Drone DCB concept and process

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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.

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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 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 graves 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 aims to address 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. This selection of challenges will be the driving ambition of the DACUS exercises and consolidated in the second iteration of the DACUS DCB concept.

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.

In addition to the DCB process outlined in the main document, additional supporting material is provided in appendices of the main document. These include an extensive overview of parallel on-going and previous research initiatives and their utility to the definition of the DCB process and an analysis of influence factors on capacity and demand, which was utilized to define the main DCB concept.

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 is to be utilized as a baseline reference for all work packages of the DACUS project. It should provide 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. An overview of these initiatives is provided in Appendix A.

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: 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 10: 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 11: 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 the project aims to address.

- Section 12: References.

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

- Appendix A: On-going and previous research initiatives.

  A detailed analysis and summary of thirteen on-going and previous research initiatives which are relevant to the U-space DCB concept. This appendix provides a list of the most relevant DCB-related aspects of each one.

- Appendix B: Detailed analysis of influence factors on capacity and demand.

  This appendix provides an extensive list of influence factors on U-space capacity and demand which was developed using the insights gained from research initiatives presented in Appendix A as well as through a series of workshops. Interrelations between influence factors and their effect on demand or capacity is graphically mapped and modelling requirements for the DACUS models are presented.

- Appendix C: DCB concepts from previous U-space projects.

  This appendix provides an overview of DCB concepts which were mentioned in previous U-space research initiatives. For each project, the interactions of U-space services to provide a DCB solution are mapped. The content provided in this appendix was used to define the service interactions within the DACUS DCB concept.

- Appendix D: Overview of UAS capabilities.

  The DACUS DCB solution must consider characteristics and limitations of the Unmanned Aircraft Systems (UAS) operating in urban airspace. This appendix provides a more detailed overview of capabilities of the drone (in terms of the flight controller, communication, navigation and surveillance systems) and its ground control station with respect to DCB requirements.

- Appendix E: DCB processes in ATM.

  A consolidated summary of how DCB is currently being performed in ATM is provided in this appendix. It serves to provide further background information for readers who are not as familiar with the process and helps to better understand the key differences between the ATM and U-space DCB processes.

2.6 Glossary of terms

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

Table 1: Glossary of terms

2.7 List of Acronyms

Acronym	Definition
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

Acronym	Definition
ES	Emergency Services
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

Acronym	Definition
MINIT	Minutes-in-Trail
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

Acronym	Definition
STS	Standard Scenario
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.

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.

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. ***Visual and noise impact* to third parties**: 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).
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.

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. 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.

