cell, providing the mean and maximum collision risk and fatality risk for the time period	Generation of 4D trajectories
Monitoring of Efficiency Indicators	Performance/efficiency?	Array of data	Centre (and size) of each cell, providing the unjustified manoeuvres per flight hour (due to conflicts which would not cause a collision)	Generation of 4D trajectories

Identification of Hot Spots	A number of hot spots and their duration	Array of data		Further DCB processes

Table 12: Summary of the data types and formats of EXP#02.

6.2.5 Validation Assumptions & Limitations

- All vehicles being considered in the scenario are rotor-craft only to limit the complexity of models validated in the experiment.
- Vehicles may have different characteristics (large, small) and different performance capabilities (operating range, preferred flight levels, nominal cruise speeds, RoCD etc).
- Vehicles are not passenger carrying, thus, only ground risk will be considered.
- No DAA solution on board.

6.2.6 Choice of experiment's metrics

In the Pre-Tactical planning phase, it is expected that the collision risk model will focus on two main performance areas, one being the level of collision risk across a set of airspace cells (or sub-cells) and the other focusing on the probability that the occurrence of a collision would result in a fatality on the ground. The second measure assumes that the vehicles involved in such an incident are not carrying passengers of course.

Hence the metrics that will be considered with relation to the collision risk service include:

- Collision Risk Level by analysis cell for a given time period (e.g. fifteen minute) across the set of analysis cells. Mean and maximum values for the time period.
- Number of Hotspots and their duration for the same set of analysis cells and range of time periods (i.e. cells where the max collision risk exceeds the acceptable risk threshold and the contiguous period that each cell remains at or above the max permitted threshold).
- Mean, and Max collision risk for a set of cells over a specified time period (n-minutes).
- Risk of fatality on the ground per flight hour, by cell.
- Success criteria can be measure using a comparison (by cell/time period) of the risk compared to the agreed Target Level of Safety for any given scenario.

In relation to the contingency plans that are provided as part of the Pre-Tactical mission plans, and the response of specific vehicles to unanticipated issues (e.g. bad weather, degraded CNS etc.) metrics proposed may include:

- Minimum number of available contingency solutions (e.g. available secondary landing locations) to any operation across its entire trajectory that are within range of the location where the issue is encountered (and based on operational range characteristics).
- No of alternate contingency solutions if one or more is unavailable (e.g. closed due to wind).
- No of contingency actions which may occur with no pre-defined action associated.
- Number of operating plans that must be cancelled due to no available trajectory or insufficient contingency planning.
- Success criteria related to these metrics will be to minimise the values and/or have low mean and max values.

With regard to the monitoring of efficiency indicators, the following metrics from the DACUS Performance Framework [4] will be considered especially for the objectives EXP2-OBJ1, EXP2-OBJ2, EXP2-OBJ3 and EXP2-OBJ5:

- Total number of meters flown [EFF1, EFF2].
- Elapsed time airborne [EFF3].
- Arrival time to the drone base [EFF4].

Further metrics for EXP2-OBJ2 and EXP2-OBJ3:

In regard to the impact of trajectory uncertainty on the collision risk service, where feasible, tests can be carried out to evaluate the change in collision risk when predicted trajectories provided in the pre-tactical flight planning vary:

- By time.
- By lateral position.
- By altitude.

6.3 Validation Experiment #03 Plan

6.3.1 Description and scope

This experiment will apply the Collision Risk Model developed in WP3 (see D3.2 [9]) to different scenarios in the Strategic Phase, to test the effect of considering different CNS performances and defining different airspace structures on the maximum acceptable capacity in a certain scenario.

Testing different CNS performance is essential to set the maximum capacity or minimum separation between aircraft because, depending on how good CNS performance systems are, the greater the capacity of the airspace will be for a given TLS (1E-6 fatalities/flight hour, as per SORA methodology

[10]). On the other hand, defining different airspace structures and the risk associated to them will be useful to find the structure which allows the greatest capacity while maintaining an acceptable level of safety.

The following simulations are going to be developed:

- Reference scenario: GPS L1 Rx, no integrity errors, 1 second communications update rate, 100% probability of detection and free-flight.
- CNS Scenarios:
  - NAV Improved receiver (1): GPS+Galileo+SBAS Rx.
  - NAV Integrity (1): Integrity risk (large error for 0.1% of the drones).
  - COM (2): Update rate 3s & 5s.
  - SUR (2): Probability of detection 95% & 90%.
- Airspace Structures Scenarios:
  - Layers.
  - Sectors or Tubes.

