EXPLORATORY RESEARCH

Final optimized drone DCB

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DACUS

DEMAND AND CAPACITY OPTIMISATION IN U-SPACE

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Abstract

This document describes the Concept of Operations for "Demand and Capacity Balancing" for drones within an urban environment. This process is supported by an extensive literature study and background information on the operational environment in which it takes place. Given the novel nature of drone operations in a civilian setting, several parallels of the proposed solution and the existing air traffic management environment are provided. Finally, the document serves as guidance material for the DACUS project and the implementation thereof within U-space.

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1 Executive Summary

The operations of Unmanned Aircraft Systems, commonly referred to as "drones", in urban environments are expected to increase substantially over the coming decade. This is because more and more viable business cases for such vehicles are becoming apparent (such as package delivery, infrastructure inspection, surveillance, public safety & security and urban air mobility) and technological advances in the field of robotics and autonomy have made such operations viable. The Single European Sky Air Traffic Management Research (SESAR) program has taken a proactive step towards facilitating such operations through the implementation of U-space: A service ecosystem designed to facilitate access to lower airspace for drones. Part of this ecosystem will be in charge of coordinating drone operations in the planning phase as well as in real-time to ensure an orderly and safe execution of these flights. The means to assure this, from a traffic management point of view, is through a process called "Demand and Capacity Balancing" (DCB). The DACUS project will explore how DCB can be provided within a U-space environment, develop a Concept of Operations (ConOps) for drone DCB in urban airspace and develop models to test fundamental aspects of this concept.

The document you are now reading is the main point of reference to the entire project. It describes the detailed operating method of the DACUS solution through the definition of a ConOps for DCB processes in U-space. This process is supported by an extensive literature study and background information on the operational environment in which it takes place. From a purely DCB-centric point of view, drone operations can be characterized based through the following seven characteristics: The operational range, flight levels, timeframe and recurrences, areas of deployment, payload, special environments, and external conditions, as well as visual and noise impact. Take-off and landing areas will also play an important role in how drone operations will take place. Given the vastly new operating characteristics of drones, these areas can be highly dynamic, ranging from existing airfields to small landing pads on rooftops to mobile vehicle-based launch platforms.

Technical characteristics of the environment (airborne and ground-based) are also considered. On-board equipage of unmanned vehicles is the protagonist in this respect, given that vehicle capabilities will define which DCB measures can be applied. Relevant for DCB are capabilities related to Communication, Navigation and Surveillance (CNS). Proper CNS for drone operations require a communication infrastructure network to be in place, which is predominately satellite-based (i.e., global navigation satellite systems) and telecommunication-based (i.e., 4G/5G telecom. network).

Finally, Characteristics of the U-space architecture are also relevant. U-space is based on a multitude of individual services which work together to provide a complete system. The DCB process fundamentally relies on three U-space services to provide a solution: The Strategic Conflict Resolution, the Dynamic Capacity Management, and finally the Tactical Conflict Resolution, whose performances will determine the need to implement DCB solutions prior to the execution phase. These do not work in isolation but count on information provided by the entire U-space ecosystem. For this information exchange to work, the ecosystem must be based on a highly dynamic and interconnected service infrastructure.

The final aspect to consider, before establishing the DCB process, is the regulatory framework which guides its implementation. The European Union is strongly supporting initiatives for commercial drone operations if they adhere to defined rules and regulations. All drones are required to be categorized as pertaining to one of three categories ("open", "specific" or "certified") depending on their weight and dimensions. DACUS highlights the need to update the existing regulatory framework to

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accommodate the envisioned high number of drone operations in urban environments. The proposed DCB concept is defined with the assumption that this future regulation is in place.

The DCB process itself is based on a series of fundamental principles, which sees the operators as the final decision makers, prioritizes measures based on their impact on the fulfilment of the drone mission, reduces constraints on drone trajectories as much as possible, is based on the quantification of uncertainty and considers operation plans as the "single point of truth" for all U-space processes.

This process begins at strategic level (several days before operation) and continuously monitors and updates the traffic situation until the actual moment of flight execution. Only when necessary it will act on the traffic itself (i.e., a potential collision or exceeding of a capacity threshold is identified). To take a decision on whether to intervene or not, the DCB process must first quantify the level of uncertainty of the demand, which it uses published operation plan data and other external influence factors (e.g., weather information). In parallel, a series of risk-based and social indicators are constantly monitored. These include the expected impact of operations on levels of safety, noise and visual nuisance. This requires the processing of a series of metrics (such as expected noise levels and populations densities) and other impact indicators, which are fundamental for the definition of the capacity of a given airspace.

DCB measures are only applied when the level of certainty of a conflict or a hotspot is high enough and the impact of operations grave enough. When DCB measures are applied, special care is taken to assure mission objectives can be achieved (to the greatest degree possible) and that overall equity is maintained. The latter will likely be facilitated through the implementation of "virtue points" to incentivise cooperative behaviour.

This document draws several parallels between existing processes in manned aviation and those proposed for U-space (such as rules of the air, operational phases, capacity enhancement and DCB in air traffic management) with the aim of highlighting differences, but also commonalities. The main differences within the U-space environment come down to the much shorter time horizon for decision-making and planning (in many cases hours instead of days), a more pronounced effect of external influence factors (such as environment, noise, and third-party risk, among others) and a much higher focus on uncertainty quantification and prediction (rather than dealing with deterministic metrics).

The document concludes with a series of research challenges which the DACUS consortium addressed through dedicated models and simulation exercises. These questions revolve around the definition of applicable DCB measures for drones, the quantification of the required level of certainty to take decisions, the use of contingency plans within the DCB process, definition of collision risk and societal impact models, consolidation of metrics to determine airspace capacity limits as well as fairness and equity within the process, among others. Conclusions of the most relevant research challenges are provided, as well as a summary of unanswered questions which would need to be addressed in future work.

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2 Introduction

The DACUS project 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 concept integrates the current state-of-the-art of drone- and U-space-related research and development alongside novel approaches to airspace demand and capacity balancing into a scheme that best fits the expected operational environment of urban drone operations.

2.1 Purpose of the document

This document outlines the concept of operations (ConOps) for the DACUS solution to managing demand and capacity within U-space. This ConOps serves as the basis for further developments within the DACUS project, by defining the concept for a drone DCB process at a high level, from strategic to tactical phase of operations, and providing relevant contextual assumptions onto the operational environment in which the DCB process is situated.

The document follows the structure of the Operational Service and Environment Definition (OSED) 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 document outlines fundamental processes of the DCB concept for U-space, with emphasis on elements which will likely be required to facilitate the management of drone traffic within an urban environment. The concept covers several important aspects of the DCB process, such as key principles, different operational phases, a list of initial U-space DCB measures and a description of the processes within each operational phase (Operation Plan submission, collision risk assessment, demand predictions, DCB indicator monitoring, DCB measure assessment and implementation).

In order to support the assumptions and concepts presented in the ConOps, a high-level overview of the operational environment of the U-space DCB concept is provided, which will cover operational characteristics of drones within urban airspace (such as missions, traffic demand, take-off and landing areas, airspace and traffic characteristics), applicable standards and regulations as well as technical characteristics of the drone and its ground control station (GCS), U-space service providers (USSPs) and relevant Communication, Navigation and Surveillance (CNS) infrastructures.

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2.3 Intended readership

This document is oriented towards two key audiences:

1. DACUS consortium: The concept of operations for the U-space DCB process outlined in this document was utilized as a baseline reference for all work packages of the DACUS project. It provided the fundamental elements which apply to all work packages contents to assure coherence among them.
2. SESAR JU: This document, which is the main reference document to the work performed within the DACUS project, shall be used as a primary reference to readers external to the consortium. It presents a consolidated summary of the U-space DCB process and provides necessary supporting information to be able to orient the content presented within the larger U-space environment.

2.4 Background

The demand for autonomous flight operations is expected to increase rapidly over the next years in Europe. This will lead to a high volume of drone traffic and the need for a safe management of simultaneous flight movements.

To face this challenge, the European Commission supports the development of the U-space highly automated and digitalized service framework. Tailored to facilitate high-density operations of automated air vehicles in very low-level airspace, it will provide a large array of services to drone users all around Europe. What makes it unique in aviation is that it will be entirely focused on general risk and performance requirements, will be inherently dynamic to respond to changes on demand and will openly adopt technologies from other sectors to accelerate deployment – all without any human in the loop in internal processes as much as possible. U-space is a highly complex system of systems, which will need to be agile and readily available.

As demand for drones over populated areas explodes, there will be a need for limiting the number of operations. Future Demand and Capacity Balancing (DCB) management processes in the context of U-space shall assist concurrent flight planning by multiple drone operators to ensure availability of access to airspace, adequate balance between system capacity and demand of drone operations, and fair and prioritized access to airspace.

DACUS aims to address several of these challenges through the definition and validation of a concept for DCB within U-space. This document summarizes these efforts in the form of a concept of operations. It was developed through a series of brainstorming sessions and internal workshops. Furthermore, the assumptions were supported by an extensive review of previous and on-going projects for the development of U-space, the development of Urban Air Mobility (UAM) as well as other relevant research initiatives.

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2.5 Structure of the document

This document is structured into six main sections, as well as four appendices. The content of each of these sections is 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 larger DACUS framework is provided.

- Section 3: U-space DCB process: A summary.

  This section introduces the high-level concept behind the DACUS DCB process for U-space and defines its core principles.

- Section 4: Operational Characteristics.

  It provides a detailed description of the operational environment which the DCB process is constrained by, such as traffic demand, take-off and landing areas as well as characteristics of the airspace and drone traffic.

- Section 5: UAS Capabilities.

  This section identifies technical characteristics of drones (and their associated ground control station) with respect to DCB.

- Section 6: Applicable standards and regulations.

  An overview of regulatory aspects which affect the DCB process. These include European regulations on drones as well as regulations on manned aircraft which influence the DCB concept.

- Section 7: U-space Concept of Operations and DCB.

  A summary of DCB guidelines from the U-space CONOPS is provided. Given that the U-space CONOPS is the main reference document for all U-space related projects, it was used as the starting point of the DACUS DCB concept.

- Section 8: DCB process in U-space.

  This is the main section of the document. It introduces the DACUS DCB concept for U-space, summarizes important considerations regarding temporal aspects, involved services and applicable traffic measures; and, most importantly, explains the entire DCB process from start to finish.

- Section 9: Operational scenarios.

This section supports the DCB concept defined in section 8 with examples operational scenarios and use cases. It encompasses scenarios for both nominal and emergency situations and their impact on DCB.

- Section 10: Differences between ATM and U-space DCB processes.

  This section highlights key differences between DCB in ATM and U-space and briefly summarizes the DCB process in ATM for those who are not familiar with it.

- Section 11: Roles and Responsibilities.

  This section defines the roles and responsibilities of actors participating in the DACUS DCB process, covering all aspects from an operator, stakeholder, and system perspective.

- Section 12: Conclusions.

  This section summarizes the advancements and conclusions gathered throughout the DCB process definition, supported by the identification of a series of research challenges which would need to be addressed in future work.

- Section 13: References.

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

- Appendix A, B and C: U-space DCB processes in the strategic/pre-tactical/tactical phase.

  Schematic representations of the U-space DCB processes in each phase of operation are provided. These illustrations serve to comprehend the flow of information and processes among the U-space services involved in DCB.

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.	SESAR Integrated Dictionary

Term	Definition	Source of the definition
	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.	
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
ACC	Area Control Centre
ADS-B	Automatic Dependent Surveillance–Broadcast
AGL	Above Ground Level
AHRS	Attitude and Heading Reference System
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
AOA	Angle of Arrival
APT	Airport
ARC	Air Risk Class
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATS	Air Traffic Services
AU	Airspace User
BVLOS	Beyond Visual Line-Of-Sight
CDM	Collaborative Decision Making
CDMA	Code Division Multiple Access
CIS	Common Information Service
CNS	Communication, Navigation and Surveillance
CONOPS	Concept of Operations
CPU	Central Processing Unit
CTR	Controlled Traffic Region
DCB	Demand and Capacity Balancing
DF	Direction Finding
DSSS	Direct Sequence Spread Spectrum
EASA	European Aviation Safety Agency
EGNOS	European Geostationary Navigation Overlay Service
EMS	Emergency Medical Services
EO	Electro-optical
ES	Emergency Services

Acronym	Definition
ESC	Electronic Speed Controller
EVLOS	Extended Visual Line-Of-Sight
FC	Flight Controller
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FHSS	Frequency Hopping Spread Spectrum
FIS	Flight Information Services
FMP	Flow Management Position
FMU	Flight Management Unit
FPV	First-Person View
GCS	Ground Control Station
GDP	Ground Delay Program
GEO	Geostationary Orbit
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRC	Ground Risk Class
GST	Ground Stop
HFR	High-level Flight Rules
HMI	Human-Machine Interface
IGSO	Inclined Geosynchronous Orbit
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IR	Infrared
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LFR	Low-level Flight Rules
LTE	Long-Term Evolution
MDI	Minimum Departure Interval
MEO	Medium Earth Orbit
MIMO	Multiple Input Multiple Output
MINIT	Minutes-in-Trail

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Acronym	Definition
MIT	Miles-in-Trail
MRO	Maintenance, Repair and Overhaul
MTOM	Maximum Take-Off Mass
NCC	Network Consolidated Constraint
NOTAM	Notice To Airmen
NM	Network Manager
NMOC	Network Manager Operations Centre
OSED	Operational Service and Environment Definition
OSO	Operational Safety Objective
PAV	Personal Aerial Vehicles
PBN	Performance-Based Navigation
PSR	Primary Surveillance Radar
RAIM	Receiver Autonomous Integrity Monitoring
RBT	Reference Business Trajectory
RC	Radio Control
RCS	Radar Cross Section
RF	Radio Frequency
RNAV	Area Navigation
RNP	Required Navigation Performance
RPAS	Remotely Piloted Aircraft System
RTK	Real Time Kinematic
RTTA	Reasonable Time To Act
SAIL	Specific Assurance and Integrity Level
SBAS	Satellite-Based Augmentation Systems
SBT	Shared Business Trajectory
SERA	Standardised European Rules of the Air
SESAR	Single European Sky ATM Research
SOP	Signal of Opportunity
SORA	Specific Operation Risk Assessment
SPR-INTEROP	Safety, Performance and Interoperability
STS	Standard Scenario

Acronym	Definition
SWIM	System-Wide Information Management
TDD	Time Division Duplex
TDOA	Time Difference of Arrival
TMA	Terminal Manoeuvring Area
TMPR	Tactical Mitigation Performance Requirement
TOLA	Take-off and Landing Area
TTA	Target Time at the Arrival
TTO	Target Time Over
tTTA	tactical Target Time at the Arrival
tTTO	tactical Target Time Over
TV	Traffic Volume
UA	Unmanned Aircraft
UAM	Urban Air Mobility
UAV	Unmanned Aerial Vehicle
USS	U-space Service
USSP	U-space Service Provider
UTM	UAV Traffic Management, Unmanned Traffic Management
VFR	Visual Flight Rules
VLL	Very Low-Level
VLOS	Visual Line-Of-Sight
VTOL	Vertical Take-off and Landing

Table 2: List of acronyms

3 U-space DCB process: A summary

The DCB process presented in this document provides a tangible solution for addressing the need of integrating SESAR U-space service functionalities to produce timely, efficient, and safe decisions regarding the management of drone traffic. It has been developed to be inherently service-oriented, permissive of implementing increasing levels of automation into the management of unmanned air traffic and open to a series of novel business models and use cases.

The DCB process is focused primarily on drone operations in an urban environment, as this is the most complex application area, however these functionalities can be extended to other operating environments.

DACUS designs a U-space DCB process which follows a **performance-based approach** during its execution. All DCB decisions, and in particular the selection of DCB measures in case of imbalances, are supported by up-to-date data through a consistent U-space performance framework. This will allow a more efficient U-space system based on informed decision-making and driven by the foreseen results, using the most up-to-date information that is available. It is built on a **series of principles which guide the DCB decisions** within the U-space framework. These principles are:

1. Application of **collaborative decision making** to include Drone Operators within the decision-making process.
2. **Prioritizing the fulfilment of mission objectives** as a service to Drone Operators when selecting DCB measures.
3. Allowing for **“free-route” operations whenever constraints allow**.
4. **Minimization** of the number of instances in which changes to drone missions are required.
5. Incorporation of predictions and the **quantification of uncertainty into the DCB process**, to increase robustness of DCB measures within a dynamic operating environment.
6. Recognizing 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.

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” to separate the strategic phase from the pre-tactical phase. 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.

This could mean that areas with high traffic uncertainty will have a pre-tactical phase which is much closer to the departure time of the vehicle than those areas in which the traffic uncertainty is very low. Subsequently, the time given to Drone Operators to react to (and negotiate) DCB measures is greatly reduced in high-uncertainty areas. This strategy aims to incentivize proactive participation of Drone Operators to provide DCB-relevant information early in the process in order to reduce overall traffic uncertainty, which benefits all Drone Operators aiming to fly in a specific area. Additional incentives include the introduction of virtue points to further promote collaborative behaviour among users.

Furthermore, given the proximity of drone operations to the general public as well as ground infrastructure, a special emphasis was placed on including risk and social indicators as an integral part of the DCB process. This will assure that overall flight safety and the safety of third parties remains acceptably high and assuring that social impact factors (such as noise, pollution and visual impact) will remain below an acceptable threshold.

Finally, the process makes use of the service-centric approach of the U-space architecture to monitor for disturbances within the traffic picture in real-time with support of other U-space services, such as Navigation and Communication Infrastructure Monitoring, disruptions caused by local weather phenomena and any emergencies identified by the Emergency Management service. DACUS proposes to address these disturbances through the deterministic, and therefore, predictable management of contingency plans. This will allow U-space to characterize the impact of the disturbance as soon as it is reported and then, implement DCB measures if needed.

4 Operational Characteristics

The DACUS DCB solution needs to complement the operational environment in which drone operations will take place. To support the assumptions of the DCB process, an overview of the expected traffic demand, types of drone missions as well as characteristics of the departure & landing sites (i.e., airports), airspace and drone traffic is presented.

4.1 Traffic demand and drone missions

The large variety of business areas where drones can be utilized results in a diverse number of **drone mission** applications, which in turn have specific operational modes and use certain technical systems. Particularly interesting for the analysis of the impact of the missions on low-level airspace is the way they intend to use the airspace to accomplish their mission objective. Therefore, a generalized categorization of drone operations mainly focusing on the different characteristics of the typical flight schemes is provided here. This overview is based on the research performed within the IMPETUS project [20] and can be summarized as follows:

- **Surveillance operations**. They are distinguished by mostly ***larger trajectory patterns*** and possibly repeating schemes to effectively monitor larger areas or points of interest. It is expected that most of these operations will not be performed in close range of any structures and therefore will be deployed in ***higher altitudes within very low-level airspace***. Typical examples for this type are aerial mapping, traffic monitoring or applications in public safety and security;

- **Inspection operations**. They refer to all business models that practically require a close approach to the point of interest and for the whole execution of the mission task, e.g., the automated recognition of structural damage to a surface with optical methods. Contrary to surveillance operations, this type of mission can be expected to stay ***inside a defined and foreseeable containment area*** that is comparably small and ***near the observed structure***. Further examples for this case are the inspections of solar power, cell towers or target-oriented photography;

- **Transport operations**. They are characterized by a ***point-to-point flight scheme*** and the actual transport of goods or persons. The cruise flight in this type is mostly distant to structures but straight forward and optimised on efficiency to reach a certain destination. It is likely that loading and unloading requires an approach to the ground and/or solid structures. Besides the industrial and private transportation of goods, this operation type also covers medical transport (e.g., medication or first responder equipment) or the carriage of persons in personal air vehicles.

This categorization can be illustrated with typical application fields where the mission types have been employed in the past:

Table 3: Classification of market sector in relation to mission types.

Surveillance	Inspection	Transport
ES (Fire, Police, EMS, Coastguard)	Infrastructure	Medical
Traffic	Facades	e-Commerce (retail, food)
Construction	Energy (Solar, Power Lines etc)	Industrial / Corporate
Private Security Services	Telecom / Cell Towers	Public Transport
Meteorology	Insurance	Private Transport
Environment	Real Estate	
Aerial Mapping / Photography	Media and Entertainment	
Media and Entertainment		

As a starting point, operational characteristics shared in all operations have been identified and listed in the following bullet points. Depending on the specific drone services and solutions that are to be provided, certain operational characteristics will be determined from the mission requirements, such as the carried payload or specific operational timeframes. Other characteristics will have more flexibility to be negotiated by the operator and U-space system, such as different flight levels and the deployment areas at certain stages of the mission. Relevant for the DCB process is the **availability of this information ahead of time** and the **flexibility to modify the characteristics** without constraining the fulfilment of mission requirements.

1. ***Operational range***: This is mostly determined by the take-off/landing areas and deployment area. Knowing the operational range will set the technical requirements of the drone (e.g., platform type, communication and navigation systems).

2. ***Operational flight levels***: On the one hand, for some mission types, it might not be possible to choose any flight levels, especially in those where the drones are required to maintain a proximity to ground infrastructure due to their mission requirements. On the other hand, others may have altitude flexibility at least at certain phases of the mission. As a result of the DACUS Experiments, it became clear that the flexibility of flight levels is additionally restricted by local wind fields strengths. These are dependent on the layout of the urban canopy layer and increase with altitude (see Prandtl and Ekman effects). In consequence the drone type and its individual weather sensitivity determine, which flight levels are actually available.

3. ***Operational timeframe and frequency of the operations:*** The availability of the operational timeframes depends on multiple factors, like when the drone services are requested or how much time the operator needs to make all necessary preparations. Important for DCB could be the type of operations where the flight times can be planned with certain time ahead. This could be the case in scheduled operations well known in advance (e.g., drone operation as part of a surveillance mission). The fact that an operation has frequent flights does not

necessarily imply that the flight times will be know well in advance, as in the case of service request at short notice (e.g., delivery of goods)

4. ***Deployment areas***: Overflown areas that are not necessarily related to the mission area that is to be monitored or inspected could be selected in consideration of external factors like ground risk minimization or societal impact. Therefore, they are interesting for the DCB process as they offer a flexibility in their selection or negotiation.

5. ***Carried payload***: The specification of the carried payload is certainly relevant for risk assessment processes and potentially interesting for the DCB process when assessing the drone trajectories over specific urban areas.

6. ***Operations in special environments* and under specific external conditions**: Some drone operations will only be possible under special environments and specific conditions (night-time operations, surveillance mission over populated areas). What is important for the DCB process is that this information is available for considering specific traffic management measures that are different from normal operations.

7. ***Environmental impact* to third parties (noise, visual, privacy)**: This characteristic is mainly determined by other operational characteristics, like flight levels and deployment areas. It also very likely that the operators will not have all the necessary information to assess this impact. It is therefore necessary that the DCB services can provide the mechanisms to assess and measure these types of impact.

To verify the presented ideas, different missions have been reviewed from use case studies. Primarily, the most distinctive characteristics have been collected. The following table maps the characteristics to the different application areas.

Table 4: Summary of operational characteristics per mission type.

Mission Type / Market sector	**Char. ID**	**Selection of relevant operational characteristics**
Surveillance		
ES (Fire, Police, EMS, Coastguard)	6	Operations under special conditions (dangerous environments, adverse atmospheric conditions).
Traffic	4	Deployment over restricted areas (streets).
Construction	1, 3, 4, 5	On-site flight operations using dedicated payload systems for surveillance and aerial Mapping techniques.
Private Security Services	4, 5	Deployment of drones over private property.
Meteorology	2, 3, 6	Deployment for measuring atmospheric conditions at different vertical levels on regular basis.
Environment	3, 7	Flight operations with noise impact to third parties (e.g., wildlife).

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Aerial Mapping / Photography	1, 4	On-site flight operations inside a foreseeable containment area.
Media and Entertainment	4	Operations inside a foreseeable containment area.
Inspection		
Infrastructure	1, 2, 3, 4	Scheduled on-site flight operations close to structures for visual inspection of infrastructure as bridges etc.
Facades	1, 2, 3, 4	Scheduled on-site flight operations close to structures for visual inspection of outer building parts.
Energy	1, 2, 4	Flight operations close to structures for visual inspection of solar panel, power lines, etc.
Telecom / Cell Towers	1, 2, 3, 4	Scheduled flight operations close to structures for visual inspection of telecom infrastructure, cell towers, etc.
Insurance (Property Inspections)	1, 2, 3, 4	Occasional on-site flight operations for risk assessment and aftermath operations.
Real Estate	1, 2, 3, 4	Occasional on-site flight operations for aerial photography and filming.
Media and Entertainment	2	Close range operations (aerial filming) inside a foreseeable containment area
Transport		
Medical	1, 3, 4	Flight operations over mixed urban areas on regular basis.
E-Commerce	1, 3, 5	Flight operations over mixed urban areas transporting retail products, food, etc. on regular basis.
Industrial / Corporate	3, 5	Flight operations transporting from small to large payloads.
Public Transport	1, 3, 5	Flight operations transporting persons
Private Transport	1, 3, 5	Flight operations transporting persons

in the **surveillance missions**, it becomes apparent that the deployment area is a common distinctive characteristic. The areas overflown in these types of mission are mainly restricted or private (due to the nature of the missions) and it can be concluded that there is a low flexibility to be adjusted for DCB purposes. But given that many operations will take place on-site, it could be possible to assume foreseeable containment areas.

In the case of **inspection mission types**, many of them also take place on place on-site and on private areas where the inspection services are required. Moreover, the flight levels can be assumed to be very low (close to inspected structures) and also with a low flexibility to be negotiated. As many inspection services can be scheduled ahead in time, it could prove beneficial for the DCB process to access the operational timeframes as soon as the operators submit their operation plans. For inspected structures that are adjacent to areas with high degree of urbanization, the environmental impact is expected to be a subject of concern.

Lastly, in the case of **transport mission types**, it is evident that they are mostly "long-range" operations and that the overflown areas encompass several mixed urban areas. The type of carried payload can play a significant role when assessing the proposed transportation routes, as well as the environmental impact. Although it is expected to see these types of mission on a regular basis, it might not be possible to have specific operational timeframes ahead of time, mainly due to their business models (service requests on short notice). However, beneficial for the DCB process could be the establishment of route networks that not only improve mission efficiency but could also be part of a mechanism to manage operations when demand increases, and capacity reaches its limits.

One noteworthy application of drone missions is their utility in times of crisis, such as during the COVID-19 pandemic. The operational characteristics of these exceptional operations resemble the characteristics from other applications to a large extent, but potentially linked to a higher priority. Given the nature of their missions, that can have a large impact on other operations taking place in the same airspace volume. An overview of exceptional operations used during the COVID-19 pandemic is given in Figure 1.