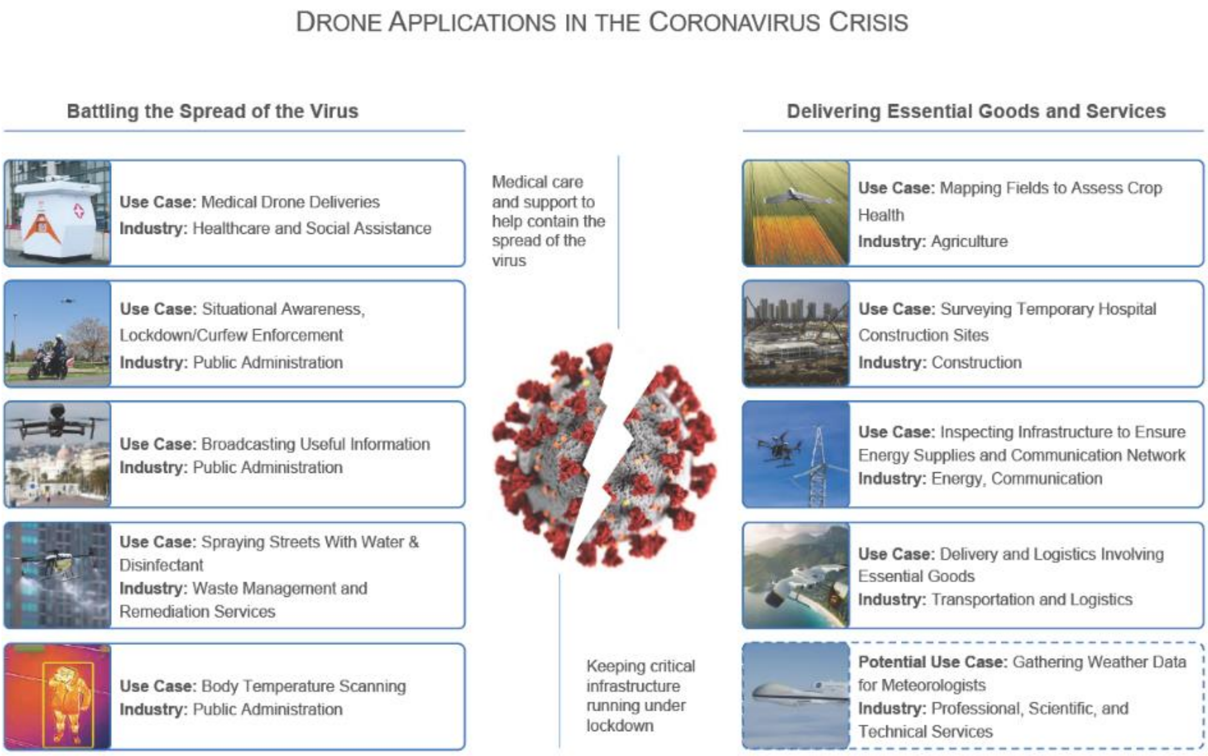

Figure 1: Overview of drone missions applied during the COVID-19 pandemic.

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. The SESAR Outlook Study [25] has provided an estimation for drone demand in Europe through 2050:

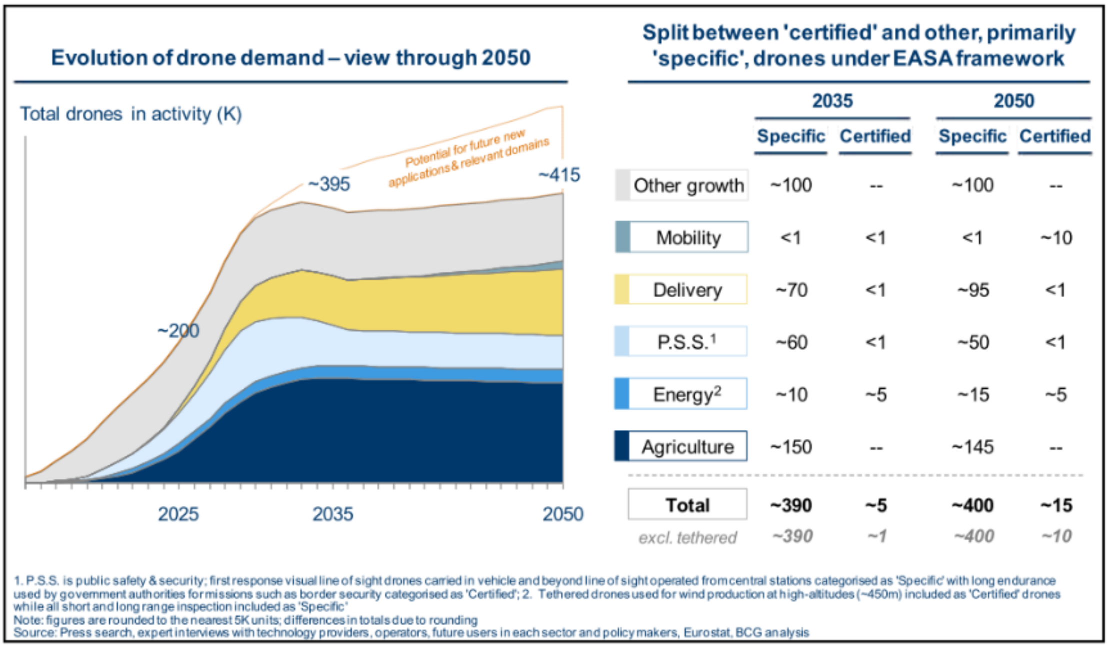

Figure 2: Predicted evolution of drone activities per market area through 2050 [25].