We will run each of them several times, increasing progressively the number of drones, i.e. the capacity, till the risk equals the TLS (1E-6 fat/f.h.).

The scenario considered will be focused in a metropolitan area.

6.3.2 Validation Objectives

Validation Objective Id	EXP3-OBJ1
Description	Assure that **overall flight safety and the safety of third parties remains acceptably high** by comparing the Collision Risk model to a certain TLS.
Success Criteria 1	The collision risk calculated in different simulations, increasing sequentially the number of drones, remains below the TLS of 1e-6, per SORA methodology [10], if the capacity (drone density) is limited to a certain threshold (maximum density of drones).

Validation Objective Id	EXP3-OBJ2
Description	Introduce in the Collision Risk model different CNS performances assumptions **to analyse the impact on the collision risk** and the different business models that will coexist in the cities.
Success Criteria 1	Estimate different acceptable capacity thresholds depending on Navigation accuracy, communications update rate and tracking integrity.
Success Criteria 2	Estimate the collision risks in a certain scenario depending on Navigation accuracy, communications update rate and tracking integrity.

Validation Objective Id	EXP3-OBJ3
Description	Estimate collision risk and maximum capacity considering **different airspace structures** (free route, layers, etc.).
Success Criteria 1	Estimate different acceptable capacity thresholds depending on the airspace structure restrictions.
Success Criteria 2	Estimate the collision risks in a certain scenario depending on the airspace structure restrictions.

Validation Objective Id	EXP3-OBJ4
Description	Estimate the **effect on false conflict alert rate of the safety margin** to minimise the collisions risk.
Success Criteria 1	Calculate the number of undetected collisions and false conflicts as a function of the safety margin.

6.3.3 Validation Scenarios

The validation scenarios will depend on the trajectories to be analysed. In principle, the scenarios considered will be focused in a metropolitan area of 1 to 6.25 square kilometres.

6.3.3.1 Scenario #1

The objective of this scenario is testing different CNS performances (navigation accuracy reporting position, communications update rate, tracking integrity and tracking probability of detection). By simulating different scenarios, acceptable values of these parameters will be set.

The different scenarios will be compared with a reference scenario (GPS L1 Rx, no integrity errors, 1 second communications update rate, 100% probability of detection and free-flight), which will be the first one calculated.

- Only cruise trajectories.

- The drones' size will be 1 m^3.
- Free flight.
- Toulouse metropolitan area (considering the population density).
- Operational volume 2.5 x 2.5 Km^2.
- CNS performances:
  - Navigation accuracy:
    - GPS basic drone receiver (e.g. ublox,…) (reference scenario).
    - GPS+Galileo+EGNOS drone receiver (e.g. trimble/septentrio/…).
  - Communications update rate:
    - 1 second (reference scenario).
    - 3 seconds.
    - 5 seconds.
  - Tracking integrity:
    - No position integrity errors. (reference scenario).
    - 1 drone gross position integrity error.
  - Tracking Probability of detection:
    - 100% (reference scenario).
    - 95%.
    - 90%.

6.3.3.2 Scenario #2

The objective of this scenario is testing different airspace structures. The different scenarios will be compared with a reference scenario (GPS L1 Rx, no integrity errors, 1 second communications update rate, 100% probability of detection and free-flight), which will be the first one calculated.

- Only cruise trajectories.
- The drones' size will be 1 m^3.
- Toulouse metropolitan area (considering the population density).
- Operational volume 2.5 x 2.5 Km^2.

- Consider the impact of different airspace structures:
    - Free flight (reference scenario).
    - Layers.
    - Sectors/Tubes.

6.3.4 Description of the architecture

The collision risk model validated in this experiment is part of the DCB process in the strategic phase where the model, together with other models, will identify hot spots and imbalances between capacity and demand given some conditions of the systems and airspace.