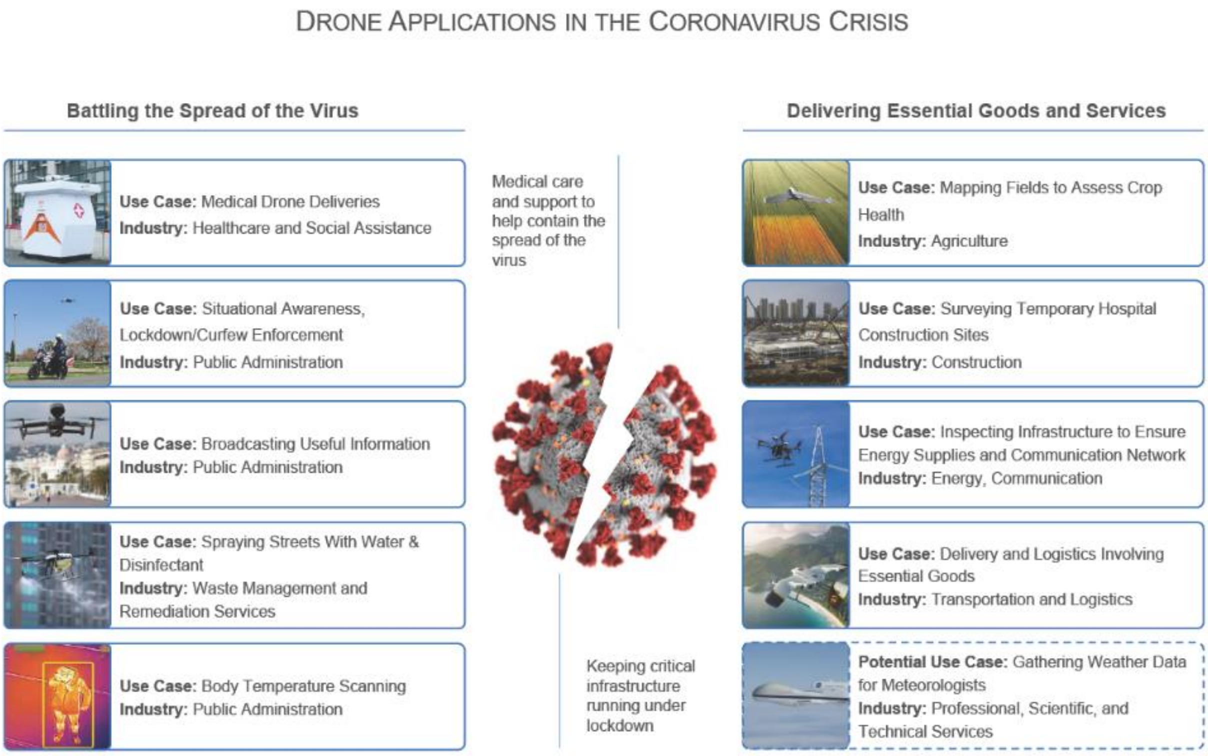

Figure 1: Overview of drone missions applied during the COVID-19 pandemic.

The estimation of drone traffic demand and **quantities expected in urban environments** is a challenge due to the still evolving drone industry and the ongoing establishment of drone applications in different market sectors. Initially, the SESAR Outlook Study [25] provided an estimation for drone demand in Europe through 2050.

Additionally, further forecast studies have been performed in the last years by NASA [46] and Levitate Capital [50]. The DACUS consortium undertook the task to compare these studies and merge the forecasts into a complete drone demand estimation for 2030-2050 in Europe:

Table 5: Optimistic drone demand scenario merging SESAR, NASA and Levitate Capital studies

Market (Study)	Number of Drones
Delivery (SESAR)	140.000
Mobility (NASA)	23.000
Public Safety & Security (SESAR)	120.000
Construction (The Levitate Capital)	400.000
Real Estate (The Levitate Capital)	70.000
Videography (The Levitate Capital)	450
Property Inspection (The Levitate Capital)	130.000
Total number:	**883.450**

Regarding the delivery sector, the SESAR study forecasts 70.000 registered drones, while the NASA study forecasts 40.000 drone vehicles. In this regard, the NASA study seems to be more moderate than the SESAR one. However, these figures are not very far from each other, especially if we consider the aforementioned difference in population between the two territories.

Regarding the mobility sector, the SESAR study forecasts around 1.000 registered vehicles, whereas the NASA study forecasts 23,000 operational vehicles. As this drone market sector is heavily subject to regulations and technological challenges, it is likely that the study conducted by NASA is more optimistic in this regard. On the other hand, the Levitate Capital study supports the numbers provided by the SESAR study. An estimation of only 16 trips for passenger per day is done for the whole USA. This number does not make it necessary to have high number of drones.

The information on the number of drones forecasted by the FAA study will not be used in this comparison. This is due to the possible difference in the definition of commercial UAS between the FAA study and the study conducted by SESAR, and also, due to the impossibility to differentiate the number of drones operating in urban environments from those that are not. This study forecasts that the commercial Small UAS (sUAS) fleet by 2025 will likely be at around 835.000 which is even higher that the most optimistic scenario in SESAR study by 2035.

These differences between SESAR and this FAA study can also be seen in the use of drones for the public safety and security sector. The SESAR Outlook Study does an estimation of 60.000 drones in 2035 for this sector, while this FAA study shows 30.000 sUAS in 2025. The annual growth rate of 24 percent showed in this study could be considered up to 2035, with a total number of sUAS of 370.000 in USA. In conclusion, the forecast of this study seems to be higher than those provided by NASA and SESAR.

The Levitate Capital study considers different drone sectors than those considered in the SESAR study. The information obtained from each study can be cross-linked, in order to create a much more complete estimation of the number of drones in each sector inside Europe. Due to the fact that the Levitate Capital study is based on the Target Addressable Market, i.e. the maximum number of drones in each domain, the scenario selected from the SESAR study should be the Higher Acceptance scenario, the one with the higher number of drones (double as the expected potential scenario). To keep this approach of selecting the most optimistic prediction, the NASA study forecast is used for the Mobility sector.

In any case, to manage such a large number of vehicles it will be very helpful to characterize the traffic demand and classifying the operations in terms of:

- ***Market sectors***: sectors like e-commerce, delivery and transport are especially relevant in urban areas.
- ***Mission profiles***: increase of BVLOS operations with light load and for surveying purposes will have a considerable impact on missions in urban areas.

From the studies analysed we conclude that estimations with a higher resolution and focused on urban environments are still required. Especially in urban areas the density of operations could be high, and the capacity could be constrained by restricted and private areas. The studies provide general quantities, that in the case of the Delivery sector was a good starting point for the DACUS traffic scenarios. On the other hand, for the Mobility sector it appears overly optimistic to expect similar quantities as in the other sectors, at least for the next 20 years. Finally, the Public Safety and Security sector should be further considered, as it shows similar quantities as the Delivery sector (around 60.000 by 2035).

Based on the numbers of drone demand from available sources, we derived a **distribution of drone operations per application field** that was useful for starting with a modelling of large-scale traffic scenarios in DACUS:

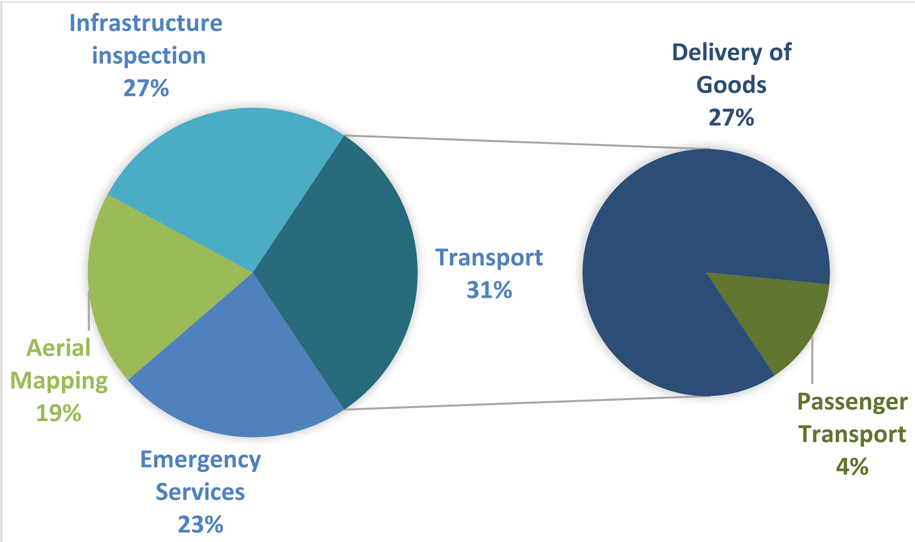

Figure 2: Distribution of application types[1]

Specifically for the traffic simulations in the urban areas of Madrid and Frankfurt, the number of operations was modelled using application-specific demand estimations and real data such as delivery orders per year or existing street infrastructure that could be inspected. The complete rationale and assumptions can be found in [51], Appendix B and D.

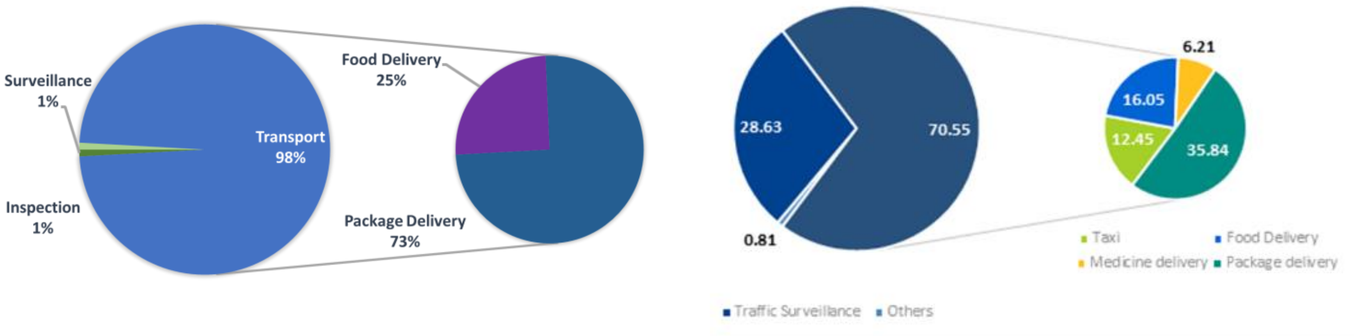

Figure 3: Distribution of application types for the urban areas in Frankfurt (left) and Madrid (right)

It can be noted that here the most predominant mission type in both cases is the transport of goods. The main reason for this is that operations for this mission type can be well modelled with existing data and well-founded estimations.

[1] For this distribution, the following numbers have been used: Railway (3K), Bridge (5K) and Property Inspection (130K) values are extracted from the Levitate Capital forecast [4]. The values from Emergency Services (120K) , Delivery and Media & Entertainment (30K) have been extracted from the SESAR study [1]. The Passenger Transport (23K) values are from the NASA study [2]. Finally, the value for Aerial Mapping (100K) is the only one that has been assumed

Finally, the daily distribution of operations was also subject of study for the modelling of traffic scenarios. In this regard, the DACUS consortium analysed consumer behaviour and working hours for every application field and elaborated a rough estimation per application field [52]. With this, it was possible to identify traffic demand peaks and focus the assessment of DCB processes at these timeframes.

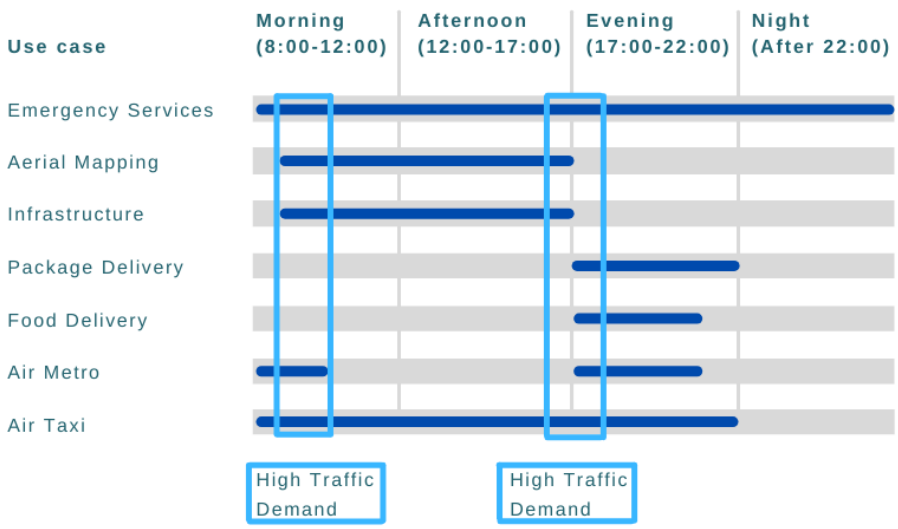

Figure 4: Distribution of operation per application field during the day

4.2 Take-off and landing area characteristics

In principle we presume that for the Urban Air Mobility context, airports or respectively **take-off and landing areas (TOLA)** will exist for small drones, personal air vehicles, helicopters and traditional manned aviation. They can be either **permanent or temporary sites** that differ strongly depending on the characteristics of the vehicles they are dedicated to.

For **small drones, TOLA can be small landing pads**, which solely support take-off and landing capabilities, or even large drone-hubs that offer a wider range of ground services e.g., for package delivery, maintenance or surveillance for public safety and security. Apart from these static installations small drones will **also launch from dynamically changing positions** depending on the operation type. As an example, it is very likely that localized missions such as search and rescue, façade inspection or police surveillance depart in the vicinity of the operation area and the aircraft are brought there through ground-based transportation modes.

PAVs require larger TOLAs due to their dimension and appropriate technical equipment. The project Metropolis elaborated the following classification of potential **PAV TOLAs** [23]:

- **Existing airfields;**
- **Dedicated PAV strips** or spots;
- Usage of **road segments** alternating with road traffic;

- **Pillar mounted strips** or spots on existing road or railroad infrastructure;
- **Waterways;**
- **Rooftops** of existing buildings.

Furthermore, **dedicated sites for vertical take-off and landing (VTOL) aircraft**, in general called **vertispaces**, can be subcategorized into vertihubs, vertiports and vertistations [21]. **Vertihubs** are comparable to small airports, which are based at the **periphery of urban and suburban areas**. Besides the main purpose as boarding station for passengers and exchange site for cargo, it offers enough space for any fleet services, such as maintenance, MRO, recharging, parking and other related services. **Vertiports** are **medium-sized stations located at the primary passenger destinations**, such as shopping malls, business districts or central stations to other modes of transport. Their layout will include fast refueling/recharging stations and a small terminal for passenger handling. **Vertistations** however are the minimal configuration for permanent, designated **PAV landing areas, sized to serve 1-2 vehicles at the same time**. Technical installations will depend on the local network layout, but as peripheral nodes it is possible that they will only offer access control and waiting areas for passenger.

Figure 5: Overview of different types of TOLA infrastructures for VTOL aircraft [21].

Existing heliports and manned aviation airports will be relevant for two reasons. Firstly, they will be **integrated inside the UAM networks** to be **utilized as additional TOLAs** or intermodal exchange points. Secondly, the **airspace design needs to take into account control zones and terminal areas** that possibly interfere with other, prioritized air traffic, such as manned aviation or helicopters departing from hospitals.

In preparation for our traffic simulation we analysed various studies to get a first impression how many stationary TOLAs can be expected per capita for a high maturity of urban air mobility in about 10 to 15 years. This includes the foremost explained vertistations, heliports and hubs for transportation services and public safety and security. Not included are permanent inspection services to maintain facilities and infrastructure, since we expect this amount be rather area-specific than proportoinal to population density.

Table 6: Predictions on quantities of stationary TOLAs per capita.

TOLA type - example area	Assumed number of TOLAs		Reference Population	Description	Population per TOLA		TOLAs per capita	
	Low	High			Low	High	Low	High
Vertispaces	2000	4000	121000000	*Estimated amount of additional vertispaces for the 15 largest metropolitan areas in the U.S. (NASA Study, 2018)*	60500	30250	0,00002	0,00003
Heliports				*Current amount of TOLAs in metropolitan areas in LA, Boston and Dallas (Analysis by Parker D. Vascik, 2020)*	32821	20179	0,00003	0,00005
- Los Angeles MA	390		12800000	*Metropolitan Area*	32821		0,00003	
- Boston MA	223		4500000	*Metropolitan Area*	20179		0,00005	
- Dallas MA	313		7200000	*Metropolitan Area*	23003		0,00004	
Transport UAV Hubs	14800		83000000	*Current amount of traiditonal dispatch departments in whole Germany (Source Statista.de, 2020)*	5608		0,00018	
Surveillance UAV Hubs				*Estimation of stationary surveillance hubs by Police and Fire Departments*	31496	14445	0,00003	0,00007
- Police Departments				*Current amount of police stations for city areas in LA, Boston and Dallas*	190476	59091	0,00001	0,00002
-- Los Angeles PD	21		4000000	*City Area*	190476		0,00001	
-- Boston PD	11		650000	*City Area*	59091		0,00002	
-- Dallas PD	7		1300000	*City Area*	185714		0,00001	
- Fire Departments				*Current amount of fire stations for city areas in LA, Boston and Dallas*	37736	19118	0,00003	0,00005
-- Los Angeles Fire Department	106		4000000	*City Area*	37736		0,00003	
-- Boston Fire Department	34		650000	*City Area*	19118		0,00005	
-- Dallas Fire Department	58		1300000	*City Area*	22414		0,00004	

As a test case we applied the calculation to the population that is living in the metropolitan area of Toulouse (about 1.2 Million people). In total a number of roughly 350 – 450 stationary TOLAs can be expected there.

Table 7: Extrapolation of TOLA quantity predictions for three major cities in the European area.

TOLA Type	Toulouse[2]		Frankfurt[3]		Madrid[4]	
	Low	High	Low	High	Low	High
Vertispaces	22	45	12	25	109	218
Heliports	41	67	23	37	201	327
Transport UAV Hubs	243	243	134	134	1177	1177
Surveillance UAV Hubs	43	94	24	52	210	457
- Police Departments	7	23	4	13	35	112
- Fire Department	36	71	20	39	175	345
Total amount of TOLAs	349	449	193	248	1697	2179

This allows for a first impression on TOLA numbers that can be expected for large, urbanized areas. Nevertheless, it should be mentioned that this estimation can be further improved in the course of the project. As an example, this calculation does not take into account density specific parameters or additonal private services other than transport, which we expect to be the most influential on the stationary hub amount. Also the question of dynamic TOLAs had to be neglected, as the level of complexity is much higher and based on the mission specific drone deployment areas and business cases.

4.3 Airspace characteristics

As it is expected that most drone operations will take place in **VLL airspace**, it is essential to first identify the boundaries of this airspace. Adhering to the definition by CORUS, VLL is the airspace below that used by manned aircraft flying under visual flight rules (VFR) [14]. The SERA regulation defines the lower limit for VFR operation above urban areas, which is "over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a **height less than 300 m** (1 000 ft) **above the highest obstacle within a radius of 600 m from the aircraft**" [15]. Where the previous is not applicable, the SERA regulation sets the lower limit of VFR operations "at a height less than 150 m (500 ft) above the ground or water, or 150 m (500 ft) above the highest obstacle within a radius of 150 m (500 ft) from the aircraft". Although these rules set a higher limit above urban areas, 150m are often stated to be the upper limit of VLL. the While most (or all) drone operations are expected to take place in VLL, it is important to note that this airspace is not currently empty as there are many reasons why manned

[2] Toulouse Metropolitan Area: 1200000 People

[3] Frankfurt City Area: 750000 People

[4] Madrid Metropolitan Area: 6600000 People

aircraft can operate in uncontrolled VLL, such as emergency or police helicopters and aircraft or small glider aircraft [53].

For the implementation of a U-space airspace, EASA envisages to allow the Member States to decide how their airspace is designed, accessed, restricted [17]. As U-space should be established in both controlled and uncontrolled airspace, it is crucial to adhere to existing structures, regulations and practices. This means for instance that air traffic service (ATS) providers are designated to **provide air traffic control (ATC) services** in controlled airspace and flight information services (FIS) providers are **providing FIS and alerting services** in many parts of uncontrolled airspace. Additionally, the principle shall be followed where the ANSPs provide **air navigation services (ANS) to manned aircraft while USSPs provide U-space services to UAS operators**. This shall guarantee that **manned and unmanned traffic** will not mix with each other within controlled airspace as they **are dynamically segregated**. In uncontrolled airspace, restriction mechanisms should be applied by the Member States when manned aircraft operations use the same airspace as unmanned aircraft.

The CORUS Consortium has proposed different **types of volumes** that divide the whole VLL airspace into different classes [14]. These volumes include the "UAS geographical zones" envisaged in current regulations [16] which are motivated by the different number of drones that are expected over certain areas and the associated air and ground risks. They mainly differ in the following aspects:

- Services being offered, and hence the types of operation which are possible; and
- Access and entry conditions, including drone capabilities required.

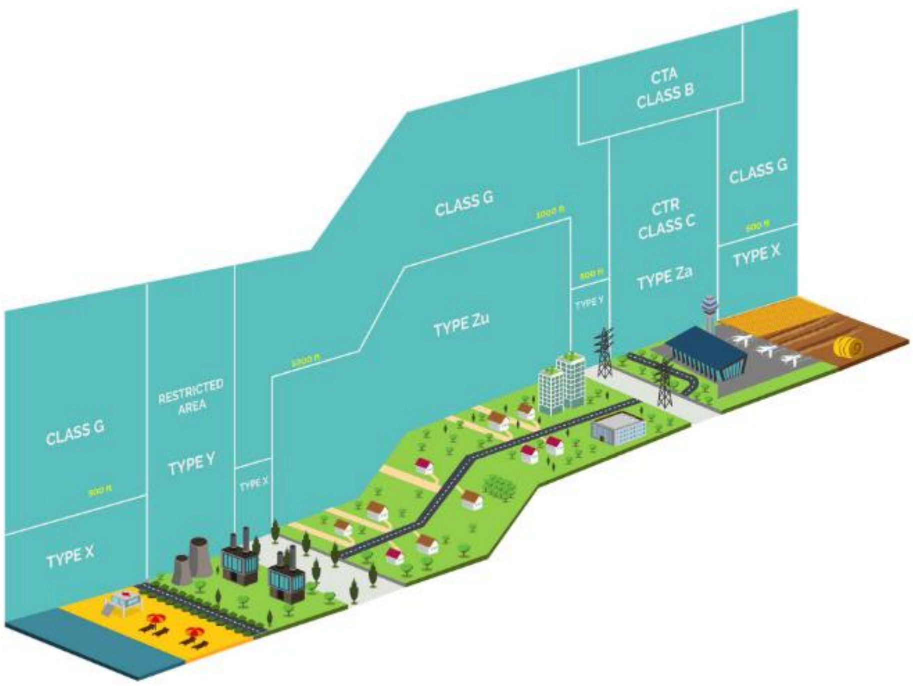

Figure 6: Overview of U-space airspace classes as defined by CORUS [14].

Furthermore, **restrictions** may be placed on drone operations at short notice and with short duration, for example to protect an emergency manned flight in VLL [14]. Given the higher-priority nature of the manned aircraft operation, these short-term restrictions might over-ride existing volumes. To ensure that these (static and dynamic) airspace restrictions are being complied with, the Metropolis 2 project

[54] emphasises the importance of geo-fences which prevent drones from entering zones where they are not allowed to fly.

Similar airspace structures have been defined in other research efforts and studies. The main goal of designing tailored airspace structures is generally both the increase of safety and efficiency of dense airspace traffic. The Metropolis Consortium have studied different **airspace structure concepts** with an increasing level of structure and traffic organisation to assess the resulting capacity [26]. Relevant concept elements taken into consideration are separation requirements, applicable conflict detection and resolution techniques, airspace usage restrictions and traffic flow management principles. McCarthy et al. have identified two core elements for the modelling of future airspaces, namely, the **airspace architecture** (how the airspace is structured and how drones can navigate through this space) and the **traffic management systems** in place (especially the features related to deconfliction and emergency handling) [34]. The UTM Blueprint from Airbus also discussed the implications of defining certain routing structures [13].

Finally, the need of defined **flight rules** at low level has been identified in most of the references that address airspace design and management. The UAS ATM Integration Operational Concept proposes that two new sets of rules are required – low-level (LFR) and high-level (HFR) flight rules - which would accompany the current visual and instrumental flight rules [18] (more details are provided in section 6). Further **operational procedures**, especially during the take-off and landing flight phase, have been treated in the simulation of future airspace structure concepts [23].

From this analysis of the state-of-the-art, common characteristics of the urban airspace for drones have been derived and classified in the following list. For each characteristic, their expected impact on the DCB process is described.

Common characteristics of urban airspace for drones:

- **VLL airspace**: A defined VLL airspace including its boundaries is one of the main factors impacting the capacity of the airspace. Although low-level operations for urban environments have been proposed so far, it is still necessary to assess how suitable are these in areas with high density of traffic, high amounts of ground infrastructure and potentially complex airspace structures. Another important characteristic is the type of airspace and whether it is uncontrolled or controlled airspace. In the case of the latter, it has considerable implications, as operations must adhere to existing regulations and practices.

- **Short term restrictions**: Like Notice To Airmen publications (NOTAMs) in manned aviation, it can be expected to have short-term and dynamic announcements in urban environments that may imply flight restrictions over certain areas. Especially considering the urban characterization (e.g., dynamics populated areas), it is reasonable to expect the activation of short-term restrictions, potentially as geofences. Relevant for the DCB processes are the temporal and spatial characteristics of these restrictions. The implications of restricted areas that reach the limits of the VLL could be very significant for airspace management.

- **Volumes of airspace** (within VLL airspace) characterized by
    - Implemented geographical zones within, which might prohibit certain drone operations or allow access to certain drone classes only;

  - U-space services available/provided;
  - Certain access and entry requirements, including drone capabilities required.

  These well-characterized volumes can be very useful for the DCB process as they could be established in urban areas where only certain type of drones could access and where only a set of U-space services can/should be provided. The reasons for this are many: high density traffic, availability of management services and CNS infrastructure performance. In general, these volumes offer flexibility for airspace management and their integration in VLL airspace is very recommended for DCB purposes.

- **Airspace structures**: In principle, drone traffic does not necessarily need to be managed through a specific airspace structure. For instance, some airspace volumes proposed by the U-space CONOPS do not consider a structure in particular and therefore drones could operate freely in airspace. This is certainly a good approach to keep airspace management complexity at a low level. But recent assessments have shown that the use of airspace structures could be very beneficial to cope with high density traffic flows in very constrained airspaces. We can also conclude that these airspace structures could offer mechanisms to further refine and adapt airspace volumes. Apart from routing structures, several other aspects need to be considered:
  - Routing strategies;
  - Traffic management systems with certain automation level and human operator involvement;
  - Traffic flow management principles;
  - Separation requirements;
  - Conflict management models (either centralized or decentralized) covering the strategic and tactical phase;
  - Airspace usage restrictions (such as min./max. speeds).
- **Operational practices**: Practices included in the current approach for airspace management are:
  - Flight rules;
  - Take-off and landing procedures;
  - Handling of abnormal situation;
  - Handling of adverse weather situations.