This estimation provides a general order of magnitude for the drone demand over the next years. Although this study does not specify which percentage of operations could take place in urban environments only, by filtering the most predominant market sectors for urban drone applications (**Mobility, Delivery and Public Safety & Security**) we can extract a total estimation of around 130.000 registered drones for urban use by 2035. Another available market study with estimated quantities is provided by NASA [46]. Although this study focusses only on two market sectors (**Delivery and Mobility**) and for only one country (US), the given quantities are worth to be considered. For the Delivery sector, 40.000 drones are estimated to be operational by 2030. These are more less the half of those estimated by the European Outlook Study around the same time (70.000 in 2035). In the other considered sector by the NASA study the expected quantities for the Mobility sector (23.000 vehicles by 2030) look however more contrasting than those expected in Europe (less than 2.000 by 2035). Not until 2050 more than 10.000 vehicles are expected. 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 could be a good starting point for the DACUS 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).

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 3: 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 5: 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	

TOLA type - example area	Assumed number of TOLAs		Reference Population	Description	Population per TOLA		TOLAs per capita	
	Low	High			Low	High	Low	High
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 6: Extrapolation of TOLA quantity predictions for three major cities in the European area.

TOLA Type	Toulouse[1]		Frankfurt[2]		Madrid[3]	
	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

[1] Toulouse Metropolitan Area: 1200000 People

[2] Frankfurt City Area: 750000 People

[3] Madrid Metropolitan Area: 6600000 People

TOLA Type	Toulouse[1]		Frankfurt[2]		Madrid[3]	
	Low	High	Low	High	Low	High
- 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]. Below that limit is considered VLL.

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.

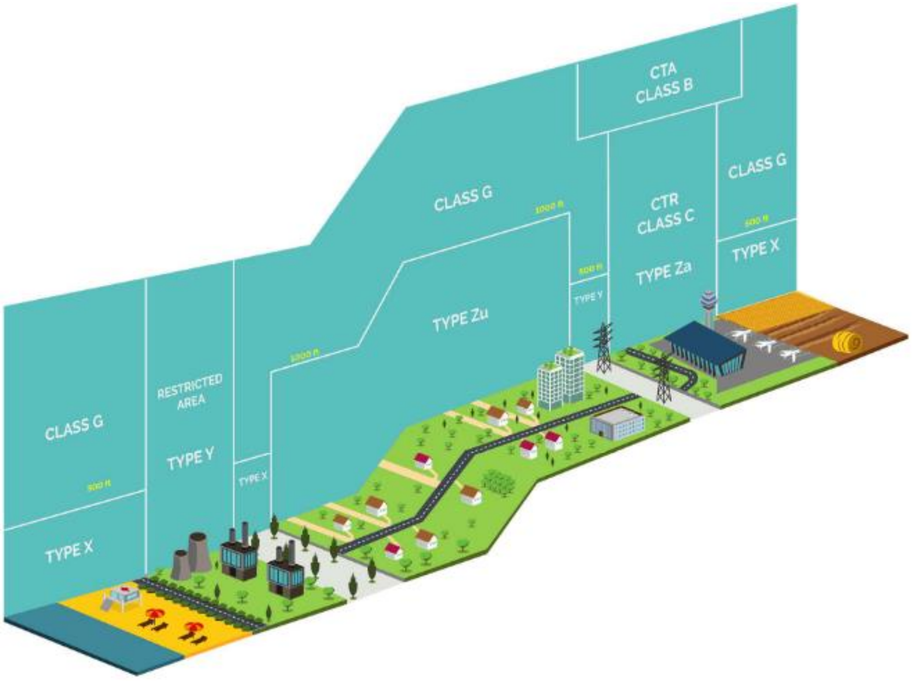

Figure 4: Overview of U-space airspace classes as defined by CORUS [14].

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.

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);
- 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.

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.

A summary of the UAS main components can be found in Appendix D. Those 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 (see Appendix D), 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.

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**.

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.

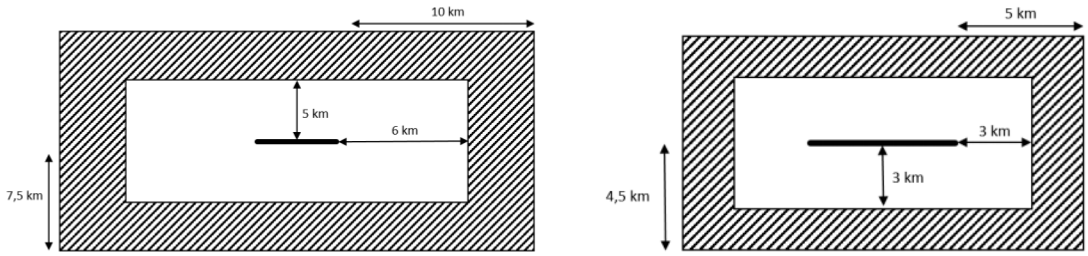

Figure 5: Graphical representation of restrictions of drone operations around public (left) and restricted-use (right) airports in Spain [47].