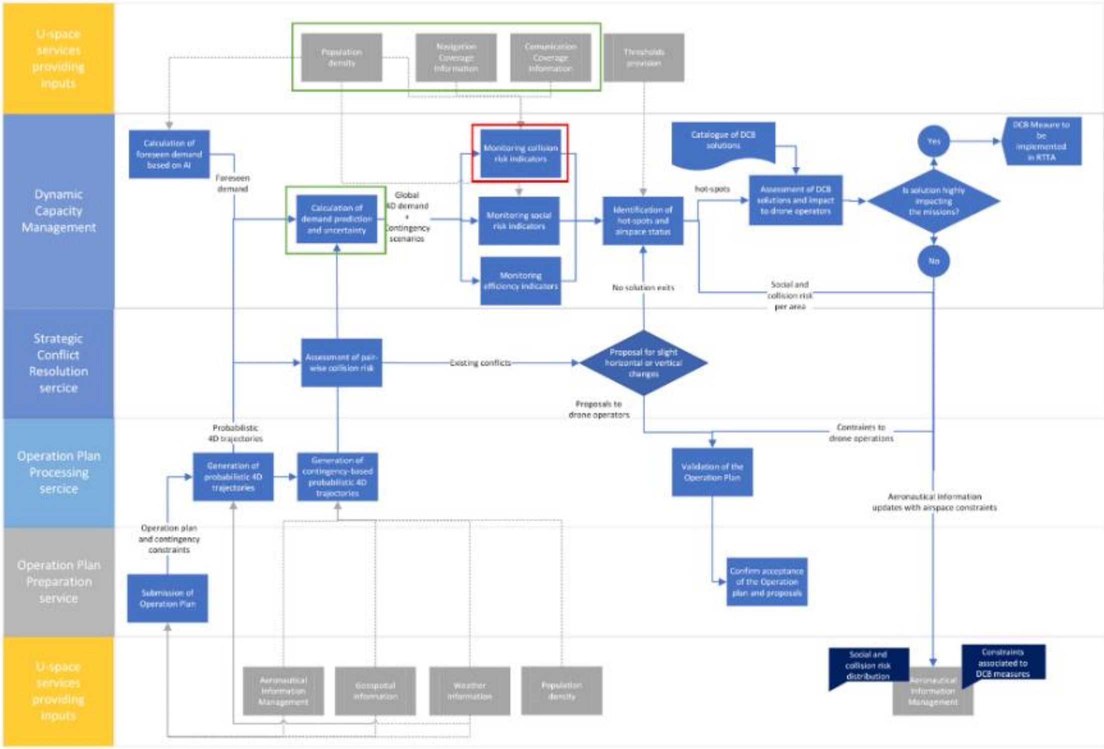


Figure 12. Strategic Phase in DCB process. Collision risk model in red with inputs in green

The collision risk model calculates the fatality ground risk derived from collisions and failures. On the one hand, collisions between drones will depend on number and performance of drones, time to react, capability of detection, CNS performances, etc. On the other hand, failures while flying will only depend on flight time. From collisions and failures, probability of fatality on the ground can be calculated. It will also depend on the size of the drones, population density and sheltering factor (if people are protected by buildings, trees or anything that could reduce the lethality).

To achieve an estimation of fatality ground risk in strategic phase, a Monte Carlo approach is used. A large number of scenarios will be simulated, and number of collisions and failures will be calculated.

These failures and collisions will cause a certain damage on ground depending on density of population, sheltering factor, size, and speed of the drone… resulting in a fatality or not. After running the simulations, an average ground risk is calculated, as well as the number of conflicts detected which would not result in a collision (false alarms).

The next diagram (Figure 13) summarizes the process that will be followed in the execution of the simulations. Average ground risk of each scenario is estimated simulating N scenarios and calculating the number of fatalities on ground.