  These procedures could also be adapted depending on requirements from drone traffic management. Furthermore, they could be expanded with procedures directly linked with demand and capacity optimization, like handling in airspace volumes with dense traffic.

- **Interaction manned of unmanned aircraft operations**: Most of the traffic management concepts agree to that is important to ensure segregate manned and unmanned operations.

Mainly due their very different technical performances and capabilities. However, it might not be possible to keep a large and static separation when manned vehicles operate especially near ground infrastructures. Here is where DCB concepts could be useful to enable a dynamic segregation based on traffic demand.

- **Provision of services**: DCB-related services could become supporting services to adapt the airspace volumes in VLL airspace. In any case, there are some that could be almost considered mandatory if airspace structures and high densities are expected in urban environments:
  - Air traffic control (ATC) services in accordance with the airspace classification;
  - Flight information and alerting services;
  - Conflict resolution services.

4.4 Traffic characteristics

There is a wide range of air vehicles which are suitable for carrying out commercial operations. Generally, these have been classified based upon their characteristics, such as size, weight, flight range, propulsion system and capabilities [19]. A further classification that will become relevant in the future is the one created by EASA for the regulation of drone operations [16]. Here, the air vehicles will need to meet certain technical and performance requirements, and they can be mainly distinguished by the following characteristics:

- Maximum Take-Off Mass (MTOM), including payload;
- Maximum speeds in level flight;
- Defined stability, manoeuvrability and data link performances;
- Equipped with certain technical systems (such as an geo-awareness system);
- Maximum allowed range under certain operation conditions (VLOS, BVLOS).

What is also important to consider when multiple drones occupy the same airspace volume is not only the flight geography they will occupy in the nominal operation, but also a potential further volume in case of contingencies. In the scope of the Risk Assessment Model for UAS operations, the European Regulation defines the **operational volume** as the **composition of the flight trajectory and the contingency volume** [16]. The flight trajectory means the volume(s) of airspace defined spatially and temporally in which the UAS operator plans to conduct the operation under normal procedures and the contingency volume means the volume of airspace outside the flight trajectory where contingency procedures described are applied. Furthermore, the operational volume shall be characterized by the position-keeping capabilities of the UAS in 4D space (latitude, longitude, height and time), in particular:

- Accuracy of the navigation solution;
- Flight technical error (the flight technical error is the error between the actual track and the desired track) of the UAS;
- Path definition error (e.g., map errors);

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- Latencies.

After analysing the types of missions and identifying relevant expected application fields in the previous sections, we can assume that multi-rotor type drones are most likely to be found operating in urban areas. They are suitable for all three types of mission due to their stability, manoeuvrability and ability to take-off and land vertically (VTOL capability). Fixed-wing hybrid VTOL drones could also be found in urban environments, as they are especially suitable for transport and surveillance missions. Operators might use them when it comes to achieve long range operations and achieve high flight efficiency. Due to its design, they could still land vertically and with high accuracy. Furthermore, drones of fixed-wing type seem to find a low use for the type of operations in urban environments. As they require larger take-off and landing areas and have a lower degree of freedom and closed spaces, operators might decide one of the other platforms. Finally, considering that technology will allow the integration of advanced technologies into the drone's platforms, it is valid to assume that most of the drones will be of small and medium size. Surveillance and inspection mission types mostly do not require to carry heavy payload. However, for transport missions the size and weight of the payload will be a limiting factor, depending on goods to be carried. As it was noticed in the market studies available, a high number of operations in the urban air mobility sector are not likely to take place, therefore reducing the number of larger-sized drones.

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5 UAS Capabilities

This section describes the technical characteristics and capabilities of elements essential to providing the DACUS DCB solution as well as technical limitations that are important to consider. It will detail capabilities of the drone platform – more specifically the Unmanned Aircraft Vehicle (UAV) – and its supporting Ground Control Station (GCS) as well as the capabilities of U-space Services and Air Traffic Services.

The components of a generic drone (UAS) which can affect to the Demand and Capacity Balancing process are:

- **Aerial Platform:** The UAV configuration (fixed wing, multi rotor, single rotor, fixed-wing hybrid VTOL or tethered drones) will affect the level of manoeuvrability of the aircraft and, thus, the capacity and structure of the airspace, as well as the solutions proposed by the strategic and tactical conflict resolution services. In particular, in the case of fixed-wing platforms, flight control surfaces (ailerons, rudder and elevator) will affect the level of manoeuvrability and the actions the aircraft could take when a conflict is detected.
  The size of the drone also affects the impact in case of accident, as the kinetic energy depends on the weight. Therefore, it has an effect on the maximum acceptable capacity.
- **Motor:** Most of the drones use electric motors which specific characteristics in terms of noise and environmental impact. In addition, the engine kinetic energy output affects the speed of the vehicle, which in turn affects capacity.
- **Battery:** Battery capacity will limit the flight time of a drone and, therefore, it sets a maximum time within the airspace for which the demand is to be estimated.
  Battery capacity will also determine the suitable contingency plans when an emergency happens, which in turn is impacting the DCB processes during the execution of the flight.
- **First-Person View (FPV) camera**: it can increase situational awareness reducing the reaction time in case of conflict, increasing therefore the capacity of the airspace.
- **Payload:** As part of the payload, drone could carry on board systems to enhance the capabilities of the drone (network remote identification, etc) and, thus, increase capacity.

In addition, the most relevant drone components related to its remote control and positioning capabilities as well as navigation, communications and surveillance data provision can also have an impact on the capacity thresholds in a certain area and on the DCB process itself.

5.1 Flight Controller

The flight controller determines the ability to follow the intended trajectory accurately and the stability of the flight. The better the ability of the flight controller to follow accurately the trajectory, the lower the number of potential unexpected conflicts. Additionally, in structured airspaces, the lower the path steering error, the lower the number of conflicts and therefore, the higher the capacity.

Given that the flight controller stability impacts the position estimation error, it could be **considered as part of the global navigation error** which will include errors related to signals in space, receivers and flight controller. This navigation error is one of the key factors which should be taken on board to determine the maximum number of drones in a certain area through the assessment of collision risks.

5.2 Communication

The command and control (C2) is the main communication link between the drone and the pilot and it depends on the communication capability of the drone. In addition, it is possible to use other technologies for drone communication, like cellular networks. The performances of the C2 link and the cellular networks will have an impact on the DCB process, and in particular, on the capacity thresholds in a certain area.

The command and control (C2) link connects the GCS (usually the pilot's radio control) and the drone to manage the flight. The C2 receiver, located on the drone, will receive the pilot's commands and send them to the flight controller (FC), which makes the drone move accordingly. More than 90% of all drones communicate over the unlicensed bands; usually 2.4GHz and 5.8GHz in some cases (normally, it is used only for video link). On 2.4GHz band, the **maximum range is typically 1km**. On 5.8GHz band, this value will be lower (higher frequency).

By far the most commonly used (>80%) radio technologies for remote drone control are proprietary implementations of Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS). To increase immunity to interference, both methods use a broader spectrum than is actually required to transmit the desired signal. FHSS and DSSS methods, which are sometimes also used in combination, are perfect for the heavily used unlicensed bands, where many user and radio technologies must coexist. The combination of two methods of transmitting radio signals allows increasing the capacity of an airspace, as they increase immunity to interference, allowing a greater number of simultaneous operations.

The main constraint of using the C2 link is that in case of failure the pilot would be unable to control the drone. The various failure modes of any typical radio-communication link include outage due to limited size of coverage area (1km); outage due to rain attenuation (significant for frequencies higher than 6-7 GHz); outage due to equipment or ground infrastructure failure; outage due to unintentional interference; outage due to malicious interference; and malicious spoofing/link takeover. It is difficult to quantify the size of safety buffers required due to C2-link performance limitations as well as these interferences because they depend on the technical characteristics of the C2 link, so it has to be defined case by case. In case of high demand environments, the C2 link robustness and the C2 link spectrum saturation will have to be assured specifying minimum technical requirements. In any case, given that the **robustness of current drones' models C2 links is generally very limited and easily jammed, they require large separation buffers**. Anyhow, in the case of autonomous operations such as those expected in urban environments, most drones will not be controlled by RF C2 link.

Command and Control over cellular networks is an alternative solution for drone communication. The drone (Flight Controller) can also be connected to the mobile network, using mobile connectivity for command and control. This solution improves safety because all the real-time information from the drone can be sent over the network to the GCS (and also to U-space).

This also allows increasing the maximum operation range from 1km to the entire cellular network, enabling Beyond Visual Line-Of-Sight (BVLOS) operations in a simple way into VLL (Very Low Level) air space. **Upper than VLL, cellular network coverage decreases dramatically, because network antennas are tilted down**. If operations close to 500ft or even up to 1000 ft are expected, specific cellular network performance studies will be required to check the provided coverage. DCB solutions which are increasing the available airspace for drones when demand is high should take into consideration this reduction in the cellular network coverage as a limiting factor.

In addition, it is very difficult to interfere with the operation of the link (intentionally or not), since the cellular networks use very stringent encryption protocols and they operate in several bands depending on the technology (3G, 4G and 5G in the future). Therefore, in the event of interference, it would only be necessary to switch to another available band (even to another operator).

In summary, it is assumed that in future operation environments most drones will be autonomous and flying BVLOS operations controlled via cellular networks. Accordingly, existing C2 links would not be used and therefore they will not be relevant to quantify the maximum number of drones which are manageable in an area taking into consideration the communication errors.

5.3 Navigation

Whether the vehicles are guided autonomously, or guided by pilots, GNSS in drones plays an important role. If sufficient satellite signals can be accessed during the entire drone mission, GNSS navigation techniques can offer consistent accuracy. Often, GNSS is used in conjunction with INS, to provide more robust drone navigation solutions. In any case, leaving INS aside, the navigation capability of the drone depends on the Global Navigation Satellite Systems (GNSS) signals and the GNSS receiver's performance.

Similarly to the Flight Controller (FC), the navigation accuracy is also impacting the ability to follow the intended trajectory accurately and the stability of the flight. Therefore, it can impact on the number of potential conflicts (if there has been a previous strategic deconfliction). Additionally, in structured airspaces, the lower the path steering error, the lower the number of conflicts/collisions and therefore, the higher the capacity. Therefore, the proper performance of the navigation systems is essential to assure safe drone operations, as the capacity of an airspace is limited by the maximum acceptable level of risk (ground risk + air risk), which depends on the collision rate.

Lower accuracy of navigation systems would imply that higher separation between drones and manned aircraft will be required, which would imply a lower capacity.

The SESAR ER Project TERRA [36] analysed the impact of navigation performances on the collision risk as the reference model to calculate the maximum number of drones in a certain area. The document "Architecture & Integration of Systems Description" from the TERRA project explained that fatal injuries due to a drone collision with another aircraft will occur if these events happen at the same time:

- There is a Navigation Integrity failure;
- The trajectory of the drone converges with another drone/manned aircraft causing a collision;
- The drones/aircraft fall over people on the ground;
- Injuries become lethal which depends on the lethality area, drone, speed, height and sheltering factor.

The data presented in TERRA project suggested that the navigation integrity failure risk in non-segregated airspace should be lower 1E-5 per flight hour. **This figure cannot be achieved without an integrity monitoring GNSS augmentation (e.g., RAIM or EGNOS/SBAS)**. In segregated airspace, receivers including integrity monitoring techniques were also considered recommendable in urban areas.

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Drones can still be flown in VLOS, without GNSS integrity monitoring, provided that **they are geo-caged to protect the rest of the users from potential deviations**. Therefore, it is envisioned the need of defining geo-cages in high density environments to allow such VLOS operations.

5.4 Surveillance

It is very important that both the pilot and the U-space system know the location of the drone at all times. This is critical in environments where there is high drone traffic demand and, especially, close to ATM airspace.

Surveillance and navigation systems can be seen as two elements whose performances will affect to the maximum number of drones which can be safely managed in an area. In case of navigation outages, an independent surveillance system would reduce the collision rate and therefore, increase the capacity.

The SESAR ER Project TERRA, analysed the impact of independent surveillance on the collision risk. The document "Architecture & Integration of Systems Description from the TERRA project explained that, when a navigation failure occurs, an independent surveillance (e.g., ADS-B, Mode-S and cellular network triangulation) system reduces the probability of collision. Fatal injuries due to a drone collision with another drone will occur if:

- There is a Navigation service failure;
- The trajectory of the drone converges with another drone causing a collision;
- The drones fall over people on the ground;
- Injuries become lethal which depends on the lethality area, drone, speed, height and sheltering factor;
- And it cannot be detected by an independent surveillance network (1% of not being detected). Thus, the surveillance system is introducing one more element that allow reducing the probability of fatal injuries.

The TERRA project suggested that if there is an independent surveillance system, the acceptable navigation system continuity and availability would be 99.9% in urban areas and 90% in rural areas. However, without the independent tracking system, the continuity and availability of the navigation system should be 99.999% in urban areas and 99.9% in rural areas. GNSS availability can reach 99.9%, but 99.999% cannot be achieved almost by any system.

In summary, to keep beyond an achievable navigation system availability level, in non-segregated airspace, **an independent tracking system to supplement surveillance by telemetry reporting should be mandatory in urban airspace** or where the presence of manned aircraft is likely. This independent tracking system could be **based on cellular networks or any other cooperative technology (e.g., ADS-B, Mode-S), to make it affordable**.

5.5 GCS capabilities

The GCS influences the situational awareness and therefore, in the reaction time in case of conflict. The GCS HMI will have to be **designed to maximize situational awareness, not affecting therefore the maximum capacity**.

The GCS can be the main source to provide the U-Space system with drone position data, to feed the Tracking and Position Reporting service. The update rate, accuracy and continuity of service of the data provided impacts on the ability and time to detect conflicts by the U-space system, as well as on the number of false alarms, affecting therefore to the capacity.

6 Applicable standards and regulations

This section provides the regulatory baseline for the DACUS DCB concept. It lists the most relevant aspects of published as well as envisioned European standards on drone operations as well as pending regulations.

6.1 European regulations for drone operations in populated/urban environment

The Commission Implementing Regulation (EU) 2019/947 established three different categories of operations based on the risk involved by the operation itself [31]. These **three categories** are **"open", "specific" and "certified"**.

Operations in the open category present the lower risk and should not require UAS that are subject to standard aeronautical compliance procedures but should be conducted using the UAS classes that are defined in the annex of the delegated act 2019/945. These operations are limited to VLOS and for drones not heavier than 25kg. Operations under the **"open" category** will be of **minimum relevance to the DACUS DCB concept**, given the restrictions imposed on these vehicles.

The **"specific" category** covers other types of operations presenting a higher risk and for which a thorough risk assessment should be conducted to indicate which requirements are necessary to keep the operation safe. A widely known risk assessment methodology is the **Specific Operation Risk Assessment (SORA)**, developed by JARUS [32]. But other methodologies could be used. This category covers operations in VLOS and BVLOS. Specific-category drone operations are expected to be the **most frequent actor within the DACUS framework**.

The **"certified" category** should, as a principle, be subject to **rules on certification of the operator**, and the licensing of remote pilots, in addition to the certification of the aircraft pursuant to a regulation which is being established. It is important to note that the European Aviation Safety Agency does not make distinction between professional and recreational usage of a drone.

6.1.1 General statements for drone operations in an urban environment

First and foremost, it is necessary to define the characteristics of the term "urban environment" regarding drone operations. This is by no means consolidated, as each member state may apply their own definition for this term. To provide an example, the Spanish definition is provided. According to recently published Spanish legislation on drones [47], the following environments are considered as "urban":

- Population nuclei with areas consolidated by buildings;
- Areas with vehicular access, paved public roads for pedestrian access, water evacuation and public lighting;
- Parks or gardens supervised by local authorities;
- Embassies, consulates and international organizations within a radius of 100 m.

To operate in the areas mentioned above, the Royal Decree prescribes the need of prior authorization and a flight altitude **300m / 1000ft above the highest obstacle.** In this particular case, the operation would be well above VLL airspace.

At a European level, the execution act (EU) 2019/947 dated on 24 May 2019 brings with **articles (21) and (22)** some important information for drone operation in urban and/or populated environment, provided that the conditions described below are usually met in that kind of areas.

(21) Some areas, such as **hospitals, gatherings of people, installations and facilities like penal institutions or industrial plants, top-level and higher-level government authorities, nature conservation areas or certain items of transport infrastructure**, can be particularly sensitive to some or all types of UAS operations. This should be without prejudice to the possibility for Member States to lay down **national rules to make subject to certain conditions the operations of unmanned aircraft** for reasons falling outside the scope of this regulation, including environmental protection, public security or protection of privacy and personal data in accordance with the union law.

As an example, in the case of Spanish legislation, drone operations over the following facilities and infrastructures require previous authorization, are subject to additional restrictions and must be executed above 300m / 1000ft over the highest obstacle within a 600m radius:

- Power plants, petrochemical or chemical industries, refineries, supply services and fuel depots;
- Port and railway infrastructures, roads and other transport infrastructures, except aerodromes;
- Infrastructures of water, gas and electricity supply and distribution services;
- Information and communication technology infrastructures;
- Police stations, warehouses and premises of the Security Forces;
- Public and private hospitals and public health centres.

(22) **Unmanned aircraft noise and emissions should be minimized as far as possible** taking into account the operating conditions and various specific characteristics of individual member states, such as the **population density**, where noise and emissions are of concern. In order to facilitate the societal acceptance of UAS operations, Regulation (EU) 2019/945, parts 13, 14 and 15 includes maximum level of noise for unmanned aircraft operated close to people in the “open” category. In the **“specific” category** there is a requirement for the operator to develop guidelines for its remote pilots so that all **operations are flown in a manner that minimizes nuisances** to people and animals.

Taking into account the article 21, **City councils and local entities should have a role in the determination of those noise or emissions thresholds which are acceptable in specific areas** within the urban VLL airspace. Consequently, they should participate in the overall DCB process and will need mechanisms to interact with U-space.

On the other hand, article 22 shows the need of promoting those operations that minimize the noise and emissions, and in general the population acceptability. This article sets the need to prioritize those operations, not only individually, but also a part of the overall DCB process. Thus, if the total number of drone operations in a certain urban area has to be reduced, those **operations which are reducing their noise and environmental impact should be prioritized**.

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It is also important to consider operational restrictions for drones around public aerodromes, as they are generally located near or within urban areas. In general, the controlled traffic regions around airports which provide air navigation services are considered No-fly Zones for drones unless explicitly authorized and coordinated with authorities. Similar restrictions apply to public or restricted-use aerodromes which do not-provide air navigation services, as is exemplified in the case of Spanish legislation presented below. The blank area indicates dimensions in which drone flights are not permitted unless coordinated with the aerodrome. The striped area indicates where drone operations are allowed up to 45 meters AGL; flights at higher altitudes require coordination with the aerodrome.

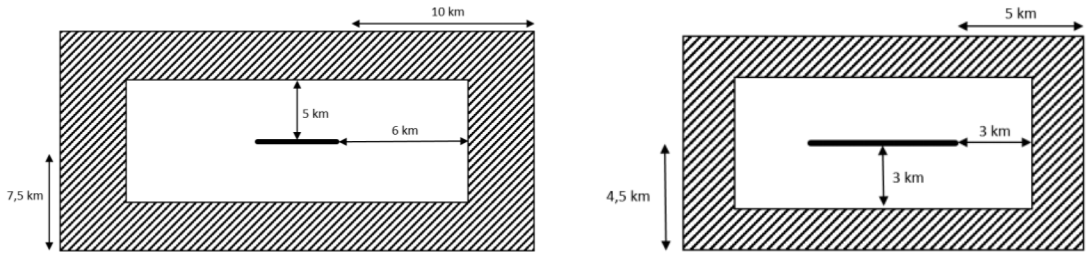

Figure 7: Graphical representation of restrictions of drone operations around public (left) and restricted-use (right) airports in Spain [47].

It is apparent that such restrictions need to be adapted as the capabilities of the U-space concept mature, in order to permit drone operations in lower altitudes in proximity to urban infrastructure and airports.

6.1.2 Operations in the “open” category

Only operations where drones are flown in Visual Line Of Sight can be part of this category. In addition, the drones’ weight must be equal to or less than 25kg. This category of operation is divided into three subcategories which encompass five classes of drone. **All the drones from the classes C0 to C2 could be flown in urban or populated environment**.

The table below provides some of the characteristics required for the drone and in which environment it could be used. **Only the characteristics which could have an impact on the DCB process have been selected.**

Table 8: Overview of DCB-relevant drone regulations of the "open" class.

Drone		Operation		
Class	MTOM	Subcategory	Restrictions	Max height
Privately built	<250g	A1(can also fly in subcategory A3	•May fly over uninvolved people or assemblies of people. •Maximum speed: 19m/s	120m above ground level +15m over obstacles taller than 105m (on request of responsible entity)
0				
Legacy drones(art.20)				
1	900g		•No flights over uninvolved people or assemblies of people •Maximum speed: 19m/s •Maximum sound power level: 81dB	

Drone		Operation		
Class	MTOM	Subcategory	Restrictions	Max height
2	<4kg	A2(can also fly in subcategory A3)	•No flights over uninvolved people and 30m horizontal distance (5m with low-speed function) •Maximum sound power level: 81+18,5 lg m/900 dB	
3	<25kg	A3	Fly away from people and outside urban area (from residential, commercial, industrial or recreational areas)- (150m)	
4				
Privately built				
Legacy drone(art.20)				

6.1.3 Operations in the “specific” category

This category of operation allows operators to **fly drones in VLOS and BVLOS**, which naturally **includes most of the delivery and surveillance operations**, but also VLOS operations above populated areas which are forbidden in the open category of operation.

In order to fly in the “specific” category, an operator:

1. shall provide the competent authority with an operational risk assessment for the intended operation according to article 11 of (UE) 2019/947.
2. Or shall provide a statement that the operation satisfies the operational requirement set out in point (1) of UAS. SPEC.020 of (EU)2019/947 and a standard scenario as defined in Appendix 1 to the Annex of (EU) 2019/947;
3. Or holds a light UAS operator certificate (LUC) with the appropriate privileges. An LUC holder is granted the privilege to authorize its own operations.
4. Shall provide the commitment of the UAS operator to comply with the relevant mitigation measures required for the safety of the operation, including the associated instructions for the operation, for the design of the unmanned aircraft and the competency of involved personnel.

Unless an operator holds a Light UAS operator Certificate (LUC) authorizing him to fly the drone above the maximum height, operations in the **specific category should fly at a maximum of 120m above ground level**.

These are important considerations as they will **imply different sets of mission constraints and requirements that the DCB process must accommodate**.

Standard scenarios

Standard scenarios refer to drone operations of the “specific” category for which a precise list of mitigating measures has already been identified [31]. The aim of these scenarios is to provide a guideline for drone operators and facilitate the mission approval process with the competent authority.

Two standard scenarios have been currently defined and the following **general provisions** are common for both:

- Maximum 120m above the ground and 15m above an obstacle of 105m high with a horizontal distance of 50m;
- The operational volume shall not exceed 30m above the maximum height allowed;
- Dangerous goods are forbidden for transportation.

STS-01: VLOS over a controlled ground area in a populated environment

The first standard scenario (STS-01) describes how VLOS missions may be performed over a populated area. The following key points which are relevant for the DACUS solution:

- For untethered aircraft:
    - The Ground must be controlled;
    - A contingency area of 10m beyond the flight geography area and a ground risk buffer up to 60m. The dimensions of the buffer vary with flight altitude (details in (EU) 2019/947 appendix 1 UAS.STS-01.020 UAS operations in STS-01);
    - A maximum speed of 5m/s.
- For tethered aircraft:
    - A radius equal to the tether length plus 5m and centred on the point where the tether is fixed over the surface of the earth.

STS-02: BVLOS with Airspace Observers over a controlled ground area in a sparsely populated environment:

The second standard scenario (STS-02) describes how BVLOS missions over a controlled ground area in a sparsely populated environment can be performed. This type of standard scenario will not apply to an urban environment, however given that it is the only BVLOS scenario available at the time of this writing, it does provide some initial insights on how BVLOS missions are expected to operate from a regulatory standpoint.

- The controlled ground area includes:
    - The flight geography area;
    - The contingency area, of which the external limit(s) shall be located at least 10 m beyond the limit(s) of the flight geography area;
    - A ground risk buffer covering a distance that is at least equal to the distance most likely to be travelled by the UA after activation of the means to terminate the flight specified by the UAS manufacturer in manufacturer’s instructions, considering the operational conditions within the limitations specified by the UAS manufacturer.
- The operation must have the following requirement:

- The flight visibility must be at least 5km;
- Drone in VLOS at least during the launch and recovery, except for an emergency flight termination. Also, in VLOS during the flight or at a maximum distance of 1km without an observer and following a pre-programmed trajectory;
- With an observer (which distance is no more than 1km from the remote pilot), the distance could be 2km from the remote pilot, but at a maximum distance of 1km from the observer (there could be several);
- The UAS must be operated with an active system to prevent it from breaching the flight geography and be operated with active and updated direct remote identification system.

The **standard scenarios introduce two new classes of drone whose characteristics which could impact the DCB process** are listed in the table below:

Table 9: Additional drone classes defined in the EASA standard scenarios.

Class	Scenario	Requirements
C5	STS-01	Rotorcraft or a tethered aircraft other than a fixed-wing aircraft
C6	STS-02	Have a maximum ground speed in level flight of not more than 50 m/s

However, for the time being it has **not been possible to quantify the impact of these standard scenarios on the DCB process** envisioned for DACUS, given that only two scenarios are available.

6.1.4 Operations in the "certified" category

A drone of the certified category of operation may only fly when the following requirements are met:

- The UAS is certified pursuant to points (a), (b) and (c) of paragraph 1 of Article 40 of Regulation (UE) 2019/945EU; and
- The operation is conducted in any of the following conditions:
  - Over assemblies of people;
  - Involves the transport of people;
  - Involves the carriage of dangerous goods, that may result in high risk for third parties in case of accident.

In addition, drone operations shall be classified as "certified" where the competent authority, based on the risk assessment for the mission, considers that the risk of the operation cannot be adequately mitigated without the certification of the UAS and its operator and, where applicable, without the licensing of the remote pilot.

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6.1.5 EASA Opinion 01/2020

EASA published an opinion in early 2020 introducing a high-level regulatory framework of U-space [17]. The following major ideas are exposed:

- A **Common Information Service (CIS)** that will enable the exchange of essential information between the U-space service providers (USSPs), the UAS operators, the air navigation service providers (ANSPs) and all other participants in U-space airspace. There could be several CIS per country but only one CIS per U-space airspace;
- Until new systems such as Detect-and-Avoid or Sense-and-Avoid are available, **all UAS shall be cooperative**;
- U-space airspace will be **dynamically segregated** from airspace where air navigation services are provided, so that manned and unmanned air traffic do not mix. This will likely be achieved through the use of permanent and dynamic geofences;
- **Manned aircraft** aiming to **fly in a U-space airspace** in an uncontrolled airspace **need to make their position available** so that the UAS can avoid it;
- The following services[5] are mandatory: **e-Registration, e-Identification, Geo-awareness, Drone Operation Plan processing and Traffic Information**. Three other services may be required to provide the four above: Tracking, Weather Information and Monitoring.