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

<table>
<tr><th colspan="2">Drone</th><th colspan="3">Operation</th></tr>
<tr><th>Class</th><th>MTOM</th><th>Subcategory</th><th>Restrictions</th><th>Max height</th></tr>
<tr><td>Privately built</td><td rowspan="3"><250g</td><td rowspan="4">A1(can also fly in subcategory A3</td><td rowspan="3">•May fly over uninvolved people or assemblies of people.
•Maximum speed: 19m/s</td><td rowspan="4">120m above ground level
+15m over obstacles taller than 105m (on request of responsible entity)</td></tr>
<tr><td>0</td></tr>
<tr><td>Legacy drones(art.20)</td></tr>
<tr><td>1</td><td>900g</td><td>•No flights over uninvolved people or assemblies of people
•Maximum speed: 19m/s
•Maximum sound power level: 81dB</td></tr>
</table>

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 4 Privately built Legacy drone(art.20)	<25kg	A3	Fly away from people and outside urban area (from residential, commercial, industrial or recreational areas)- (150m)	

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 8: 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.

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[4] 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:

[4] 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 6: 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.

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 9: 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 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

<u>The aircraft flies with Instrument Flight Rules</u>

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.

<u>The aircraft flies with Visual Flight Rules</u>

<u>At night-time:</u> 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).

<u>At daytime</u>: 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.

<u>In controlled airspace</u>

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.

<u>In uncontrolled airspace</u>

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 10: 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 10), rules of the air regarding visibility and cloud separation provide additional requirements for low-flying VFR aircraft.

Table 11: 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.

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 some exemplary operational concept scenarios and use cases to support the DCB concept definition.

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 (see Appendix E) 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**, 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 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;
- Contrary to ATFCM, 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.

8.2 U-space DCB phases

Similar to ATFCM, several phases[5] 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 in the next phase, assuming that it is necessary to increase the level of confidence in the demand prior to the implementation of such type of measures.

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

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

[5] 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** if they were not implemented in the previous phase.

Starting time will depend on the trade-off between the soonest that the Drone Operators can provide operation plans according to their business characteristics, and the latest they must be made aware of the DCB measure, in order to implement it before take-off. Thus, the start of the pre-tactical phase is linked to the point in which the demand picture is consolidated 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.

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.

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.

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".

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.

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, including contingency measures associated with the declared demand, as well as other influence factors impacting the capacity such as the population density in real-time. The **Social Impact model** will input in the picture environmental biases and social concerns related to noise, visual impact, or perceived safety, among others. The applicable airspace structure and urban rules are taken into consideration as boundary conditions in the models.

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

The following figure provides an overview of the whole process.