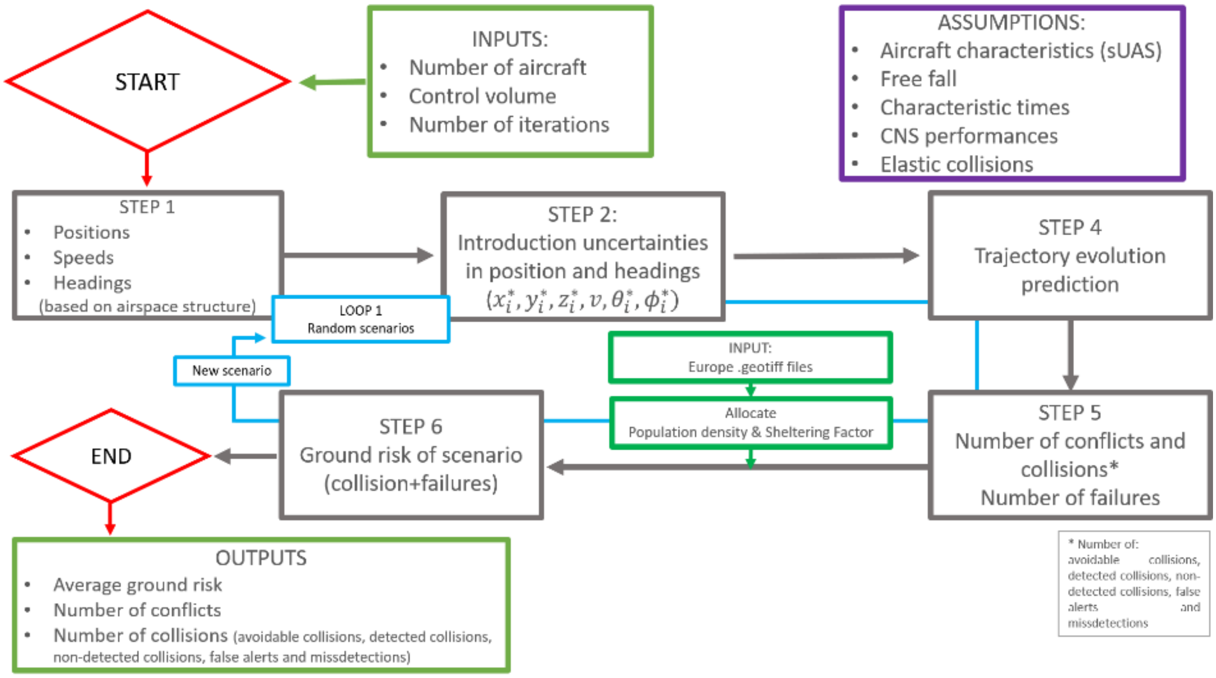


Figure 13. Diagram of Collision/Failure Risk Model in strategic phase

The average ground risk is compared with the aforementioned TLS. If the risk is lower than the TLS, the number of drones will be increased till the risk equals the TLS; this number of drones would be the maximum capacity for a certain volume of airspace, for that simulation.

The model calculates all the potential collisions, but it can differentiate among those which could be avoided by a DTM Tactical Deconfliction System and those which not; this discrimination is based on the time from the detection to the moment of the collision: if this time is greater than the sum of the communications update rate, the DTM processing time (1s) and the manoeuvring time (4s) [11], the collision can be avoided and the U-space system reduces the risk, increasing therefore the capacity with regard to an airspace volume where there is not such service deployed.

The capacity would therefore depend on the scenario (population density, sheltering factor), but also on the CNS performances and the size and features of the drones.

Additionally, the model calculates the likelihood of conflicts not leading to a collision, i.e., false alarms. These false alarms would cause unnecessary flight time and missions' disruptions, i.e., they would reduce the efficiency. Therefore, this figure can also be measured to identify if the efficiency rate is not acceptable, even being the fatality risk below the TLS. In summary, the maximum acceptable capacity could be lower than the one based only on risk.

6.3.5 Validation Assumptions & Limitations

- Only rotorcraft drones: to simplify the model so that all aircraft share the same basic characteristics, instead of mixing rotatory and fixed wing, with slightly different parameters that impact ground risk, i.e. UAS radius vs. wingspan. Not only, but also the time to perform an avoidance manoeuvre relies on this as well.
- Random trajectories: at a strategical phase, most flight plans are assumed to be unknown, therefore, they are randomized.
- Only cruise trajectories: to simplify the model, accelerations and turns are omitted. All aircraft follow a straight line, not necessarily horizontal, at constant speed at all times.
- The drones' size will be 1 m^3: to simplify, only sUAS are generated. However, more categories could be added, yet without passengers, which imply additional considerations with regards to air risk and fatality rates.
- Collision avoidance is not considered: avoidance manoeuvres, which require a change of trajectory, are not covered.
- No effect of weather in trajectories is considered: to simplify the model, the weather is not taken into account, neither wind speeds nor delays or cancellations due to harsh conditions.

6.3.6 Choice of experiment's metrics

- Number of collisions (avoidable, non-detected, false alerts): calculated at the end of each simulation, for the whole timeslot.
- Number of conflicts: calculated at the end of each simulation, for the whole timeslot.
- Risk of collision: derived from the number of collisions. Defined as a rate of collisions per flight hour. As for the definition of collisions, there is a distinction between conflicts, within which are included avoidable and non-avoidable collisions
- Probability of fatality on ground: combines fatalities due to collided drones from the estimated collisions, and fatalities that follow sudden failure of drones, resulting in a loss of control.
- False alert rate: conflicts detected by the model that actually would not cause a collision thanks to safety margins considered to calculate them.