These aspects are considered in the DACUS DCB solution. However, given that DACUS is considering a time horizon that is further ahead than that described in the EASA Opinion, several additional requirements for the U-space regulatory framework will likely be defined. Assuming that most of the operations will take place in Z airspace according to the classification proposed in CORUS and explained in 4.2, the following **U1 and U2 services** should be available in Z: Drone aeronautical information publication, Geo-fencing provision, Incident/Accident reporting, Position report submission service, Emergency management, Procedural interface with ATC, Strategic conflict resolution, Legal recording, Digital logbook. Also, the following U3 services will be mandated in Z airspace: Collaborative interface with ATC, Dynamic Capacity Management and Tactical Conflict resolution.

In addition, CORUS considers that, where available, Geospatial information service, Population density map, Electromagnetic interference information, Navigation coverage information and Communication coverage information should be provided.

The following table from CORUS shows the type of operations which are allowed in each category of airspace:

[5] Using U-space CONOPS nomenclature.

<table>
<tr><th colspan="2">Operation</th><th>X</th><th>Y</th><th>Z</th></tr>
<tr><td rowspan="6">Drone</td><td>VLOS</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Open</td><td>Yes</td><td colspan="2">Yes, provided access requirements are met</td></tr>
<tr><td>Specific</td><td rowspan="5">Yes. However, the risk of unknown drone operations must be considered, evaluated and mitigated appropriately.</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Certified</td><td>Yes</td><td>Yes</td></tr>
<tr><td>BVLOS</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Automated</td><td>As for X</td><td>Yes in Zu</td></tr>
<tr><td rowspan="2">Crewed</td><td>VFR</td><td>Yes, but the use of U-space services by VFR flights is strongly recommended</td><td rowspan="2">Yes. However, type Za is controlled airspace. Crewed flights in Za will need to behave as such.</td></tr>
<tr><td>IFR</td><td>No</td><td>No</td></tr>
</table>

Figure 8: Overview of permitted operation types per U-space airspace category.

6.1.6 The Specific Operation Risk Assessment methodology (SORA)

The Specific Operation Risk Assessment (SORA) is a concept aimed at drone operations of the "specific" category, with the goal of facilitating access to airspace of non-certified UAS operating more complex missions than those of the "open" category [32].

The methodology consists of determining:

- An intrinsic Ground Risk Class number (GRC) which depends on the environment overflown and some physical characteristics of the drone;
- A final Ground Risk Class after mitigation (e.g., emergency response plan in place);
- An initial Air Risk Class number (ARC) which depends on the air environment where the drone intends to fly (e.g., controlled airspace, uncontrolled airspace);
- Determination of the Tactical Mitigation Performance Requirement (TMPR);
- The Specific Assurance and Integrity Level (SAIL) number, which defines how dangerous the operation is;
- Identification of Operational Safety Objectives (OSO) with regards to the SAIL number.

For the current SORA, **the air and ground risks involved by several UAS flights are not considered**. This is an **important aspect which the DACUS DCB solution needs to address**, given that knowledge of the cumulative risks of all operations within an area is a prerequisite of identifying capacity constraints.

Both ARC and GRC are impacted by the urban and/or populated environment.

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For ARC, the main reason is that a lot of cities are located within or close to a Controlled Traffic Region (CTR). Similarly, there is the potential of collision risk with low-flying manned aircraft, such as helicopter operations from hospitals or urban heliports.

For GRC, the table below shows clearly (in red), that the higher risk levels occur in populated environments and further increases with increasing vehicle dimensions.

Table 10: Overview of ground risk classifications of the SORA methodology, highlighting the differences in risk caused by operations in urban environments.

Intrinsic UAS Ground Risk Class				
Max UAS characteristics dimension	1 m / approx. 3ft	3 m / approx. 10ft	8 m / approx. 25ft	>8 m / approx. 25ft
Typical kinetic energy expected	< 700 J (approx. 529 Ft Lb)	< 34 KJ (approx. 25000 Ft Lb)	< 1084 KJ (approx. 800000 Ft Lb)	> 1084 KJ (approx. 800000 Ft Lb)
Operational scenarios				
VLOS/BVLOS over controlled ground area	1	2	3	4
VLOS in sparsely populated environment	2	3	4	5
BVLOS in sparsely populated environment	3	4	5	6
VLOS in populated environment	4	5	6	8
BVLOS in populated environment	5	6	8	10
VLOS over gathering of people	7			
BVLOS over gathering of people	8			

6.1.7 U-space regulatory framework

Dated on 22 April 2021, three Commission Implementing Regulations, (EU) 2021/664, (EU) 2021/665 and (EU) 2021 666 [55] to [57], provide a first U-space regulatory framework.

(EU) 2021/664 describes the requirements and certification information for U-space stakeholders (Common Information Service providers, UAS operators and U-space service providers) and the services that should be available in a U-space airspace (Network identification, geo-awareness, UAS flight authorisation and traffic information services are mandatory, weather and conformance monitoring services could be mandatory upon member state decision).

(EU) 2021/665 introduces the Dynamic Reconfiguration of a U-space airspace where the control service is provided by air traffic control.

(EU) 2021/666 states that manned aircraft operating in airspace designated by the competent authority as a U-space airspace, and not provided with an air traffic control service by the ANSP, shall continuously make themselves electronically conspicuous to the U-space service providers.

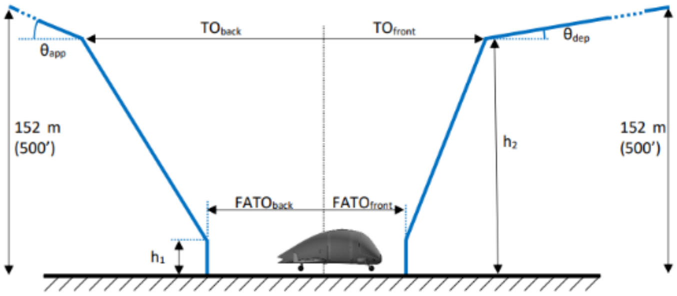
The services geo-awareness, UAS flight authorisation, weather, and conformance monitoring impact the Dynamic Capacity Management service, from the strategic to the tactical phases.
The role of the common information service provider and the data/information available in the common information service could be extended with regards to what is required for processing a Dynamic Capacity Management service. Indeed, **the DCM requires to have a global picture of the traffic demand and forecast, which could be complicated, time consuming or technically constraining in case of a U-space multi-USSP configuration.**
DCM could possibly be hosted by a CIS provider, which could then provide Demand and Capacity Balancing measures after the analysis of the global traffic in the same area. This to avoid back and forth between the potential several DCM services of each USSP. As a conclusion, the DCM service needs to be centralized to be efficient.

The Dynamic Reconfiguration of a U-space airspace will also have to be embedded in the DCB as a parameter which changes the capacity of a U-space airspace. Ideally, information related to a Dynamic reconfiguration could be part of the CIS data "f) static and dynamic airspace restrictions defined by the relevant authorities and permanently or temporarily limiting the volume of airspace within the U-space airspace where UAS operations can take place."

6.1.8 Vertiport (Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN)

The document, which is a form of guidance, "describes in detail the physical characteristics of a vertiport, the required obstacle environment, visual aids, lights and markings, as well as concepts for en-route alternate vertiports for continued safe flight and landing".
The obstacle free volume and obstacle limitations surfaces chapters (chapter D subparts 1 and 2) depicts the physical characteristics of the volume surrounding the vertiport in order to protect operations.
The restrictions would obviously reduce the number of vertiports in certain urban environments, unless existing structures are adapted and/or destroyed. This would impact demand on one hand by reducing the transportation offer (which would be the case of requirements on vehicles too), and capacity on the other hand by limiting the number of vertiports.

Limiting number of vertiports would also dramatically impact the possibility for a manned VTOL to urgently land on an adapted structure. This would affect the way the operators prepare the UAS trajectories, hence limits the use of the whole airspace capacity to a smaller one, increasing congestion and possibly reducing the possible DCB measures.



Parameter	Short description
h_1	Low hover height
h_2	High hover height
TO_{width}	Width at h_2
TO_{front}	Front distance at h_2
TO_{back}	Back distance at h_2
$FATO_{width}$	Width of the FATO
$FATO_{front}$	Front distance on FATO
$FATO_{back}$	Back distance on FATO
θ_{app}	Slope of approach surface
θ_{dep}	Slope of departure surface

Figure 9: Generic vertical take-off and landing procedure parameters (source EASA Vertiport [58])

6.1.9 Gaps identified in the European framework

As expected, given the relatively young nature of the European regulatory framework for drone operations, there are still several gaps which need to be addressed. Apart from the gaps mentioned in previous chapters (concerning the lack of urban BVLOS standard scenarios and lack of a cumulative ground risk definition), this section highlights some additional shortcomings in the existing regulations, which would need to be addressed.

The first gap identified is the **lack of regulation** for operations in the specific and certified categories **related to the minimum distance between the UAS and individual persons or an assembly of people**, whereas it is defined in the "open" category. Even if the operator, the UAS and the remote pilot are certified when operating above urban or populated environment, there should be minimum distances, vertical and horizontal, set between the UAS and any obstacle, individual persons and assemblies of people.

Another gap is the **lack of a unified definition** of what is considered a "**populated area**". An example of the Spanish point of view was provided which provides some reference guidelines, however the strict operational limitations make this case unfeasible for the DACUS DCB solution. To address this shortcoming, EASA plans to develop a map to identify the population density by launching a dedicated study.

And finally, **SORA does not consider the air risk with other drone flights**, but only with manned aircraft. JARUS Working Group 6 is already working to expand the scope of SORA to address the risk of collision when more drones are flying in the same airspace (e.g., urban), but EASA considers that in the first phase, the number of drone operations will not be too high, so this lack is not an issue for the moment. This hypothesis, however, is not compatible with DACUS which will consider several drone flights for assessing the demand and the capacity.

6.2 European regulation for manned aircraft operations in urban areas

Although not directly applicable to U-space, this section covers general regulations for manned aircraft operating in urban areas, which serve as a **boundary condition to the DACUS DCB concept**, given that low-level manned aircraft operations will need to be considered.

General rules are defined in the Standardized European Rules of the Air (SERA) [33]. Rules specifically depend on whether the aircraft flies in Instrument Flight Rules (IFR) or Visual Flight Rules (VFR) and whether the aircraft flies at day or night.

6.2.1 Minimum operating altitudes

This section focuses on the minimum operating altitudes of manned aircraft from a European regulation point of view, as well as providing an example from a European member state (France).

European Rules

The aircraft flies with Instrument Flight Rules

Except when necessary for take-off or landing, or except when specifically authorized by the competent authority, an **IFR flight** shall be flown at a level which is not below the minimum flight altitude established by the state whose territory is overflown, or, where no such **minimum flight altitude** has been established at a level which is **at least 300m (1 000 ft) above the highest obstacle located within 8 km** of the estimated position of the aircraft.

RPAS flying in controlled airspace are considered as flying in IFR. These aircraft are usually state aircraft (military) and their flight in civil controlled airspace requires coordination between the operator (usually the military) and the air traffic control. Hence, as considered flying in IFR, IFR apply to RPAS.

From the DACUS point of view **IFR RPAS may be regarded the same as manned IFR aircraft** for nominal operations. The main difference is in the case of an RPAS contingency. Yet, RPAS contingency procedures are usually pre-programmed and thus predictable (e.g., C2 link loss procedures are the same as “no-radio” procedures in manned aviation, as confirmed by the SESAR PJ13 Solution 117 project on the Integration of IFR RPAS in controlled airspace). Nevertheless, it could be imagined that the IFR RPAS pilots may be connected to U-space, even if they are not actively participating in it.

The aircraft flies with Visual Flight Rules

At night-time: except when necessary for take-off or landing, or except when specifically authorized by the competent authority, a **VFR flight** at night shall be flown at a level which is not below the minimum flight altitude established by the State whose territory is overflown, or, where no such **minimum flight altitude** has been established, at a level which is **at least 300 m (1 000 ft)** above the **highest obstacle located within 8 km** of the estimated position of the aircraft.

In case of a **helicopter**, the minimum height is **300m above the highest obstacle** which is the one situated at **a flying distance of 1 minute** around the aircraft.

However, **exemptions which allow manned aircraft to fly below the established minimum altitudes** may be authorized by the competent authorities. For instance, medical helicopters may have a “permanent” version of such exemptions. This would make it necessary for VFR aircraft (such as medical helicopters) to participate in the U-space environment, as defined in the EASA Opinion 01/2020 [17], and may be subjected to U-space constraints (i.e., landing/take-off procedure restrictions).

At daytime: except when necessary for take-off or landing, or except by permission from the competent authority, a **VFR flight shall not be flown** over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a height **less than 300 m (1 000 ft) above the highest obstacle within a radius of 600 m** from the aircraft.

In controlled airspace

Usually, the airports have been built quite far from the cities, for instance for economic reasons or to reduce the noise impact on population in an era where the aircraft were significantly noisier than today.

But during the last decades the cities expanded, and it is not rare today to have some parts of a city or even the whole urban area within a CTR.

Hence, parts of the city in the CTR may see aircraft authorized to fly below the established minima during the take-off and first part of the climb phase, final approach and landing of an aircraft. Aircraft in the aerodrome circuit (e.g., downwind) will also fly below these minima. This concerns mainly the parts of the city close to the runway and departure and arrival trajectories.

In uncontrolled airspace

If the urban area is not situated in a controlled airspace and without aerodrome in the vicinity, the minima are those define in SERA for the transit above urban areas.

Sometimes there is an aerodrome close to a city, but the airspace is not controlled. The minima are those defined in SERA, except when necessary for take-off or landing, aerodrome circuit, or except when specifically authorized by the competent authority.

Specific national regulation (case of France)

SERA are essentially guidelines for other competent authorities to establish their own regulations. In order to provide for a concrete example, the specific regulations of an EU member state (France) have been further detailed.

For VFR operations

Some countries impose additional restrictions to SERA. One of them for instance in France, is to forbid an aircraft in VFR to overfly a populated area below a certain altitude. This **minimum altitude depends on the size of the populated area overflown**. Minimum heights are as per the table below:

Table 11: Overview of minimum flight altitudes for VFR aircraft

Size of urban area	Minimum altitude
Small built-up areas used for navigation landmarks (e.g., isolated manufacturing plant, industrial building, hospital)	1000 feet for single engine piston aircraft 3300 feet for other types
Small built-up areas less than 1200 m mean wide and assembly of people or animals (e.g., beaches, stadium, public meetings, hippodromes)	1700 feet for single piston engine aircraft 3300 feet for other types
Medium built-up areas between 1200 m and 3600 m mean wide and assembly of at least 10000 people	3300 feet for all aircraft except helicopter
Large built-up areas more than 3600 m and assembly of at least 100000 people	5000 feet for all aircraft except helicopter

The city of Paris	6600 feet

These more stringent regulations for manned aircraft could provide **opportunities to expand the operating areas of low-flying drones within U-space to higher altitudes**.

For helicopters

Whatever the provided authorization allows the helicopter to descend, the operator shall always be sure that the helicopter will be able, in case of urgency, to leave the urban area, or reach a landing area in the urban area, without endangering people and properties on ground. Thus, to overfly an urban area, depending on the aircraft, its technical characteristics, the **operator will define minimum heights for each portion of the trajectory** allowing the aircraft to land outside the urban area or on a public area/aerodrome in case of engine failure.

6.2.2 Rules of the air

This section highlights aspects regarding rules of the air for manned aircraft that are relevant to the definition of DCB processes for drone operations.

Flight plan

A pilot who intends to fly with Instrument Flight Rules shall **submit a flight plan at least 60 minutes before departure**.

The same pilot wishing to fly with Visual Flight Rules can submit a flight plan, but it is not mandatory. VFR flights are forbidden in airspace of class A.

Hence, it will be **impossible to strategically de-conflict drone operations and manned aircraft** operations **whose intents are unknown**. Generally, intentions of the VFR pilot are communicated to the controller throughout the first radio contact.

Collision avoidance

The pilot-in-command of any aircraft (manned or unmanned) is fully responsible for taking necessary action to avoid collisions. However, this is a difficult task for a pilot of a manned aircraft to achieve given the given the small size of drones of the specific category and to the fact that the pilot has to concentrate on their own operation while being close to the ground.

Hence, **avoidance of collision between a manned aircraft and a drone shall be the responsibility of the remote pilot** when the drone is flown VLOS. Since it is expected that manned aircraft flying within U-space designated airspace are connected to the U-space system [17], UAS would have the position of manned aircraft available. Therefore, the remote pilot flying a drone in VLOS in dense traffic conditions may take advantage of services such as a traffic information to help avoid collision. If the drone is flown BVLOS, avoidance of imminent collision will be further facilitated by systems such as **detect and avoid**.

Right of way

The current EASA regulation provides the **right of way to manned aircraft with regard to unmanned aircraft**.

Visibility and distance from cloud minima

Provided that aircraft flying in VFR are not allowed to overfly an urban area below 1000 feet (see Table 11), rules of the air regarding visibility and cloud separation provide additional requirements for low-flying VFR aircraft.

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Table 12: Minimum visibility and cloud separation requirements for VFR aircraft.

Altitude band	Airspace class	Flight visibility	Distance from cloud
At and below 900 m (3 000 ft) AMSL, or 300 m (1 000 ft) above terrain, whichever is the higher	A B C D E	5 km	1 500 m horizontally 300 m (1 000 ft) vertically
	F G	5 km	Clear of clouds and with the surface in sight

When applied to drones, visibility and distance from clouds are clearly compatible with VLOS operations. BVLOS operations relying on non-visual means of navigation may not be impacted by these parameters.

7 U-space Concept of Operations and DCB

The U-space ConOps [14] describes the operation of U-space as a set of services used in a certain airspace structure. The airspace is broken into different volumes referred to as X, Y and Z. These volumes offer different sets of services and by doing so support different densities of traffic. In volume Zu, U-space offers both the **Tactical Conflict Resolution service** and the **Dynamic Capacity Management service**. In the view of the ConOps authors, these two services are linked. The thinking is as follows:

Conflict resolution services, whether in U-space or elsewhere, are **based on predictions of conflicts**. These predictions are always probabilities, for many reasons: The aircraft might change speed or direction due to wind or for other reasons. The prediction is based on tracking fed with surveillance data that itself contains uncertainties (errors) and/or may be delayed.

Conflict resolution is **triggered when the probability of loss of separation is too high**, based on the most likely predicted trajectory for each aircraft. However, the probability of this most likely predicted trajectory is seldom one, meaning that there is always a residual probability that conflict resolution fails to detect conflicts. The **residual risk is never zero but can be considered acceptable if below some value**. At any moment, the residual risk is a function of many parameters, one of which is the number of trajectories that may lose separation. Thus, for any scheme of conflict resolution there is a maximum safe instantaneous density of flight per volume. **The aim of the Dynamic Capacity Management service is to avoid that this maximum density is exceeded**.

The Dynamic Capacity Management service operates on Operation Plans for practical reasons. It detects periods when in execution the risk that the Tactical Conflict Resolution cannot work well enough is too high. Thus, in its design it needs to predict the uncertainties that may be present later. Once such **"hotspots" are detected**, a range of solutions may be applied, the most general being to **direct some of the flights to 4D regions where there is available capacity**, which requires changing the operation plans of the flights concerned and is most efficiently and safely done before take-off.

Having this model in mind, capacity may be defined for reasons other than safety, for example perceived noise at ground level. The general principles of Dynamic Capacity Management in the ConOps are not expanded much further, as this was seen as an area requiring more research which is being addressed by the DACUS project. However, two closely related aspects are mentioned: Fairness & timing, and performance targets.

7.1 Fairness and Timing of DCB

The ConOps sought to **establish processes that were fair**. The term fair is rather hard to define but at least the ConOps follows the principle that **being first to submit an operation plan brings no advantage**. Conflict resolution and Dynamic Capacity Management occur a short time before take-off, referred to as "**Reasonable Time to Act**" or RTTA. At that instant these processes occur on all flights concerned and treat them as equally as possible.

There will always be **prioritisation for safety-of-life operations and similar**. The ConOps suggests a rather long list of priorities. Opinion 01/2020 from EASA [17] proposes a more succinct prioritisation scheme in article 6 of the draft regulation. The thinking in the ConOps is that within any priority level, the selection of which flights to act on for DCB or strategic conflict resolution, and how to act on them should be driven by an optimisation of producing the minimum impact when all flights are considered. However, this then raises the possibility that a regular flight is always considered the best target for change. Hence one 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 suggestion that seemed to go too far for some people.

7.2 Performance targets

Throughout the descriptions of separation services and dynamic capacity management in the ConOps there are no specific numbers given. The ConOps proposes a **trade-off between separation and CNS performance**. When demand drives the need for more capacity, that capacity might be obtained by requiring better surveillance, more precise navigation, lower command and control latency and so on, this allowing smaller separation. All of the improvements imply cost, and it is expected that high demand for operations will be correlated with profitability of operating, hence the operators will be willing to bear these costs. The overall equation is parameterised by the **acceptable risk of collision** – another figure not given in the ConOps.

7.3 Further elements identified in the ConOps

- **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;
- **Strategic conflict detection** as well as Capacity limit detection are based on **probabilistic trajectories** derived from the information supplied in the operation plan, together with the weather forecast and other relevant inputs. The power of modern computers makes consideration of probability in U-space possible, avoiding "fudge factors" and "judicious approximations";
- **Dynamic Capacity Management** is invoked by the Drone Operation Plan Processing service if and **only if the airspace requires it**. The Dynamic capacity management service uses the probabilistic 4D models calculated by the Drone Operation Plan Processing service. As defined in the final version of U-space ConOps, the Drone Operation Plan Processing service is the service receiving both drone mission and flight plans from the operator;
- Dynamic Capacity Management is closely linked to the **Strategic Conflict Resolution service**, which is also invoked by the Drone Operation Plan Processing service and is in charge of detecting conflicts and proposing solutions because a new Operation Plan has been submitted or because an already submitted operation plan has changed;
- The assumption that U-space Dynamic Capacity Management is a process which is invoked if and only if the airspace requires it odds with the existing SESAR DCB concept. On the contrary, the **SESAR DCB in ATM** is envisaged as a process aiming at **maintaining the balance between demand and capacity during the course of daily traffic operations**, pro-actively monitoring the traffic situation to identify and manage real-time imbalance situations. The U-space ConOps proposals are extended in DACUS to consider a continuous and pro-active process which starts working before the RTTA.

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8 DCB process in U-space

This section details the DACUS DCB concept for U-space, through provision of an overview of key principles of the concept, an overview of DCB phases, a detailed description of the DCB processes, an overview of the differences between ATM and U-space DCB as well as a description of the DCB measures to be applied in case of imbalances.

8.1 Key principles

The DCB process in U-space takes on board some of the high-level principles that guide Air Traffic Flow and Capacity Management (ATFCM) for manned aviation. However, some important differences of drone operations to manned aircraft operations have been considered, such as diversity of drone missions, multiple drone capabilities or CNS performances among others, which are impacting how the DCB process should be managed in U-space. The principles that guide the overall U-space DCB process are:

- DCB will be a collaborative decision-making process in which the **Drone Operators are the key actors to take final decisions** on how and when the drone mission will be executed, Consequently, and similarly to ATFCM, throughout all this activity, there is continuous communication and exchange of information with all the actors involved;
- ATFCM endeavours to make first capacity meet traffic demand and, when the latest capacity opportunities have been exhausted, make the demand meet the maximum available capacity. In U-space there will a wide variety of DCB measures, which make it difficult to maintain the ATFCM classification of capacity or demand management measures. **U-space DCB measures will be categorized according to their impact on the fulfilment of the mission objectives** as the main classification criteria, assuming that not all requirements included in the operation plan are necessary to guarantee the success of the mission. U-space DCB measures can impose constraints on the drone operation plans, such as flying in a certain flight level, which are not necessarily impacting on the requirements of the Drone Operators to fulfil their missions;
- Excluding those flying restrictions which will be pre-defined by the authorities to be able to operate in urban areas, **free-route operations will be prioritized** unless constraints associated to DCB measures should be implemented;
- The diversity of Drone Operators makes it necessary to consider that some of them will have wide technological capabilities to have full access to U-space and others will not be able to dynamically react to the changes throughout the DCB process. Consequently, the process reduces **up to the minimum the instances in which changes are claimed** to the Drone Operators to adapt their missions to the DCB measures in place;
- Reliable predictions of the expected demand are the key facilitator for the decision-making processes. The **quantification of uncertainty** will be an essential component of these predictions as a mechanism to improve the predictability of the overall process and the effectiveness of the DCB measures;
- Drone **Operation Plans will be considered as the "single point of truth" for all U-space DCB processes**. As a consequence, if the drone trajectory is deviated from the initial Operation Plan during the execution phase, the Operation Plan must be updated taking into account the most up-to-date tracking information.

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8.2 U-space DCB phases

Similar to ATFCM, several phases[6] are defined within the DCB process for U-space. These phases are briefly introduced within this section.

8.2.1 Long-term planning phase

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. 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 U-space ConOps [14], and is considered out of the scope of DACUS project.

8.2.2 Strategic phase

This phase 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 when starting 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 and services involved are shown in Appendix A. They will take place before the *"Reasonable Time to Act" (RTTA)*, which determines the starting point of the next phase.

8.2.3 Pre-tactical phase

This phase 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

[6] Although similar terminology is used to facilitate the understanding, U-space phases have different timeframes and objectives in comparison with ATFCM.

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**.

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 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 the initiation of this phase, i.e. after the RTTA[7], are the first candidates to be proposed a plan change if it is necessary. 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 figure included in Appendix B represents a certain time after the RTTA, so that most of the DCB measures have been already implemented. New submitted Operation Plans will need to comply with the constraints associated with the implemented DCB measures.

8.2.4 Tactical phase

This phase 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 in order 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, drone contingencies, etc.

The main objective of this phase is to monitor the overall traffic picture and to minimise the impact of any disruption. The figure included in Appendix C represents the services in place in one specific disruption: the case in which the Navigation Infrastructure Monitoring service is reporting a degradation of navigation performances. This degradation is impacting 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.

[7] It is under discussion if RTTA should be unique and always the same in a certain area of operations, or it could change depending on how the demand is evolving in the area. Other option is to consider also different RTTAs per business type to avoid penalizing specific businesses.

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8.2.5 Post-operational phase

This is the final step in the DCB process. All stakeholders should be able to **provide feedback on the efficiency of the overall process** and the DCB measures that were implemented.

This phase **compares the anticipated outcome with the actual measured outcome**, in terms of indicators and targets which are pre-defined in the U-space performance framework. DACUS has provided a specific performance framework of U-space to monitor the effectiveness of the DCB measures [48].