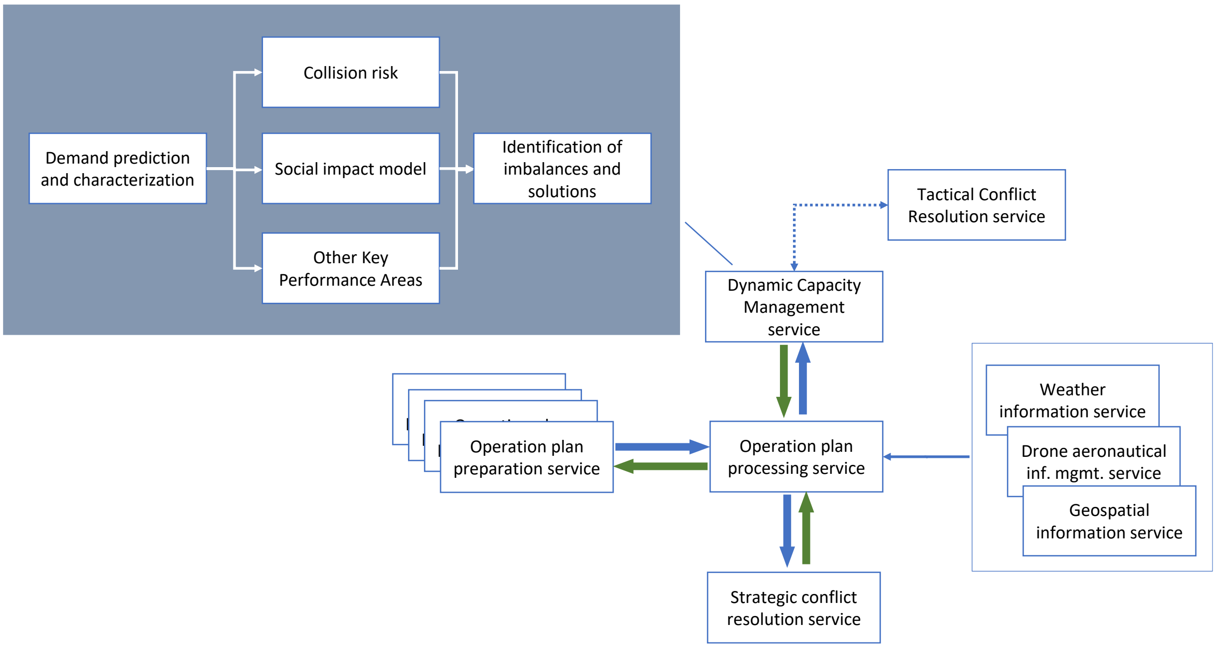

Figure 7: High-level overview of the DACUS DCB service interactions (excluding tactical processes).

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).

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.

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**[6], **drone endurance and weather-related operating limitations**. 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 horizontal/vertical changes based on the solutions identified by the Strategic Conflict Resolution service.

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.

[6] The generation of “what-if” probabilistic 4D trajectories taking into consideration these contingency volumes should be probably part of the process.

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.

Deconfliction of pair-wise trajectories will be related to slight horizontal/vertical changes which do not imply relevant changes to operation plans.

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.

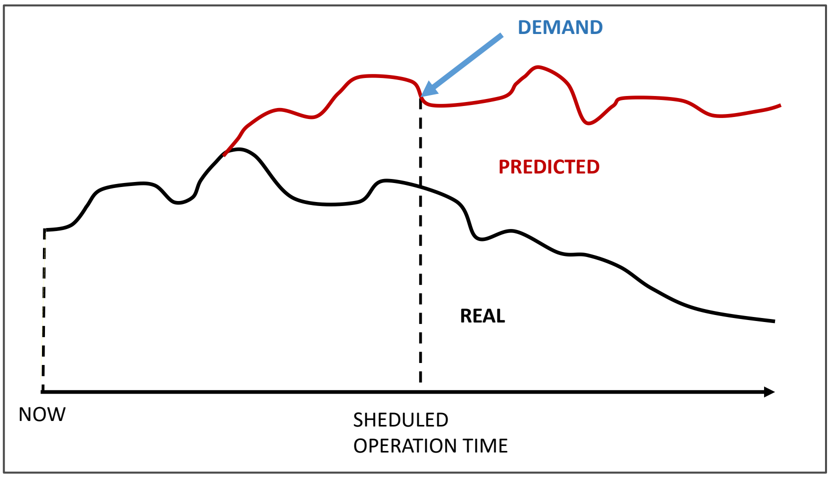

Figure 8: Integration of Operation Plans and predicted demand within the strategic phase.

The outcome of the process will be:

- **Prediction of the overall demand** – existing and envisioned operation plans - associated to predefined volumes of the airspace;
- **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 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 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[7]. 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 following image shows an example.