These metrics are aligned with the capacity indicators defined in DACUS' Performance Framework [4].

	CAP1 Cumulative risk against people	CAP2 Lowest closing time	CAP3 Number of close aircraft	CAP4 Flight time manoeuvring	CAP5 Number of severe intrusions
Experiment metric	Probability of fatality on ground (TLS)	*Implicitly computed*	Number of conflicts	Product of number of conflicts and time of manoeuvring (False alert rate (number of conflicts not causing a collision) are also calculated)	Number of non-avoidable collisions
Success criteria	TLS below 1e-6 (as per SORA methodology)	To be defined	To be defined	To be defined	To be defined
Remarks		Only closing times for colliding aircrafts are calculated	The definitions given in [4] all refer to explicit collisions. From the first paragraph of CAP3, if the lowest closing time is below the minimum closing time, no avoidance manoeuvre is effective and there is a collision. Again, for CAP4, the flight time manoeuvring is determined by drones which have a minimum closing time lower than the minimum time threshold to perform avoidance manoeuvres. Finally, in CAP5, severe intrusions also translate into collisions for pairs of drones in which both aircrafts have closing time lower that their minimum closing time.		

6.4 Validation Experiment #04 Plan

6.4.1 Description and scope

This experiment is focused on tactical phase and aims to test what happens when a perturbation is activated (drone contingency). The main goals of this experiment are the activation of new separation standards in the areas that have been affected by the contingency, and the alerting on conflicts and their resolution.

Also, the experiment analyses up to what point unexpected events could generate other hot-spots which were not identified through contingency plans. It also assesses the effectiveness of different DCB measures when unexpected events take place in the tactical phase.

The architecture followed is in line with the architecture defined in DACUS ConOps [1] and it is focussed on the Tactical Conflict Resolution service.

All the validation scenarios are modelled in RAMS Fast Time Simulator interface, with Drone Zone additional features included. The results of the fast time simulations may be used as inputs by other experiments of the DACUS project.

Fast-time simulations are used to model and measure complex dynamics and relationships within an aviation system. A fast-time simulation tool is needed to quantify the DCB experiments in measurable DCB metrics/KPI (Key Performance Indicators). First, baseline scenarios must be designed and validated to represent and measure baseline operations and DCB measurements. Then, alternative scenarios are designed using the baseline scenario, and the DCB metrics are used to compare the alternative scenarios to the baseline scenario. The comparisons are made to determine if an alternative scenario performs better or worse than the baseline scenario. Better or worse may be represented by an increase or decrease in density, risk, flow, capacity, etc., depending on the DCB KPI being considered for each experiment.

6.4.2 Validation Objectives

Validation Objective Id	EXP4-OBJ1
Description	Assess the effectiveness of DCB measures when unexpected events take place in the tactical phase.
Success Criteria 1	Analyse the time to recover from degraded to nominal conditions, in scenarios #1 and #2. This number has to be lower in scenario #2.
Success Criteria 2	Analyse the number of conflicts avoided. This number has to be lower in scenario #2.

Validation Objective Id	EXP4-OBJ2
Description	Optimise decision making between on-board capabilities and U-space separation services.
Success Criteria 1	The program establishes separation rules based on the hierarchy set.

Validation Objective Id	EXP4-OBJ3
Description	Evaluate and consolidate metrics in terms of capacity to determine the maximum number of UAS operations.
Success Criteria 1	Run different scenarios and analyse variations in capacity metrics.
Success Criteria 2	Analyse the drone base and “en-route” throughput. This one has to be lower in scenario #1.

Validation Objective Id	EXP4-OBJ4
Description	Evaluate and consolidate metrics in terms of efficiency to determine the maximum number of UAS operations.
Success Criteria 1	Run different scenarios and analyse variations in efficiency metrics.

Validation Objective Id	EXP4-OBJ5
Description	Evaluate and consolidate metrics in terms of resilience and flexibility to determine the maximum number of UAS operations.
Success Criteria 1	Analyse the number of re-scheduled, delayed and cancelled flights in each of the defined scenarios.
Success Criteria 2	Analyse the drone base and “en-route” throughput.
Success Criteria 3	Analyse the time to recover. This one has to be higher in scenario #0.
Success Criteria 4	Run different scenarios and analyse variations in resilience metrics.

Validation Objective Id	EXP4-OBJ6
Description	Evaluate how DCB measures act in scenario #2.
Success Criteria 1	Run scenarios #1 and #2 and analyse variations in all the metrics.
Success Criteria 2	Estimate the loss of capacity in airspace avoided.