The following figure shows the U-space DCB phases and the transitions between them. Transition between Strategic to Pre-Tactical phase is identified as the key milestone for the implementation of DCB measures.

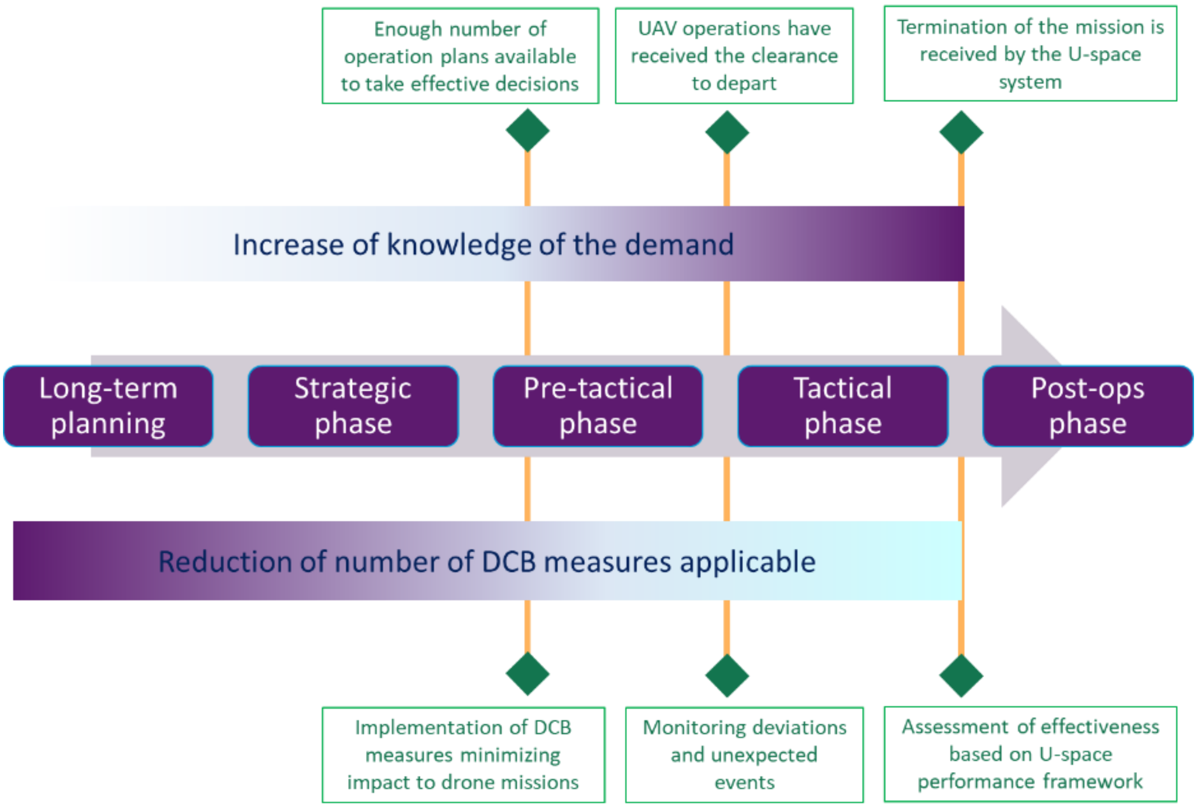

Figure 10: Overview of DCB planning phases in U-space

8.3 U-space services involved in the DCB process

The U-space ConOps 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 DCB process 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 in this section; they are included in the section "Detailed processes in the Tactical Phase" and they can also be visualized in Appendix C.

1. The **Operation Plan Preparation service** facilitates the preparation and submission of 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 drone operators, include contingency considerations for the declared flights.

2. The **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. The **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 that a certain limit. It must consider mission objectives in order to propose suitable solutions for the Drone operator. These proposals will consist of slight horizontal, vertical, speed or departure time changes to the probabilistic 4D trajectories to reduce the probability of having two UAVs at the same time in the same airspace volume. Proposals shall be consistent with pre-existing constraints to balance the demand and the capacity.

   The size of these airspace volumes will be determined by some **reference separation standards**. Factors such as the characteristics of the demand or CNS performances in the U-space airspace will determine these standards.

4. The **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. Two models will allow quantifying the collision risk and the social impact of the demand in a given airspace. The **Collision Risk model** will consider all factors influencing the mid-air collision probability and severity, 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 and visual impact, 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 are proposed and sent to the Strategic Conflict Resolution to integrate constraints coming from both services and sent to the Operation Plan Processing service.

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The following figure provides an overview of the whole process.

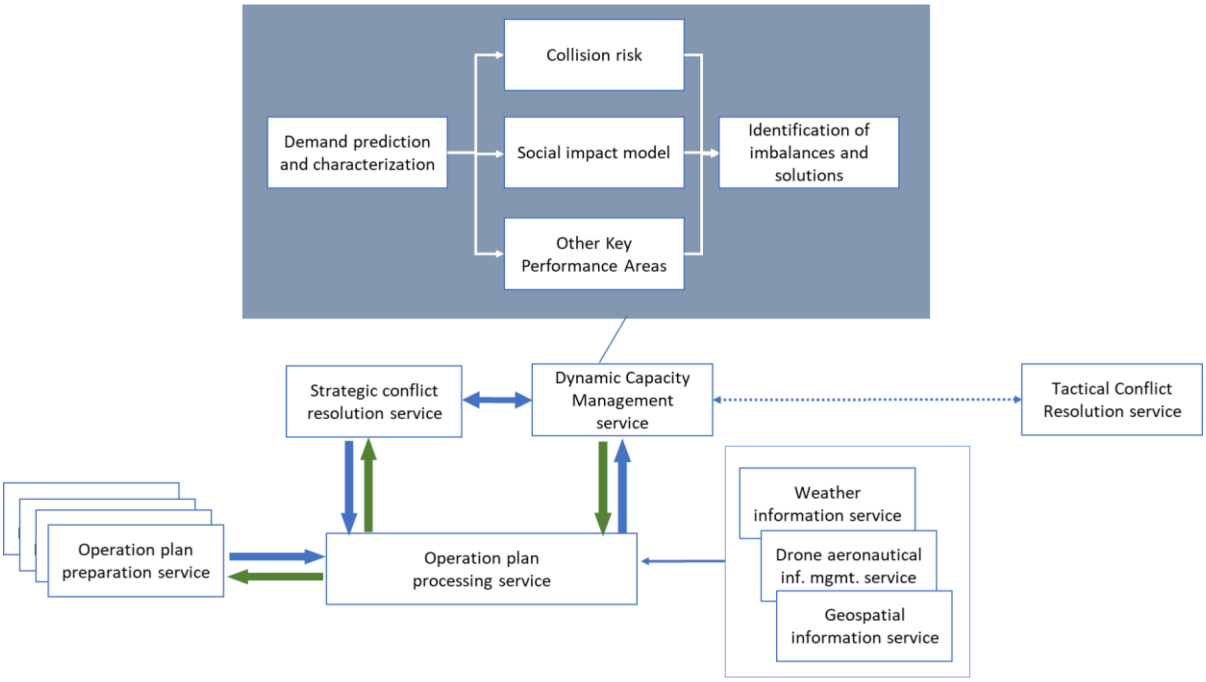

Figure 11: High-level overview of the DACUS DCB service interactions (excluding tactical processes).

The **Tactical Conflict Resolution Service** compares existing operation plans in flight, identifies potential conflicts with other flights and proposes 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 a given 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 in order 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.

8.4 Detailed processes and involved U-space services

This section provides a step-by-step overview of the DCB processes in each of the identified phases (strategic, pre-tactical and tactical). These processes are summarized in graphical charts from Appendix A to Appendix C.

8.4.1 Strategic phase

DCB processes within the strategic phase of operations follow a multi-step process, which is outlined at a high level in this section.

Refer to Appendix A for a graphical representation of the DCB process in the strategic phase.

1. **Submission of operation plans**

The operation plans are submitted by multiple Operation Plan Preparation services in charge of several authorised USSPs.

The operation plans will include information such as **type of mission, number of drones, type of vehicle, departure time, expected trajectory or set of airspace volumes, contingency volumes, drone endurance and weather-related operating limitations**. DACUS demonstrated the high impact of contingencies on the overall traffic demand, but at the same time, the wide diversity of contingencies and their different evolution make it necessary to limit "what-if" probabilistic 4D trajectories to a set of pre-defined cases based on the most common contingencies.

In addition, the overall efficiency of the DCB process will greatly improve by including:

- Identification of those **components of the operation plan which are critical for the fulfilment of the mission objectives** and those which are not, e.g., an operation plan to perform a food delivery will specify the need to fly from point A to point B at an altitude of 100 meters, indicating that the altitude is not a strong requirement to comply with the mission;
- **Quantification of the level of uncertainty** of the relevant information included in the Operational Plan.

The submission time of an operation plan is inherently linked to the mission type and mission requirements. However, specific sets of mission aspects may be available at different times: Initial mission information may already be available several hours, days or even weeks beforehand whereas a complete operation plan might only become available few minutes before departure.

The DCB process will be facilitated if drone operators provide initial mission aspects in advance. The operation plan should therefore be submitted as soon as the Drone Operator has an idea of the mission, even if the information is still incomplete. This could be facilitated by **providing very flexible mission plan formats**, which can be updated in real time as soon as more information is available. Linking the operation plan submission process to **fairness principles** (i.e., "virtue points" for good behaviour) could provide incentives for collaboration and adapted to their individual business models. On the flip side, this could also be linked to fees, such as paying higher amounts if the operator is not following best practices.

2. Validation of new Operation Plans and generation of probabilistic 4D trajectories

This process is **performed by the Operation Plan Processing service**. This service receives Operation Plans, verifies the consistency of the information submitted and **generates probabilistic 4D trajectories** and launch the Strategic Conflict Resolution service to check for potential conflict with operation plans that have been previously approved. Weather information will be probably taken on board depending on how stable this information is at this stage.

The Operation Plan Processing service is in charge of providing the feedback to the USSPs that drone operators utilize on the approval of the operation plan or requesting **slight changes** based on the solutions identified by the Strategic Conflict Resolution service, that should comply with the existing DCB constraints.

The Operation Plan Processing service **maintains a pool of data** containing the histories of all submitted operation plans that have not yet been archived. Archiving occurs at some time after the flight lands or the flight cancellation.

3. Assessment of pair-wise collision risks of new Operation Plans

This process is **performed by the Strategic Conflict Resolution service**. It receives the existing operation plans in the form of probabilistic 4D trajectories from the Operation Plan Processing service. This process is launched as soon as a new operation plan is submitted or an already submitted operation plan has changed.

The process **detects potential conflicts**, and also **identifies several solutions**:

- Detection broadly involves examining the probabilistic 4D trajectories predicted by the Operation Plan Processing service and looking for pairs which have a reasonable probability of coming closer than is allowed in any given airspace;
- Identification of solutions by changing the new submitted operation plan. The changes will come from a standard set of "recipes" which are tested and those that resolve the problem (and do not cause another problem) retained;
- Solutions proposed by the Strategic Conflict Resolution service will comply with the DCB measures already implemented.

Deconfliction of pair-wise trajectories will be related to slight changes in the operation plans such as horizontal or vertical changes or slight modifications of the departure time or speed. They should not imply relevant changes to operation plans which could compromise the fulfilment of the mission.

4. Calculation of demand prediction and uncertainty

This process is **performed by the Dynamic Capacity Management service**. It receives the existing operation plans in the form of probabilistic 4D trajectories from the Operation Plan Processing service. Then, it combines these operation plans with predictions of new ones that may be delivered in a later stage.

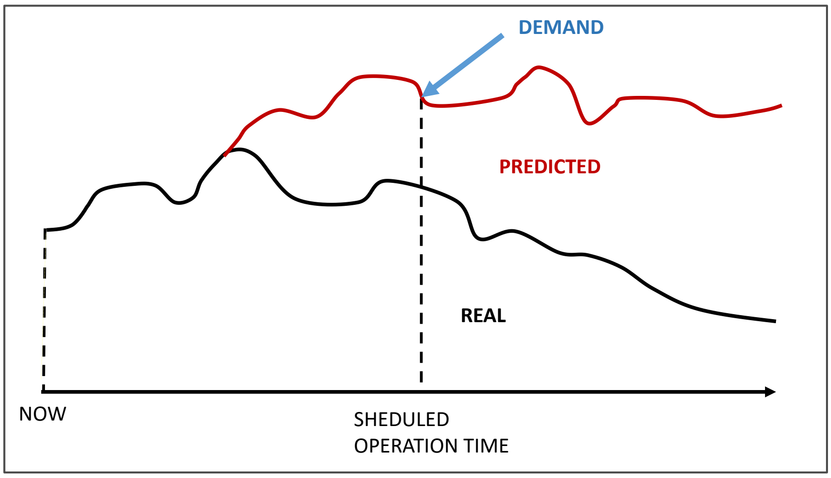

Figure 12: Integration of Operation Plans and predicted demand within the strategic phase.

The outcome of the process will be:

- **Prediction of the overall demand** – existing and envisioned operation plans - associated to the whole U-space airspace or wide pre-defined areas within the U-space;

- **Quantification of its level of uncertainty**. This level will depend upon the distribution between real and predicted demand, uncertainty included in the submitted operation plans, or weather data quality and its uncertainty, among other factors. This uncertainty will impact on the type of DCB measures to be designed and when they should be implemented, e.g., higher uncertainly should probably be addressed by designing solutions with higher resilience;

- **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.

Information included in the last bullet is relevant to understand how difficult it could be for the Tactical Conflict Resolution service to solve each foreseen demand picture. As an example, the diversity of drone characteristics (e.g., flight envelope, type, size, endurance) could be intuitively considered as a factor that will make it more difficult for the Tactical Conflict Resolution service to find a solution.

5. **Monitoring of risk-based and social indicators**

This process is **performed by the Dynamic Capacity Management service**. Demand provided by the previous process will be used for the calculation and monitoring of several indicators which will allow understanding the safety and social impact of the envisioned demand.

The indicators will be calculated for the of the airspace taking on board the following factors:

- **Safety impact** will address the fatal injuries to third parties, taking into consideration the risk of collision with manned aviation and the risk for people on ground[8]. This ground risk implies to cross-check the demand with population density, geographical information related to the characteristics of each area (e.g., metropolitan, suburban, residential, industrial) and even the weather conditions which could determine the number of people outside;

- **Social impact** will address the repercussion of the noise and the visual impact on the citizens. This implies to cross-check the noise footprint and visual impact footprint with the characteristics of the population on ground.

The monitoring of indicators will be done by comparing their value with certain **safety and social impact thresholds** for the entire U-space airspace or wide pre-defined areas within that U-space airspace. Due to the level of uncertainty of the demand, DACUS considers that it will not be possible to take decisions based on accurate distributions of drones density in the U-space airspace, as density could widely vary in later stages.

[8] The inclusion of economic and/or social impact of the collision between two drones as an additional limiting factor is under discussion.

U-space indicators were defined in the DACUS Performance Framework [48]. Those that were successfully used for the identification of safety and social impact hotspots are included in the following table.

Table 13: Safety and social indicators used for the identification of hotspots

Name	Description	Units
Cumulative risk against link-third parties	Overall risk of causing fatal incidents or injuries to people in an area.	Risks per flight hour in an area.
Noise Exposure	Total amount of persons exposed within an area in a period t.	person.dB/h
Noise Annoyance	Total amount of annoyed persons within an area in a period t. This indicator translates the noise exposure into a score level of the human population feeling annoyed by the effects of UAVs in an area.	person.annoyed/h
Visual Pollution Exposure	Total amount of persons in presence of UAVs within an area in a period t.	person.vp/h
Visual Pollution Annoyance	Total amount of annoyed persons by presence of UAVs within an area in a period t. This indicator multiplies visual exposure with the specific sensitivity of population in the area which is represented as the percentage of people annoyed or highly annoyed.	person.annoyed/h

This process identifies if the entire U-space airspace – or pre-defined areas – will be within acceptable safety and social thresholds. The city councils or other representative entities will be able to set the admissible thresholds in each area.

6. Assessment of pre-defined DCB measures

This process is **performed by the Dynamic Capacity Management service**. It assesses whether the previously identified safety and social imbalances could be solved through some of the **pre-defined DCB measures**.

Apart from the impact of each measure on the safety and social indicators considered in the previous process, additional indicators will be calculated to take on board other potential Key Performance Areas (KPAs) that are impacted by the DCB measure. These additional KPAs will take on board factors such as the impact on the efficiency of the missions (although missions can be completed, this could be at the price of increasing flight distance or consuming much more energy) or the resilience against perturbations (a solution could provide many benefits in terms of reduction of air risk, but it is very sensitive to perturbations such as wind gust, intruding aircraft or an aircraft that experiences a failure).

On the other hand, DCB measures which have **higher stability under demand changes** will be prioritized if it is necessary to implement them in this strategic phase. The process will determine the most suitable solution at this phase and will identify those operation plans which are affected.

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The following table shows the set of KPAs which are assessed to understand the impact of each solution. The two 1st ones are both linked to the overall capacity of the U-space airspace, due to safety-related aspects and to social constraints. Then, these KPAs are assessed through the collision risk and the social impact model, respectively.

Table 14: Definition of relevant KPAs in U-space DCB process.

KPAs in DCB	Scope
Safety	Assessment of the maximum number of drone operations that can be accommodated in a given airspace for a certain period whilst maintaining safety-related targets.
Environmental and Social Impact	Assessment of the maximum number of drone operations that can be accommodated in a given airspace for a certain period whist maintaining social perception and environmental impact within acceptable margins. The focus is on noise impact and visual impact linked with privacy concerns.
Mission Efficiency	Assessment of the extent to which the number of resources planned for the mission are used, and not more. These include energy used and time taken, both in terms of running hours / working hours and the actual time at which the mission goal is achieved. Significant mission inefficiency could prevent the mission goal being achieved. Before that extreme, the impact will likely be increase cost for each operation.
Equity	Assessment of how the inefficiencies of the system are equitably impacting the different airspace users.
Flexibility	Assessment of the ability to accommodate dynamic flight parameter modifications which allow users to exploit business opportunities using drones as they occur, given the restrictions of the operating environment.
Resilience	Assessment of the ability to adapt to changes of the environment by anticipating and reacting to sudden, troublesome, or negative disruptions whilst maintaining the overall performance.

7. Towards the implementation

The level of confidence in the effectiveness of the DCB measure and the uncertainly of the demand will determine if the DCB measure should be implemented in the strategic phase, or should be pre-defined for its implementation as soon as the pre-tactical phase starts. Only those measures that are not affecting the drone missions could be implemented.

8.4.2 Pre-tactical phase

This phase starts at a certain time prior to the execution in which **most of the operation plans have been submitted** and the **level of confidence in them is high enough** to ensure the effectiveness of the DCB measures to be implemented.

Refer to Appendix B for a graphical representation of the DCB process in the pre-tactical phase.

1. **Submission of operation plans**

Unexpected operation plans will imply a penalization such as for instance, low priority if it is necessary to implement DCB measures addressing the traffic. Exceptions can exist for predefined business models which cannot deliver operation plans in due time because of their characteristics (e.g., last-mile delivery) are not yet known.

As in the previous phase, these new operation plans will be validated by the Operation Plan Processing service. Strategic Conflict Resolution could propose slight changes in the operation plans such as horizontal or vertical changes or slight modifications of the departure time or speed. They should not imply relevant changes to operation plans which could compromise the fulfilment of the mission.

Solutions proposed by the Strategic Conflict Resolution service will comply with the DCB measures already implemented.

2. **Generation of 4D trajectories**

This process is **performed by the Operation Plan Processing service**. When starting this phase, the service **recalculates all 4D trajectories based on the submitted operation plans**.

The process is similar to the one performed in the strategic phase with the main difference that uncertainty will be clearly reduced. In particular, the uncertainty due to the environmental conditions such as wind and precipitation can be considered as negligible thanks to the proximity of the phase to mission execution and the use of high-precision local and micro-scale weather predictions.

3. **Calculation of demand prediction**

This process is **performed by the Dynamic Capacity Management service**. It receives the existing operation plans in the form of 4D trajectories from the Operation Plan Processing service. The percentage of unknown operation plans is negligible at this stage.

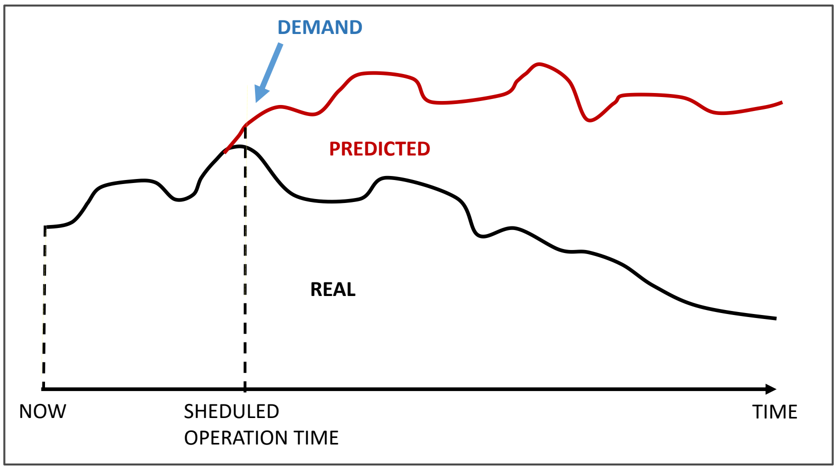

Figure 13: Most of the demand corresponds to existing operation plans the pre-tactical phase

The outcome of the process will be:

- **Prediction of the overall demand** associated to cells of the U-space airspace. The entire U-space airspace is divided into **cells of a pre-defined grill**. This demand prediction will be mainly based on submitted operation plan.

- **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.

4. **Monitoring of risk-based and social indicators**

This process is performed by the **Dynamic Capacity Management service**. 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 cells if a grid taking on board the following factors:

- **Safety impact** will address the fatal injuries to third parties, taking into consideration the risk of collision with manned aviation and the risk for people on ground[9]. At this stage, Navigation and Communication Coverage Information services will provide relevant information to calculate safety-related indicators. The ground risk implies to cross-check the demand with population density, geographical information related to the characteristics of each area (e.g., metropolitan, suburban, residential, industrial) and even the weather conditions which could determine the number of people outside;

- **Social impact** will address the repercussion of the noise and the visual impact on the citizens. This implies to cross-check the noise footprint and visual impact footprint derived with the characteristics of the population on ground.

The monitorization of indicators will be done by comparing their value with **certain safety and social thresholds for each cell of the grid**. This process identifies cells where acceptable safety and social thresholds are exceeded.

U-space indicators were defined in the DACUS Performance Framework [48]. Those that were successfully used for the identification of safety and social impact hotspots are included in Table 13.

As an example from the DACUS experiments, Figure 14 shows the average length of social impact hotspots on the left chart, and the total number of minutes with a hotspot over a 2-hour period on the right. The distribution of population in Toulouse Metropole was taken into consideration to calculate these social hotspots.

[9] The inclusion of economic and/or social impact of the collision between two drones as an additional limiting factor is under discussion.

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Figure 14: Social hotspots length in an experiment in Toulouse Metropole

5. **Assessment of pre-defined DCB measures**

This process is **performed by the Dynamic Capacity Management service**. It assesses if the previously identified safety and social hotspots could be solved through some of the pre-defined DCB measures.

DCB measures will be implemented **only in those cells of the grid where a hotspot is identified**. The specificities of some of the DCB measures could make it necessary to implement them in a wider area, but always reducing the constrained area as much as possible.

DCB measures which are not highly impacting the fulfilment of the missions will be prioritized. The process will determine the most suitable solution at this phase and those operation plans which are candidates for a modification. In case of implementing DCB measures which are impacting the fulfilment of the mission such as delays or re-routing away for certain volumes of airspace, a prioritization process will be launched.

6. **Prioritizations of Operation Plans**

This process is performed by the Dynamic Capacity Management service. 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".

Operation plans submitted after the start of the pre-tactical phase will be the first candidates in case of imposing constraints associated to DCB measures. Then, all operation plans submitted before tactical phase 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 safety and social indicators, hence whose removal would cause the largest overall reduction in risk or social impact.

7. **Towards the implementation**

At this stage, two approaches are envisioned which are characterised by:

- **Option A**: Drone Operators will provide new operation plans complying with the measure. These operation plans will be verified by the Operation Plan Processing service and slight changes could be proposed by the Strategic Conflict Resolution service.
- **Option B**: The Strategic Conflict Resolution service integrates the constraints from the Dynamic Capacity Management service and sends the information to the Operational Plan Processing service to share alternative operation plans with Drone Operators.

The processes related to each approach are included in Table 15.

Table 15: Overview of potential DCB measure implementation options in the pre-tactical phase.

Option A: Drone Operators to provide new Operation Plans complying with the measure.	Option B: U-space to propose Operation Plans complying with the measure and with pair-wise conflicts.
7a. Implementation of selected DCB measure This process is performed by the Operation Plan Processing service. It sends a request to the Operation Plan Preparation services to inform them about the affected operation plans and the constraints associated to the implemented measure.	**7b. Generation of "what-if" 4D trajectories** This process is performed by the Operation Plan Processing service. The service receives the proposed DCB measure and generates 4D trajectories taking into consideration the constraints associated to the DCB measure. These "what-if" 4D trajectories are generated only for those operation plans affected by the measure.
8a. Submission of new operations plans to comply with the DCB measure New operation plans are submitted by Operation Plan Preparation services complying with the constraints of the DCB measure. These operation plans will be verified by the Operation Plan Processing service and slight changes in the operation plans could be proposed by the Strategic Conflict Resolution service.	**8b. Assessment of pair-wise collision risks of new DCB scenario** This process is performed by the Strategic Conflict Resolution service. This process is launched as soon as a DCB measure is going to be implemented and "what-if" 4D trajectories of those operations affected by the measure are sent by the Operation Plan Processing service. The process detects potential conflicts, and also identifies several solutions by changing either of the pair. The changes will come from a standard set of "recipes" which are tested and those that resolve the problem (and do not cause another problem) retained. Deconfliction of pair-wise trajectories could be related to slight changes in vertical, horizontal or speed profiles which do not imply relevant changes to Operation Plans.
	9b. Implementation of DCB measure and pair-wise solutions This process is performed by the Operation Plan Processing service. It sends a request to the

Option A: Drone Operators to provide new Operation Plans complying with the measure.	Option B: U-space to propose Operation Plans complying with the measure and with pair-wise conflicts.
	Operation Plan Preparation services to confirm their acceptance of the proposed solution that comply with the DCB measure and solves the pair-wise collision risk. If not accepted, a resubmission of the operation plan should be performed complying with the implemented DCB measure. This new operation plan should be also validated by the Strategic Conflict Resolution service.

8.4.3 Tactical phase

This phase takes place during the execution of the operations. The main objective of this phase is to monitor the overall traffic picture and to minimise the impact of any disruption. Refer to Appendix C for a graphical representation of the DCB process in the tactical phase.