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

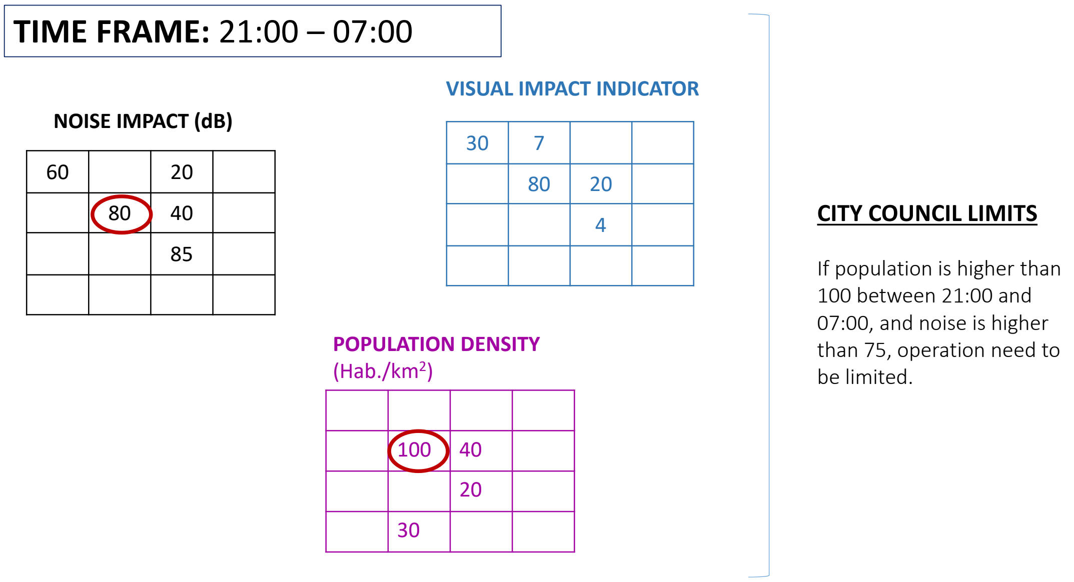

Figure 9: Examples of city council-imposed limits on drone operations

The monitoring 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, together with the associated level of uncertainty that will be directly derived from the demand uncertainty calculated in the previous phase.

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 hotspots 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:

- **Impact of each measure 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;
- **Impact of the demand uncertainty on the effectiveness of the solution**. The behaviour of the solution concerning potential changes in the overall demand needs to be quantified;
- **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;
- **Resilience 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 wind gust, intruding aircraft or an aircraft that experiences a failure.

DCB measures which have higher stability under demand changes will be prioritized in this strategic phase. The process will determine the most suitable solution at this phase and will identify those operation plans which are affected.

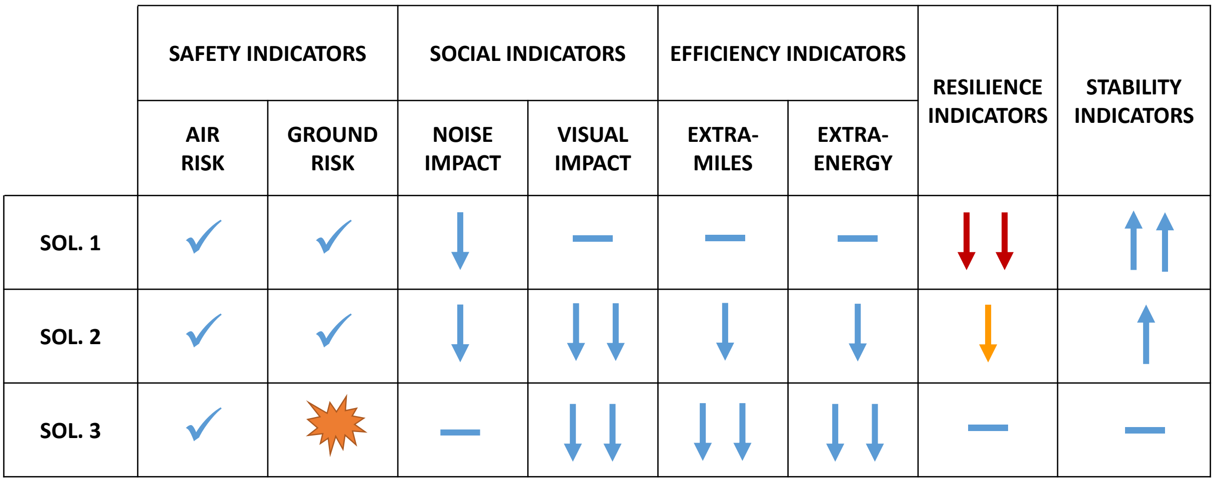

Figure 10: High-level conceptual example of DCB-measure comparison based on indicators.