Validation Objective Id	EXP4-OBJ7
Description	Evaluate the effectiveness of the DCB measures in scenario #2.
Success Criteria 1	Run scenarios #1 and #2 and analyse variations in metrics. These values have to be higher than a “threshold value” to determine if they are effective or not.
Success Criteria 2	Estimate the loss of capacity in airspace avoided. This one has to be higher in scenario #2.

Validation Objective Id	EXP4-OBJ8
Description	Determine which DCB measures are better in scenario #2.
Success Criteria 1	Run scenarios #1, #2 and #8 and analyse variations in metrics.
Success Criteria 2	Design a matrix that assigns a value to each of the DCB measures in terms of their effectiveness in each simulated scenario. Then, the measures which present the best values will be selected.

Validation Objective Id	EXP4-OBJ9
Description	Evaluate the possibility to assign "virtue points" to specific drones in order to prioritize their operations within the DCB process.
Success Criteria 1	Run scenarios #1, #5 and #8 and analyse variations in metrics.
Success Criteria 2	Analyse the number of re-scheduled, delayed and cancelled flights in each of the defined scenarios.
Success Criteria 3	Estimate the loss of capacity in airspace avoided.

Validation Objective Id	EXP4-OBJ10
Description	Evaluate the impact of assigning virtue points in the DCB process in terms of capacity, effectiveness and resilience.
Success Criteria 1	Estimate the loss of capacity in airspace avoided.
Success Criteria 2	Run scenarios #1, #5 and #8 and analyse variations in metrics.

Validation Objective Id	EXP4-OBJ11
Description	Evaluate the impact of meteorology (strong wind gusts) in drone trajectories in terms of capacity, resilience and efficiency.
Success Criteria 1	Run scenarios #1, #7 and #8 and analyse variations in metrics.
Success Criteria 2	Assess DCB measures in bad weather condition scenarios.

6.4.3 Validation Scenarios

All of these scenarios are compared to a reference scenario (Scenario #1). Drone traffic is calculated by the means of demand predictions based on historical road traffic in Madrid. These predictions are taking into account the measured vehicle movements on the main roads and streets of the city.

Considering traffic share analysis made by the Council, and the population data published by INE (the Spanish National Institute of Statistics), taxi movements and cargo vehicles are expected to be replaced by drones in the coming years.

Surveys on urban environments answered by drone operators are used as supporting material for the characterization.

In addition, the following traffic characteristics are defined as common in all the scenarios:

- Wide range of drone sizes, from camera drones (< 1 m^3) to air taxis (> 27 m^3).
- Free flight.
- Geofence activations.
- Operational volume: Madrid city and surroundings.
- Ascent, cruise and descent trajectories.
- Each drone has a performance set previously defined in RAMS as an input of the simulation. These sets are provided from different sources, such as BADA, and directly included in RAMS.

6.4.3.1 Scenario #1

In the reference scenario, all drones are flying with operational plans. Moreover, all the problems are foreseen and solved by the Strategic Conflict Resolution service.

Some different kinds of missions:

- Drone package delivery.
- Traffic monitoring.
- Drone medical.
- Air taxis.
- Buildings' façade inspections.

6.4.3.2 Scenario #2

In this scenario, there are different types of airspace, depending on the level of CNS performances. Therefore, there are changes in separation minima configuration in those flight plans that cross through different areas.

The purpose of this scenario is to evaluate the different types of responsibilities:

- Autonomous drone separation.
- Minimum separation set by Area ("live" changes).

- Shared responsibility.

6.4.3.3 Scenario #3

In this scenario, there are different DCB measures applied in an area. The following DCB measures are evaluated:

- Increasing CNS infrastructure.
- Implementing speed-controlled zones.
- Implementing the organization of flows per flight layers.
- Requesting higher individual aircraft operational performance requirements, with alternative routing/delay/cancellation for those vehicles that cannot comply.
- Imposing re-routings or delays on ground.

The purpose of this scenario is to evaluate when the DCB measures should be activated (e.g. per area, time period, etc.) and to determine which DCB measure is better from the point of view of capacity, resilience, and efficiency.

6.4.3.4 Scenario #4

In this scenario, there are some areas with "no entry" restrictions. In these areas, there are some exceptions that allow some drones to enter into them.

These exceptions could be defined by type, number of virtue points, time period, etc.