1. **Reporting a disturbance**

Different type of disturbances may trigger the need to adjust the initial traffic picture. The origin of the disruption determines the U-space service that identifies it. The following bullets describe the set of disruptions considered in this ConOps:

A. **Navigation disturbances**: associated to the loss of navigation. The Navigation Infrastructure Monitoring service will be in charge of monitoring the navigation performances and reporting alerts to U-space in real-time;
B. **Communication disturbances**: associated to the degradation of the communication infrastructure. The Communication Infrastructure Monitoring service will be in charge of monitoring the communication performances and reporting alerts to U-space in real-time;
C. **Electromagnetic disturbances**: The Electromagnetic Interference Information service collects and presents relevant electromagnetic interference information for the drone operation. The specific area which is affected by these disturbances will be reported;
D. **Meteorological disruptions**: associated to significant meteorological phenomena that will be alerted by the Weather Information service in real-time, identifying the affected area;
E. **Drone emergencies**: These contingencies will be reported by the Emergency Management service which is in charge of providing assistance to a drone pilot experiencing an emergency with their drone and communicates emerging information to interested parties. An emergency for a drone user/operator is an incident/accident which causes the drone to be out of control. Contingency plans may be expected to appear as standard operating procedures. Several examples are mentioned in the U-space CONOPS:
    - CP1: If the drone experiences a loss of datalink, position emitter/receiver failure, directional loss, or flies through an area of electromagnetic interferences, it must either return to home/launch or land at a dedicated landing area, automatically;
    - CP2: If a drone experiences a flight controller failure, unintentionally loses altitude, flies through severe weather, collides with an obstacle or other air traffic, or is totally lost, it must activate the emergency landing protocol immediately. Emergency

equipment (e.g., parachute, lights to be seen at night, and a signal to be heard on ground) must be activated. Furthermore, either the pilot or the drone must immediately send an emergency signal via the Emergency Management service;

- CP3: In the case of a critical human error or medical issue with the remote pilot, a backup pilot must take over the flight immediately, if available. If no control input is received by the drone for longer than a determined time period, CP1 must be activated.

F. **Service performances degradation or services emergencies**: associated to the degradation of the performances of a U-space service or even the failover of the service provision. The U-space architecture will allow detecting and absorbing failures in the system, and also incorporating countermeasures able to react in real-time. A deterministic management of failure modes will allow treating differently and deterministically the failure of each service. A contingency plan of a U-space service enters into force if a misbehaviour of the service is detected or the plausibility check of the service detects input data from external sources that are missing, wrong or arrives with high latencies [14]. As an example, Tactical Conflict Resolution Service may use weather information from the Weather Information service to improve its performances. A failure of the weather service may imply the need to increase the separation standards managed by the Tactical Conflict Resolution service. This increase of separation could imply that the system cannot manage the envisioned demand in a certain area (see [20], [37] and [38]). Another example is detailed in the U-space CONOPS regarding the monitoring service. This service detects erroneous data from the tracking service, so it gives a warning to affected drone users/operators.

G. **City-originated disturbances**: These disturbances are not directly linked to the drone operations or the U-space system itself. They are provoked by unexpected events in the urban environment such as emergency helicopter operations, protests, police actions or fire fighting among others. These disturbances can be reported by external actors such as firefighting service, police, city council or sanitary service, among others. In most of the cases, they should be managed in U-space through ad-hoc geofencing areas.

H. **Airport-originated and ATM-originated disturbances**: These disturbances are not directly linked to the drone operations or the U-space system itself. They are linked to airport or ATM operations or specific needs such as manned aircraft emergencies or the detection of incursions in the airport vicinity that trigger specific processes to prevent damages. These disturbances will be reported by airport or ATM service providers through specific services allocated to this purpose i.e., through the U3 *Collaborative Interface with ATC* service.

I. **Surveillance disturbances**: Need for a dedicated surveillance infrastructure monitoring service, assuming there is a dedicated surveillance network. However, if drones are the primary source of surveillance information, this would be covered by the communication infrastructure, and alerts will be reported by the Communication Infrastructure Monitoring service.

In general, **the aforementioned services will be in charge of identifying the characteristics of the disturbance and the affected area**, which will not be necessarily the entire airspace above the urban area. They will also inform about the **expected time to recover if it makes sense** according to the type of disruption. On the other hand, not all these services are aware of the drone operations affected by the disturbance. Consequently, the Operation Plan Processing service should be in charge of identifying the operation plans affected by the reported perturbation, or by the activated contingency plan or emergency procedure.

2. **Managing the disruption caused by the disturbance**

All disturbances can be categorised in terms of the duration and impact of the disturbance on drone operations. The qualitative assessment of the duration is done taking the mean duration of a drone operation in urban environments as a reference. Thus, long duration means that most of the operations affected are still on ground, while short duration means that affected operations are mainly on the air. On the other hand, the impact of the disturbance will also be linked to the possibility of predefining and standardizing the solution to put in place when the disturbance happens. Disturbances such as drone emergencies could happen with high frequency and even daily in urban environments with high density of drones. The remote pilot will not be able to safely handle safety-critical in-flight contingencies, which drives the need for autonomy. However, any autonomous drone behaviour should be deterministic and predictable to allow U-space to perform standard decision-making processes. Consequently, as stated in [37], besides planning the nominal flight trajectory, it is crucial to anticipate any foreseeable off-nominal situation such as in-flight contingencies that can compromise safety and thoroughly prepare contingency management procedures to effectively cope with them.

Table 16: Qualitative categorisation of the disturbances.

	Duration	**Impact**
A. Navig.	**Short.** If the disturbance is caused by increased latencies, momentary loss of signal or travel of vehicles through urban canyons. **Medium.** Signal jamming or spoofing may cause short-term or localized navigation issues. **Long**. Navigation infrastructure outages may take long time periods to rectify.	**Low**. If secondary navigation means are in place that can meet Required Navigation Performance (RNP) levels for the airspace. **Medium**. If secondary navigation means are in place but cannot meet Required Navigation Performance (RNP) levels for the airspace. RNP requirements need to be reduced, thus reducing capacity. **High.** If no secondary navigation means are in place. This is improbable given that urban airspace operations will likely require at least one form of backup navigation source.
B. Comm.	**Short.** If the disturbance is caused by increased latencies or momentary loss of signal. **Medium.** If the drone leaves the communication range of the C2 link. **Long**. Navigation infrastructure outages may take long time periods to rectify.	**Low**. If secondary communication means are in place. **Medium**. If secondary communication means are in place but the latency is increased or if communication is lost but vehicles have a contingency procedure in place to recover the communication link. **High.** If no secondary communication means or contingency procedures are available.

	Duration	Impact
C. Electro.	**Short**. Localized electromagnetic interference (such as those caused by the cellular network, lightning or solar flares) may affect drone operations only for a short while. **Medium**. Intentional use of radio jamming equipment may cause electromagnetic interference issues for a longer duration.	**Low**. If electromagnetic interferences only affect specific drone operations within a localized area. **High.** If a wide-spread electromagnetic interference (such as a solar flare) is present.
D. Meteo.	**Short.** Significant short-term meteorological phenomena such as wind gusts, lightning, wind-shear or microbursts. **Medium.** Significant phenomena such as precipitation, strong winds and turbulences or phenomena that affect visibility such as fog or haze. **Long**. Prolonged meteorological phenomena such as a passing of a front, heatwaves or blizzards.	**Low**. Short-term and localized meteorological phenomena may affect individual drones, but not have significant repercussions in the DCB process as a whole. **Medium**. Significant medium-term weather phenomena may affect airspace capacity over a larger surface area. **High**. Prolonged meteorological phenomena may cause urban drone operations to cease completely.
E. Emerg.	**Short**. Affected drones are mostly in the air.	**Low** if pre-defined contingency plans are predefined. **Medium** if the lack of contingency plans makes necessary to define ad-hoc geofencing areas with several drones affected.
F. Serv. Degr.	**Short.** if there is a back-up service. **Long.** if no back-up service can provide the same level of performances.	**Low** if there is a back-up service. **High**. Contingency Plans can be defined in advance, but the impact will be extended to a wide area in which separation should be increased for a long time period e.g., failure of high-performance micro weather service in a dense urban area.
G. City-origin.	**Short**. If the unexpected event is brief (e.g., emergency helicopter operations, firefighting, police actions). **Medium**. If the unexpected event is of longer duration (e.g., protests).	**Low**. If the increase in risk caused by unexpected event the area is negligible. **Medium.** If the increase in risk caused by unexpected event the area is significant (e.g., increased third-party risk or risk of collision).
H. Airport or ATM-origin.	**Short**. If the disturbance is brief (e.g., manned aircraft emergencies). **Medium**. If the disturbance is of longer duration (e.g., reservation of specific areas for manned aircraft operations).	**Medium.** These types of disturbances will likely have a pronounced effect on airspace capacity or imply flight restrictions for drones.

	Duration	Impact
J. Surv.	(Only applies if a dedicated surveillance network is in place, otherwise see point "B"). **Short.** If the disturbance is caused by increased latencies or brief loss of contact with vehicles. **Medium.** Signal jamming or spoofing may cause short-term or momentary surveillance-station unavailability. **Long**. Surveillance infrastructure outages may take long time periods to rectify.	(Only applies if a dedicated surveillance network is in place, otherwise see point "B"). **Low**. If secondary surveillance means (e.g., collaborative surveillance) are in place. **Medium**. Localized station or infrastructure outages may affect surveillance coverage in a specific area. **High.** Wide-spread surveillance infrastructure outages.

The following table shows the processes that are affected by each type of disturbance.

Table 17: Overview of the impact of disturbances to drone traffic on tactical DCB processes.

	Generation of 4D trajectories	Calculation of demand prediction	Monitoring of risk-based and social indicators	Assessment of pre-defined DCB measures	Prioritizations of Operation Plans
A. Navig.	4D trajectories are updated in case of navigation performance degradation	Demand picture in the area where new 4D trajectories are proposed.	Recalculation of safety-related indicators based on Navigation Coverage Information.	If an imbalance is present, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.
B. Comm.	No new 4D trajectories	No new demand prediction	Recalculation of safety-related indicators based on Communication Coverage Information.	If safety-related indicators in the affected area are above the thresholds, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.
C. Electro.	No new 4D trajectories	No new demand prediction	Recalculation of safety-related indicators based on Electromagnetic Interference Information.	If safety-related indicators in the affected area are above the thresholds, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.

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	Generation of 4D trajectories	**Calculation of demand prediction**	**Monitoring of risk-based and social indicators**	**Assessment of pre-defined DCB measures**	**Prioritizations of Operation Plans**
D. Meteo.	New 4D trajectories exiting the affected area and completing the missions are submitted by the drone operators.	Demand picture in the area where new 4D trajectories are proposed.	Recalculation of safety-related and social indicators in the affected area.	If safety-related indicators in the affected area are above the thresholds, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.
D. Meteo.	Contingency-based 4D trajectory.	Demand picture in the area affected by the contingency.	Recalculation of safety-related and social indicators in the affected area.	Re-routing away from the affected volumes of the airspace	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.
E. Emerg.	No new 4D trajectories	No new demand prediction	Recalculation of safety-related indicators based on the loss of performances.	If safety-related indicators in the affected area are above the thresholds, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.
G. City-origin.	New 4D trajectories for affected drone operations.	Demand picture in the area affected by the disruption.	Recalculation of safety-related and social indicators in the affected area.	If an imbalance is present, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.
H. Airport or ATM-origin.	New 4D trajectories for affected drone operations.	Demand picture in the area affected by the disruption.	Recalculation of safety-related and social indicators in the affected area.	If an imbalance is present, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.
K. Surv.	4D trajectories are updated in case of Surveillance Coverage degradation	Demand picture in the area where new 4D trajectories are proposed.	Recalculation of safety-related indicators based on Surveillance Coverage Information.	If an imbalance is present, re-routing or delays on ground.	Selection of candidates based on priority, 'virtue points' and impact on safety and social indicators.

The list of disturbances presented above could affect the DCB process, and which actions might be performed to deal with them. Some concrete examples of use cases are included in chapter 9.

8.4.4 Summary of U-space service interactions

This section provides an overview of **interdependencies of the Dynamic Capacity Management and Conflict Resolution services** (which will be the core of the DCB concept) **with other services in the U-space ecosystem,** according to the DCB concept presented in 8.4.

Within the DACUS DCB solution, the **Operation Plan Processing** service generates probabilistic 4D trajectories (based on mission requirements and uncertainties) which are then used within the DCB process. This information is gathered from multiple **Operation Plan Preparation** services. Furthermore, it will need accurate **Weather Information** to make reasonable trajectory predictions. The Operation Plan Processing service also receives proposed DCB measures as well as pair-wise conflict resolutions – both constraints previously integrated by the Strategic Conflict Resolution service - to generate "what-if" trajectories on affected operation plans. Depending on the type of approach implemented, the Operation Plan Processing service will either forward the DCB measure to the Operation Plan Preparation service and wait for updated operation plans from the operators or integrate the DCB constraints directly and propose alternative operation plans to Drone Operators. Within the tactical phase, the Operation Plan Processing service will receive warnings about any disruptions coming from the following services: **Navigation Infrastructure Monitoring, Communication Infrastructure Monitoring, Weather Information, Emergency Management** and **Geofence Provision (Dynamic Geofencing).**

4D trajectory information is ingested by the **Dynamic Capacity Management** service to calculate demand and uncertainty. Moreover, it will perform the monitoring of risk-based and social indicators. The monitoring of risk-based indicators will be assisted by **Navigation and Communication Coverage Information.** For social indicators, although not specifically mentioned by the DACUS DCB concept, the origin of this information will likely come from services such as **Geospatial Information** and **Population Density Maps**. In the pre-tactical phase, it will also count on **Weather Information** and **Drone Aeronautical Information** as additional indicators. Furthermore, Dynamic Capacity Management will award "virtue points" as a means to promote "good" behaviour among Drone Operators concerning the submission of Operation Plans as well as a means to prioritise drone flights. With this information, the Dynamic Capacity Management service assesses the implementation of DCB measures.

Strategic Conflict Resolution receives probabilistic 4D trajectories created by the Operation Plan Processing service to identify pair-wise collision risks and return potential solutions for conflict resolution as well as to simply check whether new operation plans are in conflict with existing ones. This service takes into account the constraints previously provided by the Dynamic Capacity Management service.

Tactical Conflict Resolution receives probabilistic 4D trajectories created by the Operation Plan Processing service as well as real-time tracking information to identify pair-wise collision risks and return potential solutions for conflict resolution.

The image below depicts the services that are directly involved in the DCB process as well as 2nd-level links to prior services.

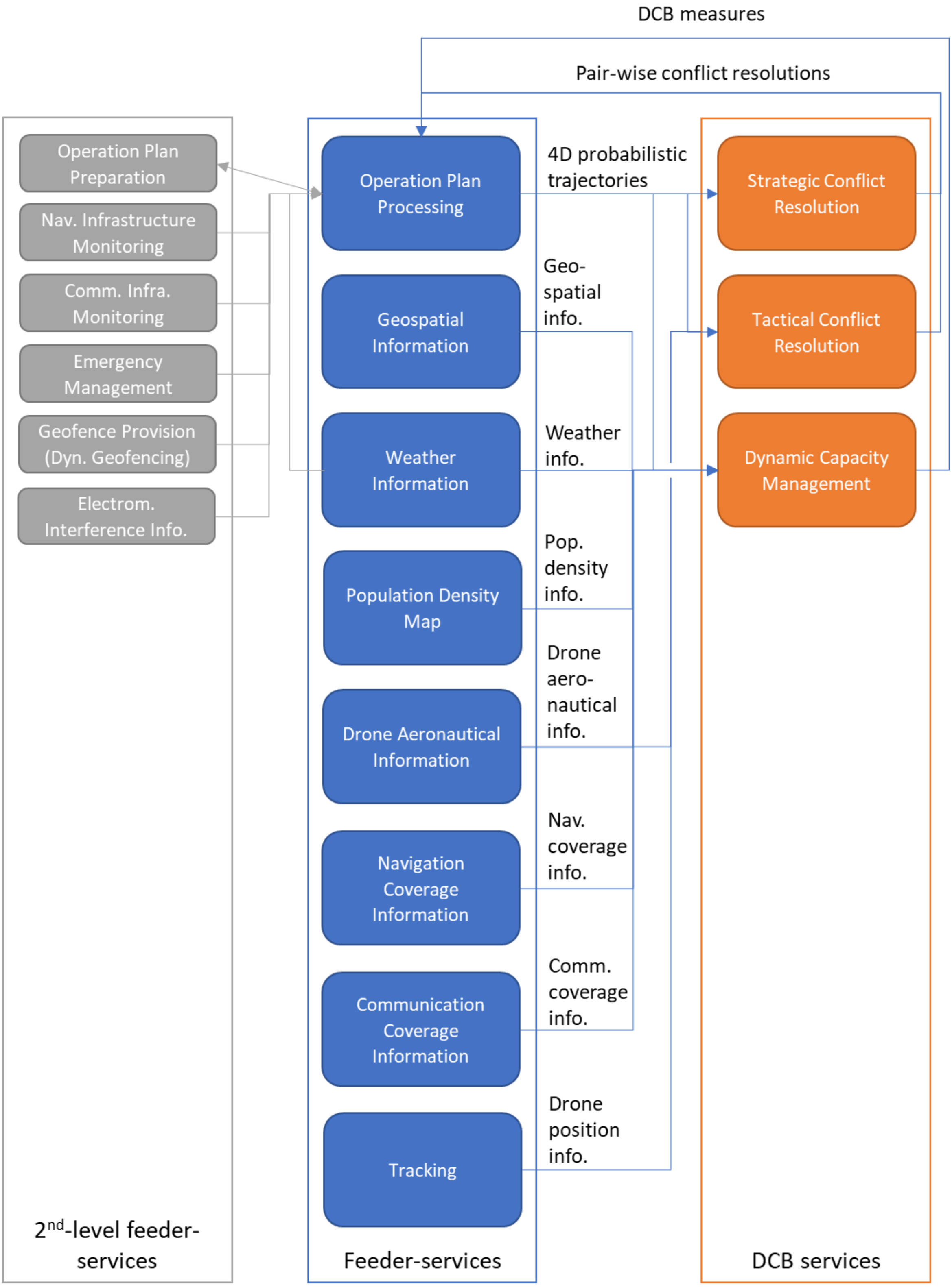

Figure 15: Overview of service interactions within the DACUS DCB solution.

The service interactions introduced in this section were in part based on concepts for service interaction provided in the U-space CONOPS [14] and other projects within the U-space framework, specifically IMPETUS and DREAMS, as well as their implementation in the architectures of the U-space demonstration projects DOMUS and SAFEDRONE. U-space DCB measures

8.4.5 Principles for the selection of a DCB measure

DCB measures can be classified according to their **range of applicability in each of the DCB planning phases**. In general terms, those measures which are more stable against changes in the demand are suitable for those planning phases which are further from the execution. They are supposed to be affecting to a wider set of operations, whereas other measures which allows the cherry-picking of flows, or even a set of individual flights, are more suitable in the execution phase, when other measures may not be available, but the knowledge of the demand is high to take decisions on individual flights.

Other classification to be considered is the **effectiveness of the measure with respect to the type of imbalance** to be solved. For instance, an imbalance due to a number of drones which are generating unacceptable noise in an area could be solved by a solution increasing the mean altitude of the operations in that area. This measure could be very effective for the resolution of this type of social impact hotspots but however, its implementation may not increase or even reduce the maximum capacity associated to safety-related targets. The measurement of effectiveness against hotspots is captured through the definition of applicable performance indicators within the DCB process. Relevant Key Performance Areas (KPAs) for the DCB process were identified by DACUS in its performance framework [48] and summarize in Table 14. They are Safety, Environmental and Social Impact, Mission Efficiency, Equity, Flexibility and Resilience.

The set of DACUS Key Performance Indicators (KPIs) will not only serve to capture the impact of each measure on safety, environmental and social aspects, but also on other elements which are relevant in the drone operations. U-space DCB measures can also be categorized according to **their impact on the fulfilment of the mission objectives**, assuming that not all requirements included in the operation plan are necessary to guarantee the success of the mission. U-space DCB measures can impose constraints on the drone operation plans, such as flying in a certain flight level, which are not necessarily impacting on the requirements of the Drone Operators to fulfil their missions. Then, mission efficiency indicators will capture the impact on the fulfilment of mission objectives. For instance, the organization of flows per flight layers can reduce the safety impact without significantly impacting the fulfilment of most of the business models in urban environments. In addition, those indicators will capture the fact that, although missions can be completed, it could be at the price of increasing flight distance or consuming much more energy.

On the other hand, resilience indicators will capture that **stability of the solution against perturbations**. For instance, a solution could provide many benefits in terms of reduction of air risk, but it is very sensitive to perturbations such as intruding aircraft or an aircraft that experiences a failure. In addition, flexibility indicators will assess the impact of changes on the demand on the effectiveness of the DCB measure.

Finally, equity indicators will measure the **differences in the impact to the drone operations**. The impact of the DCB measures on each single Drone Operator will depend on the characteristics of its specific business, e.g., for package delivery, it is not a problem to organize the traffic per flight layers but this is not the case for other business models, such as inspection missions which must adhere to specific flight profiles.

Other aspect to take into consideration is the **applicability of each DCB measures in hyper-localized portions of airspace**. In ATM, DCB indicators are calculated at macroscopic levels, given the large volumes of airspace which are managed within the air traffic management domain, e.g. airspace indicators are calculated "sector-wise", as this is the fundamental workspace is used by air traffic control. In U-space urban airspace, the expected level of granularity is much higher and then, DCB measures which can be implemented in localized areas without high impact outside of the hotspot seem to be more applicable.

8.4.6 List of DCB measures

This section describes potential DCB solutions and their applicability. We are assuming that, excluding those flying restrictions which will be pre-defined by the authorities to be able to operate in urban areas, free-route operations will be prioritized unless constraints associated to DCB measures need to be implemented. Then, this list assumes that pre-defined route designs do not exist by default and they will only be implemented if the traffic demand makes it necessary.

DACUS tested the most relevant DCB measures applicable in the pre-tactical phase: Speed controlled zones, organization per flight layers, organization with route structures, increase the operational ceiling and imposing delays in the departure time. Results are shown in [49] and a summary of the conclusions are included in 12.1.

INCREASING CNS INFRASTRUCTURE

This measure is applicable in the long-term planning phase due to the large amount of time required to invest in CNS infrastructure. Thus, these measures are out of the scope of DACUS.

IMPOSING SUBSCRIPTION TO HIGH-PERFORMANCE U-SPACE SERVICES

Similarly, another long-term measure to increment the number of drones that can be managed is to prescribe a certain level of U-space service capability in a given area. As an example, to increase the density of drones at lower altitudes the provision of a high-fidelity micro weather service in combination with a high-fidelity terrain mapping service may be required, and Drone Operators should make use of these services.

These high-performance services will allow reducing the separation standards, and then, increasing the capacity.

It can be implemented in the strategic phase. The applicability in the pre-tactical phase is under discussion and it will highly depend on the time before the execution in which this phase will start. As an example, if this phase starts 10-15 minutes before the execution, there could be no time to request the update of the operation plans to the affected drone operators. On the contrary, if the requested upgrade of services is easy to implement - e.g. by clicking a box in the operation plan edition tool - the implementation of this measure is only a problem of increasing the operating costs of the affected drone operators.

INCREASE THE NUMBER OF TAKE-OFF / LANDING AREAS

This measure could be applied in the strategic phase.

These measures should increase capacity and also demand over the whole urban area. The rationale behind this is that some operations could be limited by the drone range (a drone takes-off from a point but cannot reach the next landing pad). Then, food delivery companies cannot deliver to the customers close enough to their houses.

HIGHER AIRCRAFT OPERATIONAL PERFORMANCE REQUIREMENTS

It could be applied in the strategic over certain areas where the traffic requires it.

Requesting higher individual aircraft operational performance requirements in order to optimize the capacity utilization of the airspace. Increasing these requirements makes it necessary to increase the level of equipment and associated capabilities of the drone. As a consequence, it is necessary to identify those equipment categories that are more dynamic in nature to be considered as a DCB solution. An example is to request contracting with USSPs which are offering service provision with higher performances, i.e., imposing higher precision tracking and navigation performances may allow closer spacing between aircraft. Other example is to request for a human in the loop to be able to react in contingency situations for operating in more complex airspace [14]. Probably, the impact on the fulfilment of the mission objectives will be higher when implementing these solutions.

LIMITING MAXIMUM TIME OF OPERATIONS

This measure could be applied in the strategic phase and it should reduce both capacity and demand over certain areas.

The idea behind this measure is to limit the time passed in the zone of operation for operations which reserve volumes of airspace (e.g., inspection, surveillance). Limiting the time will increase the capacity at “t” time, and probably reduce the demand if some operators consider that they need more to conduct their mission properly.

MAXIMUM SIZE OF AIRSPACE RESERVATIONS

This measure could be implemented in the strategic phase.

Some drone missions may require the reservation of a dedicated volume of airspace to fulfil mission requirements. The DCB process can impose a size limit on the maximum dimensions that a reserved volume may have if capacity constraints require it. However, this size restriction should still be large enough to achieve mission objectives. It should be applied in the strategic phase.

Drone traffic characterization in urban environments show that the percentage of operations that may request a dedicated volume of airspace are not so much to think that this will be a measure highly increasing the overall capacity of the airspace.

SPEED-CONTROLLED ZONES

This measure could be applied in the strategic and pre-tactical phase. The implementation in the tactical phase could imply that some in-flight drone operations would not be able to complete their missions.

Revision of traffic organization schemes by implementing speed-controlled zones [14]. This measure can be applicable both in the strategic and the pre-tactical phases. Probably, the impact on the fulfilment of the mission objectives will not be high for most of the business models in urban environments. The capacity improvements derived from this measure need to be further explored.

ORGANIZATION PER FLIGHT LAYERS

Revision of traffic organization schemes by implementing the organization of flows per flight layers [23]. This measure can be applicable both in the strategic and the pre-tactical phases. Probably, the impact on the fulfilment of the mission objectives will not be high for most of the business models in urban environments. The capacity improvements were quantified in METROPOLIS project by analysing the reduction in the conflict rate of spreading traffic.

ORGANIZATION WITH ROUTE STRUCTURES

It can be implemented in the strategic and in the pre-tactical phases. This measure combines the previous one with pre-defined routes in each layer.