7. Towards the implementation

At this stage, there could be two different approaches that are introduced in Table 12.

Table 12: Overview of potential DCB measure implementation options in the strategic 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. The level of confidence in the effectiveness of the DCB measure will determined when the DCB measure should be implemented.	**7b. Generation of "what-if" probabilistic 4D trajectories** This process is performed by the Operation Plan Processing service. The service receives the proposed DCB measure and generates probabilistic 4D trajectories taking into consideration the constraints associated to the DCB measure. These "what-if" probabilistic 4D trajectories are generated only for those operation plans affected by the measure.
8a. Submission of new operations plans complying 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	**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" probabilistic 4D trajectories of those

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.
slight horizontal/vertical changes could be proposed by the Strategic Conflict Resolution service.	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 horizontal/vertical changes 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 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.

8.4.2 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.

1. **Submission of operation plans**

Unexpected operations 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 horizontal/vertical changes which do not imply relevant changes to operation plans.

2. **Generation of 4D trajectories**

This process is **performed by the Operation Plan Processing service**. At this stage, 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 can 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.

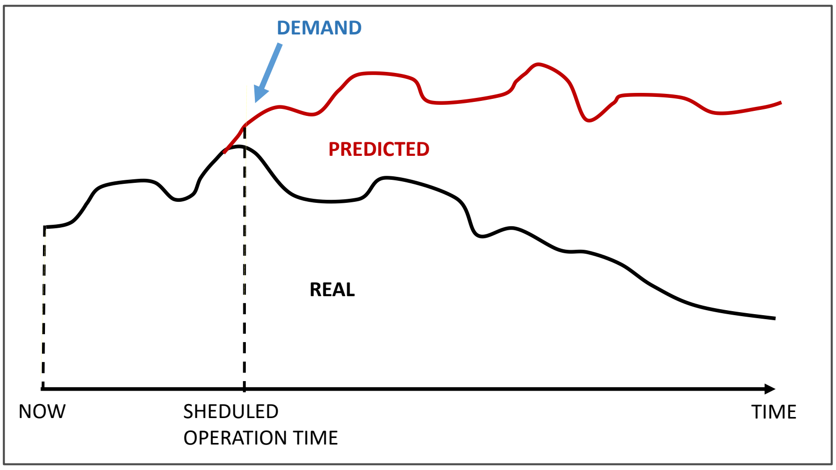

Figure 11: Most of the demand corresponds to existing operation plans the pre-tactical phase

The outcome of the process will be:

- **Prediction of the overall demand** – based on existing operation plans - 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.

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 volumes 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]. 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 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.

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.

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:

- **Impact of each measure on the fulfilment of the mission objectives**. For instance, the organization of flows per flight layer can reduce the safety impact without highly impacting the fulfilment of most of the business models in urban environments;

- **Impact on the efficiency of the missions** (e.g., extra-miles, consumed energy);

- **Resilience 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 wind gust, intruding aircraft or an aircraft that experiences a failure.

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[9] away for certain volumes of airspace, a prioritization process will be launched.

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

[9] These measures with are highly impacting the Operation Plans will not be implemented in the previous strategic phase.

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 to be selected for 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, as in the strategic phase, 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 horizontal/vertical changes could be proposed by the Strategic Conflict Resolution service.
- **Option B**: The Operation Plan Processing service integrates the constraints from the Dynamic Capacity Management service and the Strategic Conflict Resolution service and proposes alternative operation plans to Drone Operators.

The processes related to each approach are included in Table 13.

Table 13: 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 *Similar to the strategic phase, see* ***Table 12****.*	**7b. Generation of "what-if" 4D trajectories** *Similar to the strategic phase, see Table 12.*
8a. Submission of new Operations Plans complying with the DCB measure *Similar to the strategic phase, see* ***Table 12****.*	**8b. Assessment of pair-wise collision risks of new DCB scenario** *Similar to the strategic phase, see Table 12.*
	9b. Implementation of DCB measure and pair-wise solutions *Similar to the strategic phase, see Table 12.*

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.

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 14: 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.
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.

	Duration	Impact
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 15: 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.

	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.

	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
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 next paragraphs provide some concrete examples of cases from the list of disturbances presented above could affect the DCB process, and which actions might be performed to deal with them.