The purpose of this scenario is to assess the feasibility of defining restricted zones (that allow preferences between drones in the same airspace volume) and their impact on DCB in terms of capacity and efficiency.

6.4.3.5 Scenario #5

In this scenario, drones are categorized by "virtue points". The higher number of virtue points that a drone has, the higher preference in conflict resolution is given to it.

Additional traffic characteristics:

- Different drone categories based on the number of virtue points awarded.

The purpose of this scenario is to assess the feasibility of assigning virtue points and their impact on DCB in terms of capacity and efficiency.

6.4.3.6 Scenario #6

In this scenario, some geofences are activated. Geofence activation could vary depending on the date, time, or other circumstances.

The purpose of the scenario is to test the Tactical Conflict Resolution service in an area with dynamic geofencing activations.

6.4.3.7 Scenario #7

In this scenario, drones are flying by strong winds areas. Wind gusts are forcing drones to change their trajectories compared to the nominal ones. The angle of deviation will vary depending on the wind speed.

Meteorology data is provided by different sources, such as AEMET and NCAR (e.g. from GRIB and gridded files). This information is based on real measured and reanalysed data.

The main purpose of this scenario is to test how meteorology conditions can affect to drone trajectories and assess their impact on capacity, resilience and efficiency metrics.

6.4.3.8 Scenario #8

A mix of the previous ones.

6.4.4 Description of the architecture

ISA Software's DroneZone fast-time simulation model is an extension of the commercially-available RAMS Plus ATM gate-to-gate fast-time simulation model (www.RAMSPlus.com). DroneZone includes all the features of the RAMS Plus model, plus micro-scale functionality for drone performance and conflict detection. The RAMS Plus model is used around the world for the analysis of current and future ATM operational concept validation and analysis and is one of the leading fast time simulation modelling tools currently in use for airspace design, risk analysis, capacity and efficiency studies, ATC route network assessment, ATC/Airport operations analysis, and NextGen and SESAR concepts and programmes. DroneZone can be easily installed and used on any standard MS Windows platform.

The core Features and algorithms to be applied for DCB objectives are:

- *Traffic Demand:* Traffic demand can be created using a schedule of missions, and/or by defining mission types (with base stations, routes, drop-points) with stochastic scheduled times and stochastic number of missions created.
- *4D Profile calculation*: Using a set of 100+ drone models dataset, a full 4D profile is calculated using the drone performance parameters (cruise/climb/descend rates), plus respecting the constraints or boundaries of routing, corridors, airspace volumes, speed/altitude constraints. Additional drone performance datasets are expected to be acquired soon.
- *4D profile insertion*: 4D profiles provided outside of the *DroneZone* simulation model can be loaded and simulated within the model, with access to all the simulation features outlined here, especially features such as the separation minima, conflict detection and density measurements.
- *Separation priorities by equipage/type/volumes/etc.*: Separations can be set for any combination (or individual) aircraft types, missions, and volumes. These separations are applied in a priority-based rule to determine the appropriate separations to apply. This

priority-based approach provides a scalable scenario definition for dynamic pair-wise separation minima, as opposed to choosing a minimum or maximum separation when multiple separation strategies exist. Separations can be defined to as small as 1m or less. Pair-wise separations be further manipulated based on the relative geometry of the aircraft pair, for example if the aircraft are on a head-on trajectory, the separation can be expanded to represent a longer lead-time to react to the conflict situation.

- *Conflict detection*: Pair-wise Conflict detection is full 4D separation violation, where a conflict is defined by a start and end time and closest-point-of-approach. Pair-wise conflict detection for separation violations can be performed at various phases in the flight profile, as determined by the airspace scenario definitions. Detection can be performed on a given section of the flight profile, or as a look-ahead time for the next portion of the flight profile. Detection parameters can be stochastically parameterised to provide missed-conflicts (failure to detect) and false-conflicts (detect conflict that does not exist). Conflict (Separation Violation) outputs represent each pair-wise separation violation and the conflict's associated situational values, including a start and end time (in decimal seconds), closet-point-of-approach distance/time/location, convergence ratio.

- *4D Conflict resolution*: drones in conflict situation can be applied a 4D conflict resolution to avoid the conflict, including lateral and vertical deviation, holding in the air, return to base, and to land immediately.