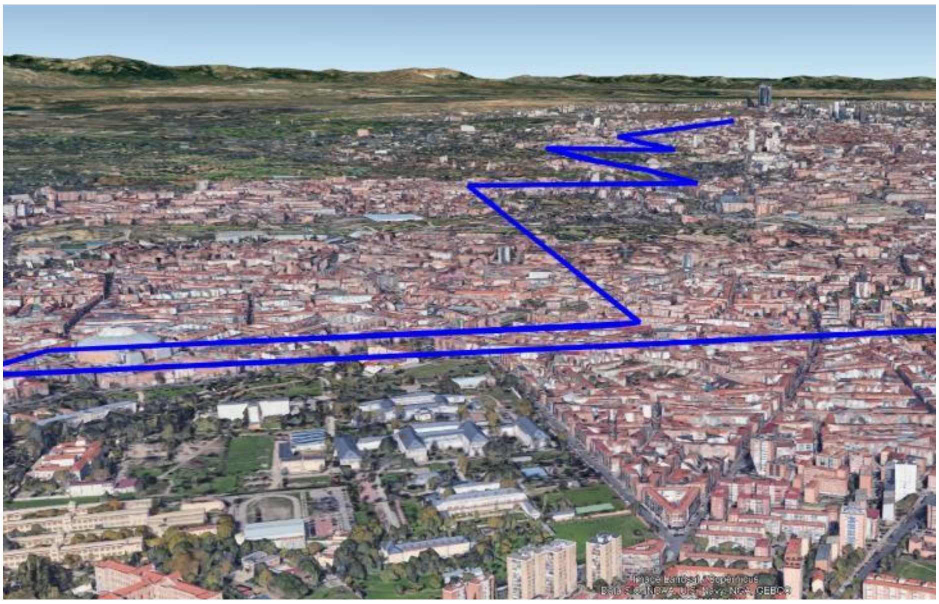

Figure 16: Implementation of route structure in hotspots areas in Madrid VLL airspace

INCREASING THE OPERATIONAL CEILING OF U-SPACE AIRSPACE

It should be probably applied in the strategic and also in the pre-tactical phase.

By definition, U-space designated airspace is linked to VLL airspace boundaries, which extend up to 400ft above ground level. However, the minimum operating altitudes for manned aircraft above urban areas are limited to 1000ft above ground level. This provides a buffer area where, under normal circumstances, no flights would take place. If conditions allow it, and CNS infrastructure as well as service connectivity are provided at such altitudes, U-space operating altitudes may be increased in order to increase airspace capacity.

CHANGES IN THE DEPARTURE TIME

Slight changes in the departure time can be proposed to individual drone operations to remove certain hotspots. If major changes need to be proposed, they could be highly impacting the fulfilment of the mission objectives and consequently, some of the missions could be at risk.

It can be implemented in any planning phase, and they are one of the alternatives in case of unexpected events in the tactical phase.

Re-routing or flight level changes

Slight flight level changes can be proposed to individual drone operations to remove certain hotspots. If major changes need to be proposed, they could be highly impacting the fulfilment of the mission objectives and consequently, some of the missions could be at risk.

It can be implemented in any planning phase, and they are one of the alternatives in case of unexpected events in the tactical phase.

Rejection of mission plans

Given that ground and air risk play an important role in the DCB process, measures to decrease the overall risk of operations must consider the possibility to deny any additional operations in the area if no other means to reduce the overall risk are found. This measure should only be considered as a "last resort" and specially, as a solution in case of unexpected events in the tactical phase.

9 Operational scenarios

This chapter provides some examples of operational concept scenarios and use cases to support the DCB concept definition. This section shows four operational scenarios in which workflow information and actors could be identified easily on different real situations.

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.

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- **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.

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

9.1.1 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.

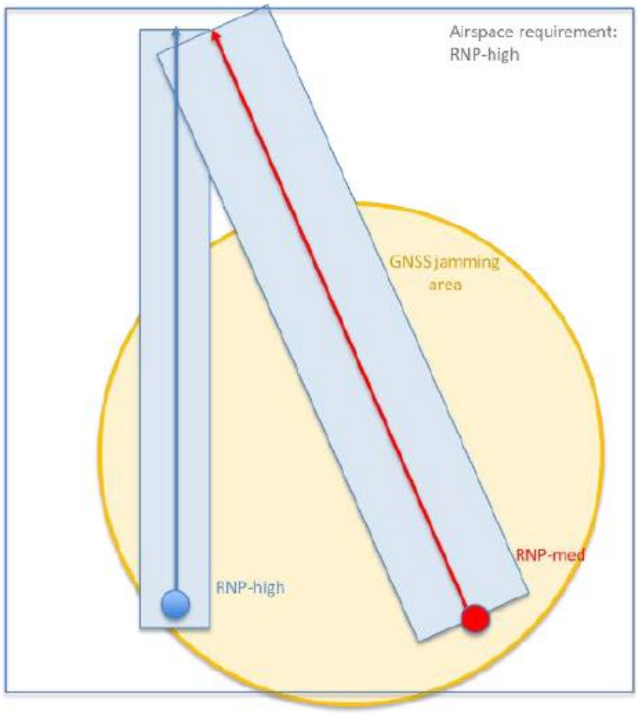

Figure 17. Operational Scenario #01

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.

9.1.2 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").

9.1.3 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.

9.1.4 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.

9.1.5 Post-conditions

9.1.5.1 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.

9.1.5.2 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.

9.1.6 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.

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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.

9.1.6.1 Main flow of events

This section outlines the proposed content of the information contained in the information flow.

Table 18: OS #01 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.	-
6	U-Space Service Provider	Dynamic Capacity Management service assesses whether the airspace requirements can be reduced to RNP-med	-

Step	Actor(s) Involved	Actor(s) Action	System Response
		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.	-

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

9.2.1 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.

9.2.2 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.

9.2.3 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.

9.2.4 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.

9.2.5 Post-conditions

9.2.5.1 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.

9.2.5.2 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.

9.2.6 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.

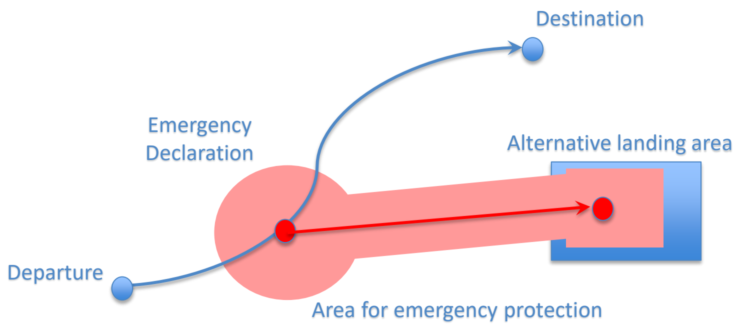

Figure 18: Visualization of the activation of an emergency with contingency plan to land in an alternative drone port.

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 19: 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.

9.2.6.1 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.

Table 19: OS #02 Main flow of events.

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 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	Assessment of pre-defined DCB measures. A prioritization process will be launched.

Step	Actor(s) Involved	Actor(s) Action	System Response
		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[10].
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[10]. Operation Plan Processing service proposes alternative operation plans to the Drone Operators.	Operation Plan Preparation service confirms acceptance of the operation plans and proposals.

9.3 OS #03 - DCB workflow information under nominal conditions

9.3.1 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

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

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[11] 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, 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 Appendix A.

9.3.2 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;

[11] 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.

- All services identified in U-space U1 and other specific U2 and U3 services which are part of the DCB process -see Appendix A -, 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[12] 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.

9.3.3 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;

[12] 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.

  - 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.

9.3.4 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.

9.3.5 Post-conditions

9.3.5.1 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.

9.3.5.2 Failed end-state

A failed end-state is:

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

9.3.6 Scenario description

9.3.6.1 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.

Table 20: OS #03 Main flow of events.

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.	USSP1 assimilates mission requirements based on the aeronautical, geospatial and weather information, and forward the information in the

Step	Actor(s) Involved	Actor(s) Action	System Response
		Two operation plans[13], 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.	form of operations plans to the CISP.
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.	-

[13] 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
		Flight levels are not rigid mission requirements for Company A as they are interested in flying the shortest distance at maximum speed.	
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.

9.4 OS #04 – Weather impacting vertiports capacity

9.4.1 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.

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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.

9.4.2 Actors involved

In addition to the actors previously mentioned, 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.

9.4.3 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 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[14] 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.

9.4.4 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.
  - 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.

[14] 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.

  - 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.

9.4.5 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.

9.4.6 Post-conditions

9.4.6.1 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.

9.4.6.2 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.

9.4.7 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.

9.4.7.1 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.

Table 21. OS#04 Main flow of events

Step	Actor(s) Involved	Actor(s) Action	System Response
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 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).	-

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Step	Actor(s) Involved	Actor(s) Action	System Response
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 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 first leg of the mission.
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.	-

Step	Actor(s) Involved	Actor(s) Action	System Response
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 Learning and past data (in the order of single digit minutes).	Operation Plans including uncertainty and contingency plans are sent to the CISP.
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).	-

10 Differences between ATM and U-space DCB processes

Given the different approach to managing U-space airspace from legacy ATM concepts, the DCB process outlined in this document differs in many ways to the one performed in ATM. This section highlights these differences by drawing parallels between the new concept and that of ATM. In order to facilitate this process, the section begins with an overview of how DCB is performed in ATM nowadays.

10.1DCB process in ATM

In today's air traffic management system, demand and capacity balancing is considered a tool that is part of a larger Air Traffic Flow & Capacity Management (ATFCM) system. The aim of ATFCM is to assure that air traffic control is protected from overloads whilst optimizing the available capacity of the airspace.

10.1.1ATFCM performance indicators

In general terms, air traffic management uses the term **"capacity"** to **describe the number of flights that can be handled safely and efficiently in a defined volume of airspace within a given time period** (usually one hour) and **"demand"** to refer to the **number of flights that intend to fly**. Any time demand exceeds capacity, or vice-versa, an imbalance is present, which ATFCM aims to solve. **Several metrics are proposed in ATFCM to detect these imbalances**, the **"capacity" metric** being the most common one, i.e., number of flights entering in a sector per hour. Additional metrics were also proposed by SESAR, and some of them already implemented in the system, to improve the detection of controllers' overloads. The most important ones to mention are the **"occupancy" metric**, which is number of flights that can be handled at the same time and the **"complexity" metrics**, which are focused on quantifying how complex the traffic is for the air traffic controller to ensure the safe separation.

One of the key challenges of DCB in U-space is to define new metrics to determine how many drones can be safely managed by the U-space system in a given 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 could represent a density of aircraft beyond which there is a probability that the tactical conflict resolution process will be unable to keep the risk of conflict acceptably low.

10.1.2ATFCM phases

Balancing traffic demand and capacity can be done so in a wide range of time scales, from strategic (long-term) to tactical ("day-of-operations") ATFCM phases. There are **five phases** in which ATFCM, and thus DCB measures, are performed. These phases are, in chronological order, Strategic, Pre-Tactical, Tactical and Post Operations in conjunction with continuous Air Traffic Management Planning.

- Air Traffic Management Planning is a **continuous process** to improve the ATM organizational structure, staff employment and training as well as the implementation of airspace design, standard operating procedures and organizational structures.

- Strategic planning takes affect from **around six months to two days prior to operation**, in which airport slots are assigned, capacity enhancement and optimization activities take place, major events are planned, and flexible/special use airspace is facilitated.
- The **day prior to operation and up to two hours prior to operation** encompasses the processes of the pre-tactical phase, in which weather and system constraints on capacity and demand are assessed, potential demand/capacity issues and solutions are identified, a dialling mitigations plan is developed and Collaborative Decision Making (CDM) processes are launched.
- From **two hours up to flight execution**, tactical measures are made to manage demand and capacity in response to real-time events by implementing CDM and ATFCM-measures.
- After operations, the post-ops phase will assess historical data to determine the impact, compliance, effectiveness and benefits obtained from the implemented ATFCM measures and formulate lessons learned.

For U-space DCB it was necessary to redefine these phases and the ATFCM measures that can be applied in each phase according to their effectiveness.

10.2Overview of differences

The following table highlights the major differences between DCB processes of ATM and U-space.

Notion	Air Traffic Management	U-space
Determination of capacity	Capacity is used to describe the number of flights that can be handled safely and efficiently in a defined volume of airspace within a given time period. The definition of capacity is fundamentally linked to the capability of a (human) air traffic controller to manage aircraft within a certain airspace volume (Controller Cognitive Load). Capacity is just one of several metrics to define limits on operations within a specific sector. There metrics are: • Capacity: Number of flights entering a sector per hour. • Occupancy: Number of flights that can be handled at the same time. • Complexity: Quantification of the complexity of the traffic	Capacity is a function of risk-based and social indicators per pre-defined airspace volume. Risk-based indicators include measures of third-party ground and air risk. Thresholds are defined for each of these indicators which, in conjunction, define the overall capacity limit of an area.

Notion	Air Traffic Management	U-space
	for the air traffic controller to handle.	
Determination of demand	Sector entry or sector occupancy	Demand is a function of probabilistic 4D trajectories of vehicles within a specific volume of airspace and time frame. This process also includes demand characterization. The identification of additional characteristics (such as drone type, level of autonomy, type of operation, priority and proximity to manned aviation) that are relevant to understanding the demand picture.
Granularity of DCB indicators	DCB indicators are calculated at macroscopic levels, given the large volumes of airspace which are managed within the air traffic management domain. Airspace indicators are calculated "sector-wise", as this is the fundamental workspace is used by air traffic control, with update rates of several (tens) of minutes.	DCB indicators will be calculated at localized (and in some cases even hyper-localized) levels in both space and time. This level of granularity is a necessity for urban airspace management to function properly, as well as provide the highest level of service to its users.
DCB phases	Air traffic management divides the ATFCM process into five phases in which DCB measures are performed. These phases are, in chronological order, Strategic, Pre-Tactical, Tactical and Post Operations. These phases are strictly divided into time segments, with respect to the day of operations of flights. These begin at strategic level from around six months up to two days prior to operations, pre-tactical one day prior to operations and tactical as of the day of operations.	The U-space DCB process is divided into long-term planning, strategic, pre-tactical, tactical and post-operational phases, similar to ATFCM. The largest difference with respect to ATM is the link of the start of the pre-tactical phase with the establishment of a consolidated global traffic picture, which may vary in time and location.

Notion	Air Traffic Management	U-space

DCB measures	Within ATFCM, measures for managing air traffic imbalances come down to:
	
	1. Improving declared airspace/airport capacity.
	2. Capacity optimization solutions; or
	3. Application of ATFCM measures.
		Pre-defined measures to solve imbalances within the U-space DCB process include:
		
		1. Increasing CNS infrastructure
		2. Revision of traffic organization schemes by
		    a. implementing speed-controlled zones; or
		    b. implementing the organization of flows per flight layers.
		3. Requesting higher individual aircraft operational performance requirements.

DCB measure selection	Generally, the selection of DCB measures follows a hierarchy, in which primarily capacity optimization solutions are applied, since they do not have a direct impact on airspace users. ATFCM measures are typically only applied when capacity optimization measures have been exhausted, because they directly impact airspace users.	DCB measures are means to reduce the impact of a traffic situation on the following indicators: • Safety • Social indicators • Fulfilment of mission objectives • Overall demand uncertainty • Mission efficiency • Resilience against perturbations DCB measures with the highest overall stability under demand changes will be prioritized.
Impacted aircraft	The selection of aircraft to apply DCB measures to depends on the type of imbalance that is present and the type DCB solution which is to be applied. DCB measures are applied to individual aircraft. Typically, the treatment of aircraft follows the “First-Come First-Served” principle, however flow managers are incentivized to minimize the overall delay of aircraft as much as possible when	The selection of vehicles to solve DCB imbalances is susceptible to a specific set of prioritization criteria. These are dependent on: 1. The type of mission performed (e.g., urgent medical delivery vs. package delivery – see priority list in [14]); as well as 2. The time of submission of the operation plan with respect to

Notion	Air Traffic Management	U-space
	selecting aircraft to be penalized (i.e., "cherry picking").	the start of the pre-tactical phase.
Monitoring	Monitoring in ATFCM is strictly focused on elements which are relevant to the trajectory of aircraft. The monitoring process is, for the time being, based on deterministic metrics (i.e., numbers of planned flights, delay, 4D trajectories).	Monitoring of risk-based and social indicators is an integral part of the U-space DCB process. The monitoring of indicators will be done by comparing their actual or predicted values with certain safety and social thresholds for each pre-defined volume of airspace.
Definition of hotspots	Areas in which airspace demand exceeds airspace capacity within a given time frame are considered "hotspots".	Areas in which thresholds for risk-based and social indicators are exceeded are considered "hotspots".
Utilization of uncertainty values	Flight operations are assumed to adhere to standardized position uncertainty values, such as maximum allowed deviations from traffic routes (i.e., RNAV requirements). Values related to time are considered absolute. All deviations with respect to planned times (e.g., off-block times, take-off times, overflight times) are considered "delay".	The provision and association of uncertainty values to DCB relevant information is a fundamental part of the overall DCB process.

Table 22: Differences between ATM and U-space DCB processes

11 Roles and Responsibilities

Several actors will participate in the process of demand and capacity balancing of U-space airspace. This section defines the roles and responsibilities of these entities within the DACUS DCB process, covering all aspects from an operator, stakeholder and system perspective. These roles will apply to actors regardless of the type of U-space architecture that in place (centralized, co-federated, fully-federated – see [14]). This section will not make any U-space architecture-specific assumptions.

11.1 Drone Operator roles and responsibilities

Drone Operators are responsible for the execution of the operation and the following of indications delivered by the DCB process, whereas the responsibility of the pilots lies in the correct execution of the operation. It could be interesting to analyse this role from 2 different perspectives:

a) The role of the separator is the accountable for the separation provided;

b) The role of the Drone Operator is the accountable for the separation from other airspace users.

In this context, the future envisioned consider a scenario in which the figure of the pilot is just a supervisor, and most of the operations are fully autonomous.

The following assumptions are made regarding the Drone Operators:

Assumption ID	Assumption Title
1	One pilot is in charge of more than 1 drone.
2	Most of the operations are fully autonomous.

11.2 USSP roles and responsibilities

Within the DCB process DACUS foresees these services to be those providing the core DCB process itself, namely **Dynamic Capacity Management** as well as **Strategic and Tactical Conflict resolution**.

Assumption ID	Assumption Title
1	**Dynamic Capacity Management** service: • Calculates demand prediction and uncertainty; • Defines a DCB solution using measures as well as safety and social indicators; • Incorporates priority and "Virtue Points" into the DCB solution; • Assesses and imposes pre-defined DCB measures; • Considers external factors such as weather, geospatial information, population density, etc.
2	**Strategic Conflict Resolution** service: • Assesses pair-wise collision risks of probabilistic 4D trajectories; • Detects potential conflicts among original and "what-if" probabilistic 4D trajectories; • Proposes conflict resolution.
3	**Tactical Conflict Resolution** service: • Assesses pair-wise collision risks of actual trajectories; • Detects potential conflicts among actual trajectories; • Proposes conflict resolution.

These "core DCB" services require different sets of data from other U-space services in order to function properly. Within the DACUS context, "feeder-services" will forward, receive and negotiate information with the DCB services throughout the DCB process. These services include, **among others, Operation Plan Processing, Geospatial Information, Weather Information, Population Density Map, Drone Aeronautical Information Service and Operation Plan Preparation**.

For more detailed information on how feeder-services interact with core DCB services refer to section 8.3.

Assumption ID	Assumption Title
1	**Operation Plan Processing** service: • Verifies the consistency of the information submitted; • Generates probabilistic 4D trajectories; • Generates "what-if" trajectories; • Negotiates trajectories with Operation Plan Preparation services; • Implements DCB measure and pair-wise conflict resolutions.
2	**Geospatial Information** service: • Provides localized information relevant to monitoring risk-based and social indicators.
3	**Weather Information** service: • Provides hyper-localized probabilistic weather predictions; • Provides real-time weather observations; • Provides alerts associated to significant meteorological phenomena.
4	**Population Density Map** service: • Provides historic information on local population density values; • Provides real-time information on local population density values.
5	**Navigation Coverage Information** service: • Provides localized information about navigation coverage and performance.
6	**Communication Coverage Information** service: • Provides localized information about communication coverage and performance.
7	**Drone Aeronautical Information** service: • Provides information on urban airspace structuring; • Defines safety thresholds per airspace area.
8	**Operation Plan Preparation** service: • There can be multiple of these services; • Provided to Drone Operators by diverse USSPs; • Responsible for defining the mission parameters and uncertainties required for generating probabilistic 4D trajectories.
9	**Navigation Infrastructure Monitoring** service: • Provides warnings related to navigation accuracy disruption.
10	**Communication Infrastructure Monitoring** service: • Provides warnings related to communication infrastructure degradation.
11	**Emergency Management** service: • Communicates drone contingencies.
12	**Geofence Provision** service: • Manage unexpected events and crises through dynamic geofencing.

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Assumption ID	Assumption Title
13	**Electromagnetic Interference Information** service: • Collects and presents relevant electromagnetic interference information for the drone operation.
14	**Tracking** service: • Provides real-time tracking information of drones.

11.3 ATM roles and responsibilities

The ATM role in the DCB process is focused in managing controlled airspace in the surrounding of U-space airspace and airports, where manned aviation shares the same airspace with unmanned aviation. The ATM role will be to be in charge of keeping proper separation between manned aviation and the rest of aircraft, and to monitor unmanned aviation in the surroundings of controlled airspace like the CTRs and TMAs around airports. In addition, the ATM is responsible of the dynamic reconfiguration of the airspace, and providing all actors with this information, which could also have an impact on DCB process.

Assumption ID	Assumption Title
1	ATM focused on manned aviation.
2	ATM focused on controlled airspace.
3	ATM monitors unmanned aviation surrounding its airspace of responsibility.

11.4 City council roles and responsibilities

City councils, as well as other government entities, will have an important role to play in the definition of the boundary conditions for the operation of drones within urban areas. The DACUS DCB concept specifically includes this actor as a fundamental stakeholder in the definition of DCB limits, which are described in further detail in section 8 and Appendix B.

Assumption ID	Assumption Title
1	Define admissible thresholds on noise impact of drone operations within a given area.
2	Define admissible thresholds on visual impact of drone operations within a given area.
3	Define maximum population densities which permit drone operations within a given area.

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12 Conclusions

This document has outlined the operational environment within which the U-space DCB solution is situated. It has become evident that this environment is much more **dynamic and multi-facetted than in traditional air traffic management**, which requires the DCB concept to do the same. The concept must incorporate new business models, novel vehicles, non-human centric approaches to traffic management, much smaller operating scales, greater levels of information fidelity, diverse mission requirements and associated flight profiles, greater inclusion of societal metrics and shorter timeframes for implementation. The proposed DCB concept is based on these requirements and makes use of the state-of-the-art of relevant research to achieve them (e.g., CORUS ConOps or SESAR ER3 sibling projects).

The proposed concept is built on a series of **principles which guide the DCB decisions** within the U-space framework. These principles are:

1. Application of collaborative decision making to include Drone Operators within the decision-making process;
2. Prioritizing the fulfilment of mission objectives as a service to Drone Operators when selecting DCB measures;
3. Allowing for "free-route" operations whenever constraints allow;
4. Minimization of the number of instances in which changes to drone missions are required;
5. Incorporation of predictions and the quantification of uncertainty into the DCB process, to increase robustness of DCB measures within a dynamic operating environment;
6. Recognizing the Operation Plan as the "single point of truth" which maintains continuous up-to-date information about the situation and expected evolution of the drone operation.

Similar to 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. 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.

One of the key challenges of DCB in U-space is to define **new metrics to determine how many drones can be safely managed by the U-space system in a given 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 in order to keep the risk of conflict acceptably low, and by the various constraints on drone operations defined by external actors. Drone components related to its remote control and positioning capabilities, environmental factors as well as navigation, communication and surveillance data provision will have an influence on this risk of conflict, which in turn affects capacity.

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The U-space DCB concept should rely on some **assumptions related to UAS capabilities and CNS technologies that should be in place in urban environments** with high-density operations. In summary, it is assumed that the majority of the drones will be autonomous and flying BVLOS operations. Drone communication will rely on cellular networks, whose coverage can dramatically decrease with increasing altitude (above antenna height). Drone navigation performances will be achieved through GNSS augmentation such as RAIM or EGNOS/SBAS. Although some drones will still fly in VLOS without GNSS integrity monitoring, they should be geo-caged to protect the rest of the users from potential deviations. In addition, a secondary independent tracking system (e.g., ADS-B, Mode-S, mobile network triangulation) in support of surveillance by telemetry reporting will probably be mandatory in urban airspace or where the presence of manned aircraft is likely. This system could be based on cellular networks or any other cooperative technology, to make it affordable.

12.1 Research challenges

Several gaps and challenges have been identified during the elaboration of this document. This is not an exhaustive list that describes all the work to be done by DACUS. Instead, we aim to capture some points which were controversial during the elaboration of the concept, together will those ideas that are challenging and imply further research to assess their feasibility.

DACUS addressed some of these ideas through their validation activities, which include the design of advanced models for the assessment of demand and the most relevant influence factors on capacity such as the level of risk, environmental impact or social acceptability, the development of new functionalities of the U-space services to be able to support the defined DCB processes, and the execution of fast-time simulations to assess the evolution of Key Performance Areas when implementing specific DCB measures.

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 was identified as a point to investigate.

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.

Conclusions

DACUS integrated several sources of uncertainty of the drone demand, and assessed how this demand uncertainty may impact the identification of collision risk and social hotspots in Frankfurt. DACUS analysed two different contingencies: unavailability (or closure) of landing locations simultaneously, and degradation of the navigation performance with several strategies to recover the situation (return to base, divert to alternative location, land immediately). The uncertainty of the demand due to these contingencies was integrated with other potential sources: the impact of changes in the departure time of +/- 5 minutes, and the influence of micro-weather.

These sources of uncertainty produce high variations of traffic patterns. Routes were altered to a different extent and had **downstream influences on the collision risk and social impact hotspots**. Contingency plans, such as the redirection to emergency landing sites, impacts the localization of collision risk hotspots, as well as the areas where social impact hotspot are located.

In addition, the displacement of operations due to the delays caused by the contingency event leads to a higher appearance of hotspots. There are some contingencies that change the overall set of social and collision risk hotspots more critically than others - In particular, the closure of a vertiport for 1 hour and GNSS disruptions such as those related to misleading satellite information for 1 hour.

As a conclusion, **contingency plans and related outcomes, need to be considered** not only for a safe conduct of the single flight but also considering the effects on the overall network.

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.

Conclusions

Both models were successfully combined in experiments performed in Frankfurt and Madrid. Social impact model used a 2D grid of $1km^2$ cells grid. **The grid enables to identify and comprehend source of social impact hotspots**, and cells of this size were also appropriate to implement local DCB measures resolving social impact imbalances.

This social impact grid was consistently integrated with the one proposed by the collision risk model, which displayed a $0.5km^2$ cells-grid both in 2D and 3D. Possibly, due to the size of the cells and the criteria to identify hotspots, **collision risk values were highly sensitive to pair-wise interactions** among drone operation plans that are in the same cell at the same period. These potential collisions should be solved through strategic conflict resolution actions, without the need of implementing DCB measures.