- *Probabilistic Features*: Probabilistic behaviour can be modelled through a range of various features. First, the flight profile calculation can apply stochastic variation to the aircraft performance and to the position (lat/long/altitude) of the flight profile's points. Second, uncertainty can be applied to the Detect and Avoid (DAA) algorithms to represent uncertainty in position. For detection, a conflict situation may be stochastically missed using a rulebased approach. For example, miss 5% of conflict situations, or miss 25% of conflict situations with certain airspace or geometry or aircraft type or mission characteristics. For the Avoidance part of DAA, stochastic variation can be applied to the time-to-react (latency time) to a conflict situation, as well as variation in the resolution manoeuvre attempts to avoid the conflict situation. Stochastically applied anomalous events affecting drone intent can be modelled, such as loss-of-communication link or battery-life, and the associated behaviour of this anomalous event.

- *Airspace volumes: 3D A*irspace volumes may be a combination of traditional sectorised airspace, corridors and flows, geo-fenced areas, or a grid-cell structure. Airspace throughput outputs are recorded with airspace volume entry and exit times and lat/long location, and the associated airspace flight counts during these times.

- *Dynamic density recordings* represents snapshots of 3D airspace volumes with aircraft count, density, structure/flow, attitude (climb/cruise/descend), aircraft proximity to other aircraft and to volume boundaries, and variance in direction. These recordings can be aggregated in a range of density and capacity metrics.

- *Metrics*: simulation outputs are used to aggregate metrics by time, airspace volume, location, etc. Metric aggregation is performed using a range of tools, including Excel, Tableau, and 4D animation visualisation. All simulation outputs are column-formatted text files, with geo locations represented as lat/long in decimal format, and altitude in 100's of feet.

6.4.5 Validation Assumptions & Limitations

- Random trajectories generated by stochastic distributions (DroneZone).
- Conflict resolution manoeuvres are set before flight.
- Drone preferences are set per flight and/or airspace.
- Drone operating characteristics and constraints are known for each Drone type (e.g. max wind, precipitation, temp range etc.).

6.4.6 Choice of experiment's metrics

During the execution of the wide range of Validation Experiment #04 scenarios, the following metrics will be monitored[10]:

Capacity:

- Drone base throughput, in challenging airspace, per unit time.
- Flying drones throughput, in challenging airspace, per unit time.
- Peak arrival throughput in drone bases (% and flight per hour).
- Peak departure throughput in drone bases (% and flight per hour).
- Re-scheduled traffic reduction.
- Number of hotspots.
- Number of conflicts derived from other conflicts' resolution.
- Number of impacted operations [FLX1, FLX3…].
- Lowest closing time (seconds) [CAP2].
- Number of Close Aircraft [CAP3].
- Percentage of time doing avoidance manoeuvres (%) [CAP4].

[10] References to DACUS Performance Framework metrics [4] are included in brackets.

- Number of severe intrusions [CAP5].

Resilience and flexibility:

- Time to recover from degraded to nominal conditions.
- Minutes of delay [FLX1, FLX2…].
- Number of flights that have been cancelled [EFF5].
- Loss of airspace capacity avoided.
- Loss of drone base capacity avoided.
- Number of drones impacted by a contingency [RES2].

Efficiency:

- Total number of meters flown [EFF1, EFF2].
- Arrival time to the drone base [EFF4].
- Number of batteries consumed.
- Energy required (kW).
- Elapsed time airborne [EFF3].

7 References

[1] DACUS. Drone DCB concept and process. D1.1. Version 01.00.00. March 2021.

[2] DACUS Grant Agreement Number 893864. May 2020.

[3] CORUS Concept of Operations. Version 01.01.03. September 2019.

[4] DACUS. Performance Framework. D5.3. Version 00.00.10 [Draft]. 18th of June 2021.

[5] DACUS. DCM Service architecture & prototype. D2.1. Version 00.01.00 [Draft]. 29th of June 2021.

[6] DACUS. Drone Trajectory Management Framework prototype. D2.2. Version 00.01.00 [Draft]. 29th of June 2021.

[7] DACUS. Prototype of services to support large number of simultaneous operations. D2.3. Version 00.01.00 [Draft]. 20th of June 2021.

[8] DACUS. AI demand prediction models. D3.1. Version 00.01.00 [Reopen for revision]. May 2021.

[9] DACUS. Demand Models in support of DCB. D3.2. Version 00.01.00 [Reopen for revision]. May 2021.

[10] JARUS, «JARUS-RPAS,» [Online]. Available: http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v2.0.pdf.

[11] N. Peinecke, L. Limmer y A. Volkert, «Application of "Well Clear" to Small Drones (Institute of Flight Guidance, NLR)» 2018.

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