In conclusion, it is considered necessary to perform further work to analyse the size of the cells and **the notion of a *collision risk hotspot***. The experiments performed consider that a hotspot exists if the instantaneous collision risk – risk in 1 minute – is above the target threshold. Peaks and duration of the collision risk values are parameters that should be taken into account to redefine this notion of collision risk hotspot.

This conclusion can also be extended to the notion of ***social impact hotspot***, as an area where the drone traffic demand generates noise and visual exposure or annoyance above acceptable thresholds for a pre-defined duration, or pre-defined frequency in a given period. In some situations, one or two-minutes duration of the hotspot can be acceptable whereas a twenty-minutes duration is not

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.

Conclusions

The **collision risk model** and its main associated indicator, i.e. the cumulative risk against link-third parties, was proven to be applicable **to determine the maximum number of drones** that can safely operate in a given U-space airspace. The model was demonstrated to be sensitive to variations in the CNS performances, the impact of implementing U-space services, the population density in the cities and the sheltering effect of the buildings to reduce the risk of injury due to collision or vehicle failures.

This model was used in the strategic phase to determine the **maximum number of drones that can operate in the entire U-space airspace** without exceeding the fatality rate established by SORA (1E-6). The uncertainty of the demand impacts the stability of the collision risk hotspots to take effective DCB decisions.

The collision risk model was also used in the **pre-tactical phase –** when most of the drone operation plans are known - for the identification of local urban areas with air and ground risk above the threshold established by SORA (collision risk hotspots). The stability of the demand allows taking local DCB decisions only in the portions of airspace where collision risk hotspots exist.

On the other hand, **4 indicators –based on Noise and Visual annoyance and exposure – were used by the social impact model** to determine a pseudo-maximum number of UAS operations per cell. The distinction between noise and visual impacts remains important as they behave in a slightly different way, even if they are highly correlated to the number of drones and the population density in a cell. However, the distinction between annoyance and exposure is more complex:

For noise impact, annoyance, and exposure are highly correlated and could be merged as one indicator.

For visual impact, annoyance, and exposure these are also highly correlated for areas with a high population density, but they exhibit more complex patterns at low population density.

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.

Conclusions

DACUS tested the most relevant **DCB measures applicable in the pre-tactical phase**: Speed controlled zones, organization per flight layers, organization with route structures, increase the operational ceiling and imposing delays in the departure time. We concluded in [49] that although all the DCB measures reduced the total number of collision risk hotspots – with different effectiveness –, they were not always suitable in reducing the number of social impact hotspots, with the exception of the increase of operational ceiling. Hence, there is a **need to define additional DCB measures, addressing the reduction of the noise and visual impact on citizens**.

As an example, the following figure shows a comparison of these measures in Madrid.

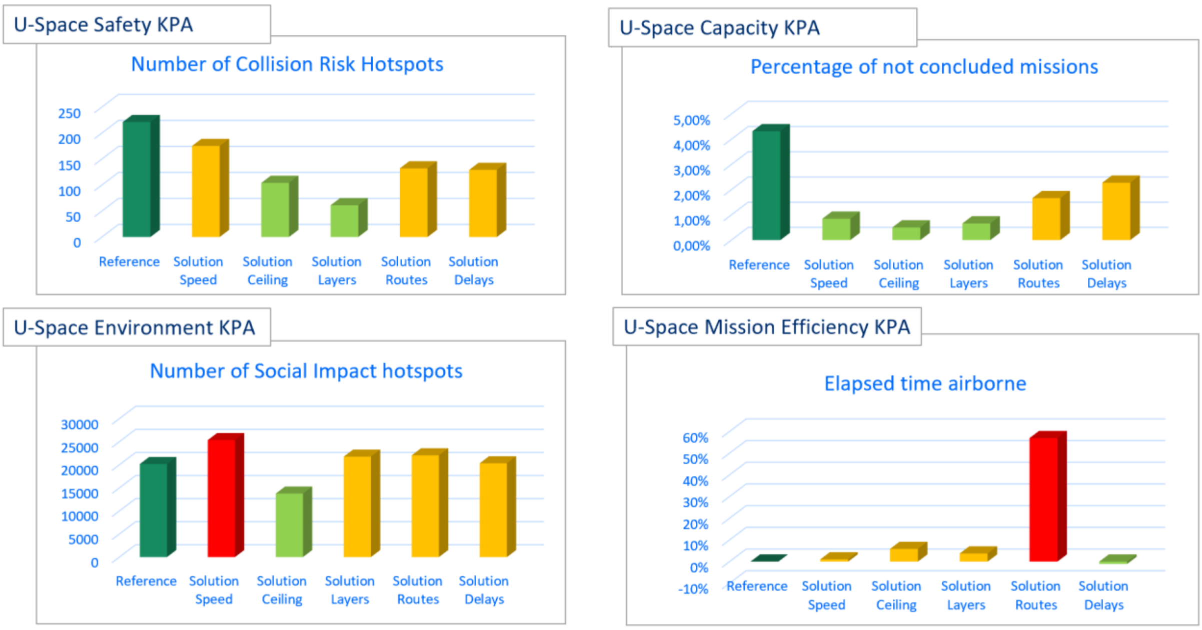

Figure 20: Results of the implementation of pre-tactical DCB measures in Madrid VLL airspace

As can be seen in the figure, only the **increase of the operational ceiling** was able to simultaneously reduce both the collision risk and social impact hotspots. However, this DCB measure makes use of the portion of airspace between Very-Low Level (VLL) airspace, i.e. 400 ft, and the minimum altitude for manned aviation in urban environments, i.e. 1000 ft. Using this airspace in peak hours is beneficial to manage higher drone demand with less safety and social impact, but the safety buffer with manned aviation is not maintained. Consequently, interactions with ATM traffic should be taken into consideration and additional research may be required before implementing/recommending this measure.

Besides the increase of the operational ceiling, the **organization per directional flight layers** is the most effective DCB measure in reducing the number of collision risk hotspots. This DCB measure also shows improvements on indicators associated with Flexibility and Resilience KPA and exhibits better behaviour when disruptions such as contingencies take place. In addition, this measure presents lower penalization on the efficiency of the missions than others, although all the DCB measures increase mission inefficiencies in comparison to free-route operations.

Although the use of **speed-controlled zones** is the least effective measure in reducing the number of hotspots, it does reduce the number of severe conflicts, and therefore improves the overall safety of the scenario. For this reason, it should be applied to those zones where higher number of severe intrusions are predicted.

The use of **delays on the ground** is shown to be effective in deconflicting some trajectories that are in conflict before taking off. By applying this DCB measure for short timeframes (e.g. between 2 and 10 minutes) the overall mission efficiency is improved - i.e. flight duration and number of batteries and energy required. However, this measure was only implemented to reduce the number of collision risk hotspots. Nevertheless, it could be a promising measure to delay, re-route or cancel those drone operations that are generating severe social impact on the population as well and this may support mitigating the negative effects on human health (e.g. sleep disturbance, increase of blood pressure, etc.).

Although the **organisation per routes** appears to be the most restrictive measure. (the implementation was based on organization per flight layers and routes in each layer), it does not present the best results in reducing the number of hotspots. On the other hand, this measure is highly penalizing the overall mission efficiency as it can be seen in indicators such as the Elapsed Airborne Time. In conclusion, it is not recommended to implement this measure in urban air mobility scenarios because it reduces the degrees of freedom in drone trajectories and, therefore, in avoidance manoeuvres, without significant improvement in the KPAs with respect to the free flight scenario. However, further analysis to identify a more operationally efficient temporary route structure may increase the efficiency of the solution it should not be fully ruled out at this stage and additional research may be of interest.

However, as none of the DCB measures tested manages to resolve all hotspots completely, it will be necessary to be able to **dynamically combine the measures** to optimise DCB actions. For example, a combination of the flight layers organization combined with a temporary increase of operational ceiling could be tested in future scenarios by taking into consideration not only the directions of the operation plans, but also the drone dimensions, shape and noise and visual impact. drones causing higher impact on population should fly at higher altitudes.

5. 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.

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Conclusions

The underlying assumption for the need of providing some sort of prioritization mechanisms was shown within the DACUS experiments, where social impact capacity thresholds were found to be more detrimental specific types of drone missions than others. For instance, package delivery was found to have a lower impact than food delivery, given that they operate in more crowded areas. High noise and visual impact restrictions in urban areas are detrimental for food delivery business models, whereas package deliveries, which commonly operate from warehouses in industrial areas are not so constrained.

The inclusion of "Virtue Points" as part of the DCB ConOps seems to make sense. However, since this concept was not tested as part of the DACUS experiments 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.

6. 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.

Conclusions

The results of the DACUS simulations have proven the feasibility of using Drone Operation Plans (DOP) as the main source of reference for demand modelling. Given that the proposed DCB concept requires a sufficient level of certainty in order to take appropriate measures, the availability of detailed information about the planned mission and potential contingency situations is fundamental for the process to work. Apart from information about the planned route, DACUS found that the **integration of contingency plans**, such as the redirection to emergency landing sites, impacts the localization of collision risk hotspots, as well as the areas where social impact hotspot are located. The DACUS experiments showed that increasing the time uncertainty in the calculation of Collision Risk for the scenario, leads to higher values for the instantaneous and average Collision Risk values. As a conclusion, contingency plans and related outcomes also need to be considered as part of the drone operation plan, not only for a safe conduct of the single flight but also considering the effects on the overall network.

7. Role of the drone operator in the implementation of DCB measures

DACUS proposed two different approaches to implement the required changes in the operation plans that can be associated to some of the DCB measures: Drone Operators to provide new operation plans complying with the measure; or U-space to propose operation plans complying with the measure and with pair-wise conflicts.

Conclusions

DACUS experiments provided some valuable insight on the question of whether or not to implement DCB measures automatically. Automatic DCB measures were found to be more effective for resolving hotspots, however allowing drone operators to implement changes based on constraints resolved a significant number of cases. Therefore we could not fully define an approach which is better in all cases. Rather, the decision on whether or not to implement DCB measures automatically depends on the traffic scenario at hand.

8. Location of take-off and landing areas in cities as a limiting factor of "U-space capacity"

This document identifies diverse possibilities to accommodate drone operations dependent on the layout of cities. In principle we presume that for the Urban Air Mobility context, airports or respectively take-off and landing areas (TOLA) will exist for small drones, personal air vehicles, helicopters, and traditional manned aviation. They can be either permanent or temporary sites that differ strongly depending on the characteristics of the vehicles they are dedicated to. In addition, specific sites for vertical take-off and landing (VTOL) aircraft will also exist, including vertihubs (which will likely be situated at the outskirts of urban and suburban areas), vertiports (which will be located at the primary passenger destinations) and vertistations (which will only serve 1 or 2 vehicles at the same time).

Conclusions

DACUS experiment results showed that, more than just the distribution of TOLAs, knowledge of the existence of take-off and landing areas was particularly relevant for allowing automatic DCB measure implementations to lower social impact. When flights are not concentrated in specific departure and arrival locations, such as in food deliveries, the process of searching for automated DCB measures is more unpredictable. The automatic process is more effective in the case of package deliveries, which have fixed departure or arrival locations (high distribution of moderate social hotspots in a wider area) than in the case of food deliveries, which have random departure and arrival locations (concentration of critical hotspots in the city centre).

12.2Future work

Along the previous sections, some details on the scenarios to be considered in the next phases of the project can be identified:

9. Fair access to airspace versus "Reasonable Time to Act"

The U-space ConOps follows the principle that being first to submit an operation plan brings no advantage regarding flight priority. Conflict resolution and Dynamic Capacity Management actions are implemented a short time before take-off, referred to as "Reasonable Time to Act" or RTTA. At that instant these processes occur on all flights concerned and treat them as equally as possible.

The impact of this "Reasonable Time to Act" on the diverse business models coexisting in the urban areas is subject to further investigation. It is necessary to assess the DCB processes in place to ensure the fair access to the airspace to those business models that can be constrained by the need of providing the Operation Plans before the RTTA.

10. "Reasonable Time to Act" as starting time of the pre-tactical phase

"Reasonable Time to Act" means in practice that areas with high traffic uncertainty will have a pre-tactical phase which is much closer to the departure time of the vehicle than those areas in which the traffic uncertainty is very low. Subsequently, the time given to Drone Operators to react to (and negotiate) DCB measures is greatly reduced in high-uncertainty areas. This strategy aims to incentivize proactive participation of Drone Operators to provide DCB-relevant information early on in the process in order to reduce overall traffic uncertainty, which benefits all Drone Operators aiming to fly in a specific area. Additional incentives include the introduction of virtue points to further promote collaborative behaviour among users.

Further research is needed to set the starting time of the pre-tactical phase, identifying if it will start at a pre-defined time (e.g., 10 minutes prior to the execution), or it will start as soon as a demand certainly value from which the traffic picture can be considered to be "consolidated". The 1st option could allow Drone Operators to know when they will be requested to adapt their Operation Plans if necessary. The 2nd option could allow Drone Operators to have more time to adapt their Operation Plans. A systematic analysis of the diverse business models in urban environments should be performed to address this question.

The idea that underlies here is explained with an example: Two drone flights with the same departure time but in two areas: Area 1 with high traffic demand uncertainty, and Area 2 will low traffic demand uncertainty. Area 1 will take much longer to get a consolidated traffic picture than Area 2. Therefore, the pre-tactical phase will begin earlier in Area 2 than in Area 1, giving drone operators in Area 2 much more time to adapt to DCB measures than those in Area 1.

It is relevant to mention that, although the notion of Required Time to Act (RTTA) is described both in the CORUS ConOps and also in DACUS ConOps, there could be differences in its interpretation. DACUS understands RTTA as a certain time before the execution in which the drone traffic demand is stable enough to take decisions with regards to the implementation of DCB measures. For DACUS, this is the transition between the strategic and the pre-tactical phase and it is a notion closely linked to overall management of the drone traffic network. On the other hand, CORUS (and its extension in CORUS-XUAM) is also considering the possibility that RTTA is associated to the time in advance that the drone operator can consolidate its operation plan, providing a stable departure time. These different interpretations make it necessary to further clarify this notion, which is a relevant point in the overall DCB process.

11. Manned aviation operating above 1000 ft AGL

Some scenarios could take on board the integration needs between manned operations at or above 1000 ft AGL and U-space DCB processes, in particular when implementing measures to increase the operational ceiling of U-space airspace AGL to accommodate more demand. This measure likely implies that manned aviation at or above 1000 ft AGL should be known.

It is necessary to assess how these manned operations should be taken on board in the DCB process, first, in case of implementing measures above the standard VLL airspace definition, and second, in those situations in which manned aviation needs to enter into the VLL airspace and interacts with drone operations.

12. Deterministic management of failure models

Diverse non-nominal situations could occur during the execution of the operation (tactical phase). These events can consist of reductions in expected CNS performances, disruptions caused by local weather phenomena or emergencies identified by the Emergency Management service.

DACUS proposes to address these disturbances through the deterministic, and therefore, predictable management of contingency plans. They will allow U-space to characterize the impact of the disturbance as soon as it is reported and then, implement DCB measures if needed. The feasibility of this predictable management of failure modes is subject to further research.

13. Decentralized architectures to manage DCB processes

The DACUS DCB concept is designed to be agnostic to the type of U-space architecture in place (centralized, co-federated, fully-federated), however further research is needed to assess if services which are provided today by a unique system in ATFCM can be distributed in U-space, in particular, the Dynamic Capacity Management service as the service in charge of testing and implementing DCB measures.

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Appendix A U-space DCB processes in the strategic phase

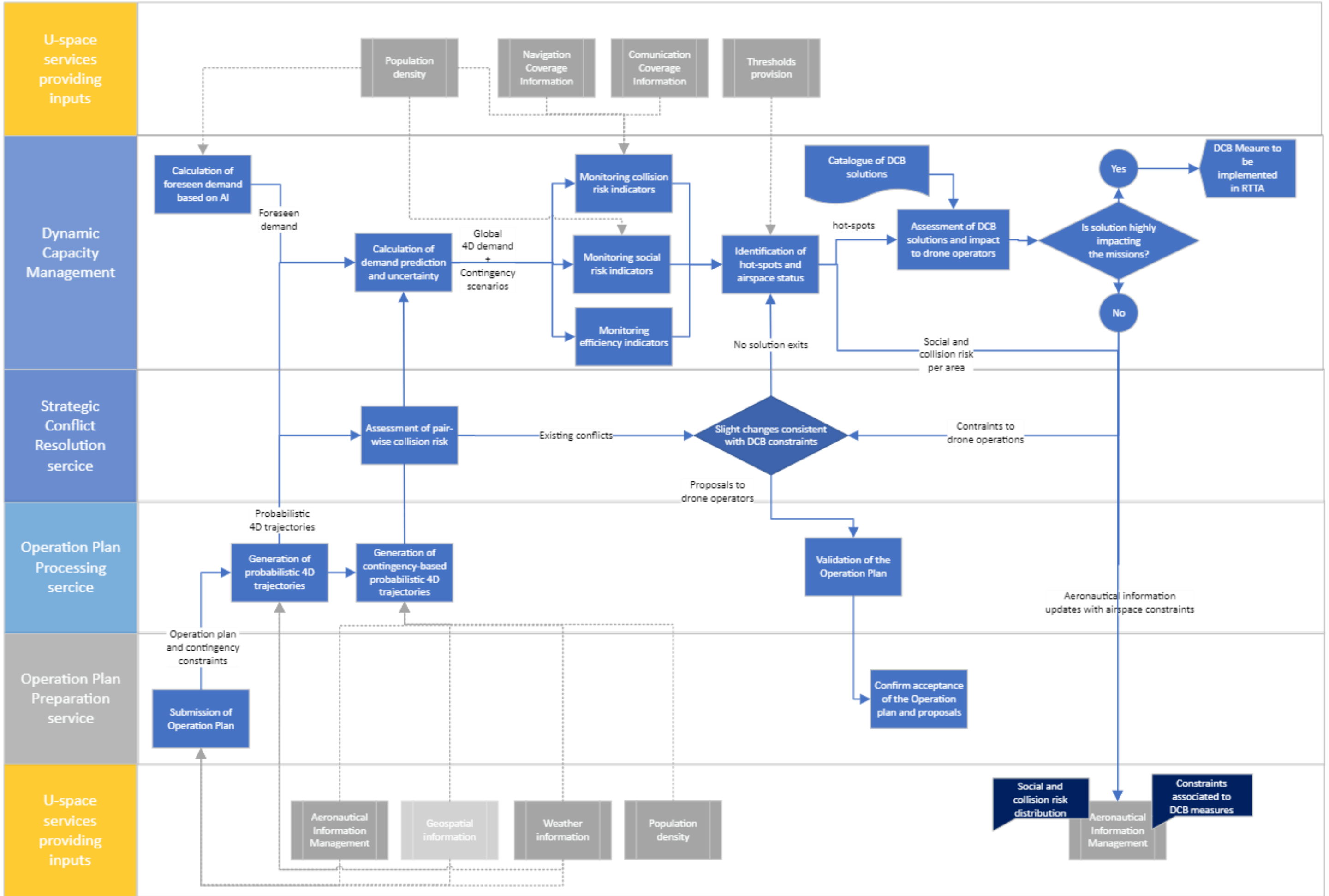

Figure 21: Detailed DCB processes in the strategic phase

Appendix B U-space DCB processes in the pre-tactical phase

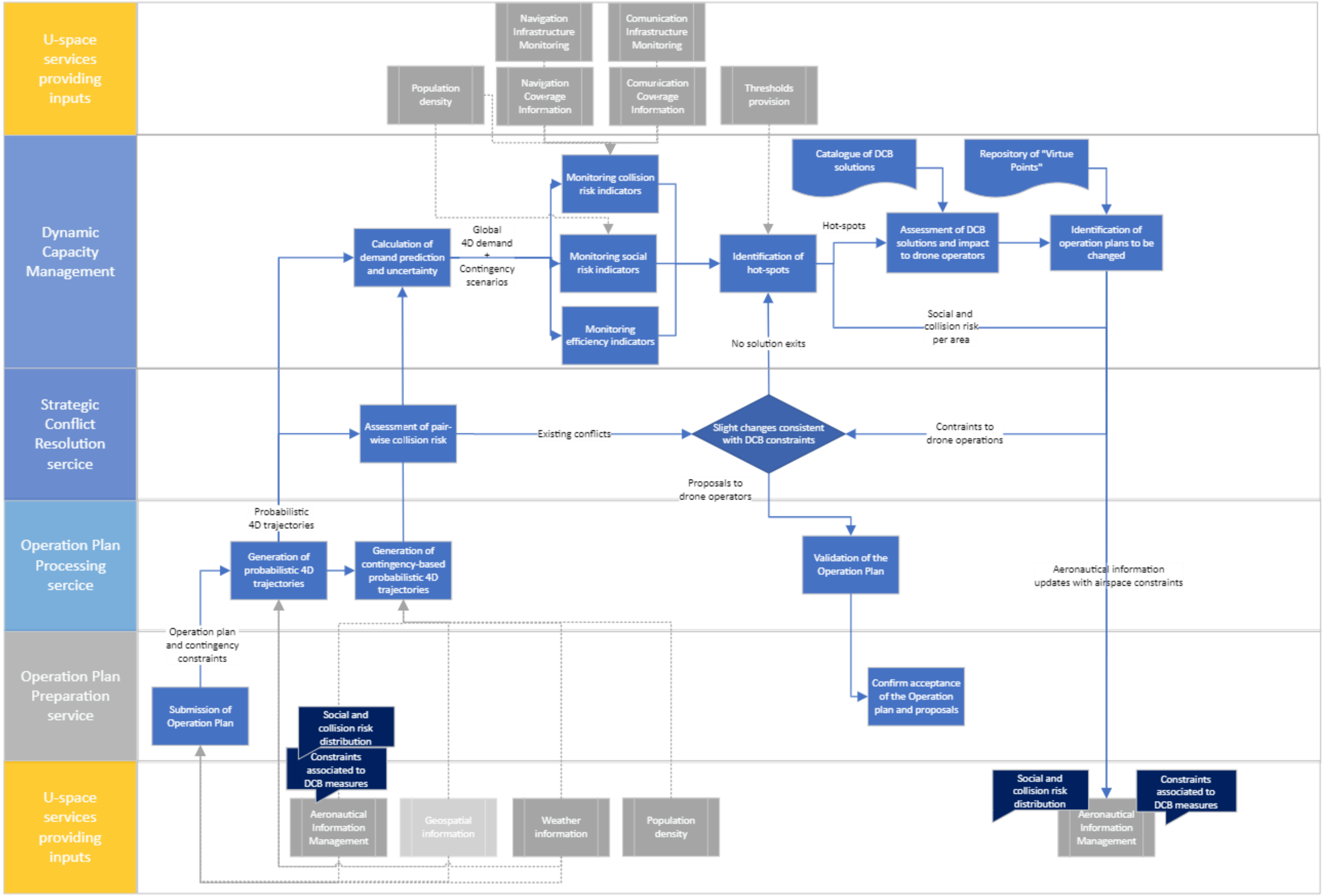

Figure 22: DCB processes in the pre-tactical phase

Appendix C U-space DCB processes in the tactical phase

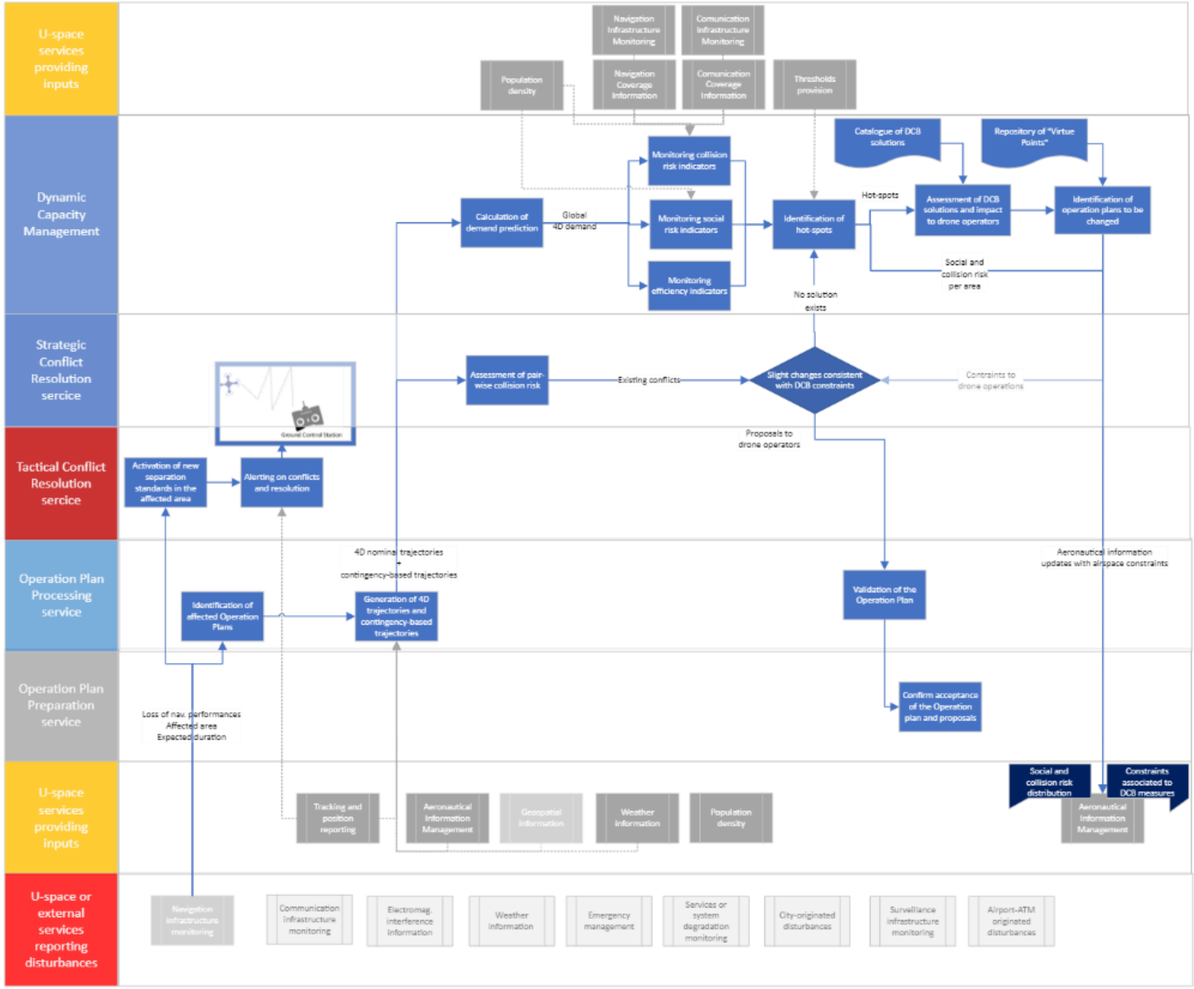

Figure 23: DCB processes in the tactical phase activated by the Navigation Infrastructure Monitoring

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