Case A: Navigation disturbances reported by the Navigation Infrastructure Monitoring service

The following processes aim to describe how **disturbances in navigation integrity** might affect DCB processes through a concrete example, which is introduced in the next paragraph, after a brief introduction into navigation in U-space.

As previously explained in section 5.3, the **primary source of navigation for drones operating in U-space will most likely be space-based**, through a combination of:

- Global Navigation Satellite Systems (i.e., GPS, GLONASS, Galileo and BeiDou);
- Satellite-Based Augmentation Systems (e.g., EGNOS); and
- Real Time Kinematic solutions for positioning corrections sent from:
  - Satellites (good coverage);
  - Cellular network (good coverage in urban environments); or from a
  - Base station (limited coverage).

However, **secondary navigation sources** will likely be utilized as well, which include technologies such as visual navigation, signals of opportunity (SOP) and infrared.

In order for U-space to be technology agnostic, it would make sense to apply **Required Navigation Performance (RNP) standards for specific routes or sections of airspace**, similar concepts that are in place for manned aviation. In this way as long as the navigation performance is maintained the means through which it is achieved is irrelevant.

In the **hypothetical example of Case A**, we consider two drones flying within a U-space designated airspace with a high level of navigation performance requirement (we will call it "RNP-high" for the sake of simplicity). Both drones utilize 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 need to rely on secondary navigation sources to navigate. 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"). Figure 12 depicts this situation graphically.

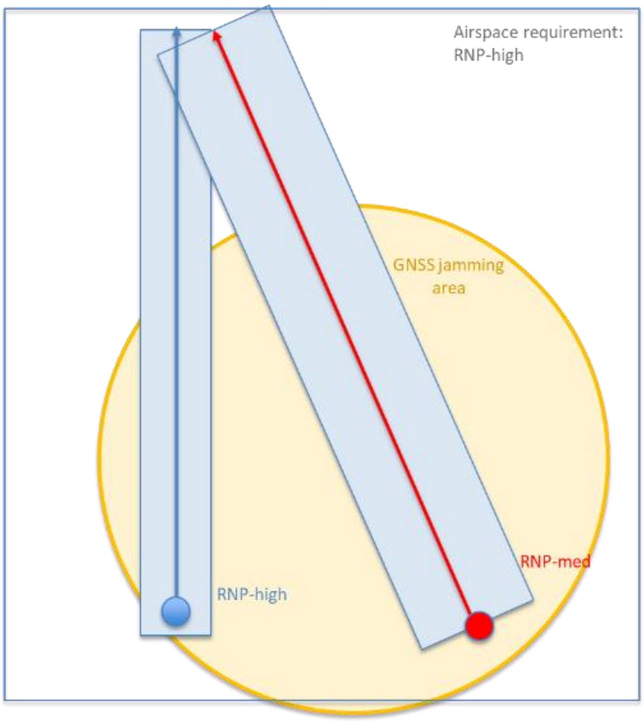

Figure 12: Visualization of the navigation disturbance scenario addressed in Case A.

This navigation disturbance is identified by the 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.

This is the starting point for Case A. The next segments will exemplify how such a disturbance could affect DCB processes and introduce potential means to mitigate its impact.

1. **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**.

2. **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 (see points 4 and 5).

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.

3. 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.

4. 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**.

5. Prioritizations 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.

6. 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.

The processes related to each approach are included in Table 16.

Table 16: Overview of potential DCB measure implementation options in the 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 *Similar to the strategic phase, see* ***Table 12****.*	**7b. Generation of "what-if" 4D trajectories** *Similar to the strategic phase, see Table 12.*
8a. Submission of new Operations Plans complying with the DCB measure *Similar to the strategic phase, see* ***Table 12****.*	**8b. Assessment of pair-wise collision risks of new DCB scenario** *Similar to the strategic phase, see Table 12.*
	9b. Implementation of DCB measure and pair-wise solutions *Similar to the strategic phase, see Table 12.*

Case E: Drone emergency reported by the Emergency Management service

The following processes 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.

1. **Generation of contingency-based 4D trajectory**

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**. 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. Other drone operations in the surrounding should avoid the area for emergency protection. Affected Operation Plans are updated taking into consideration this new constraint.

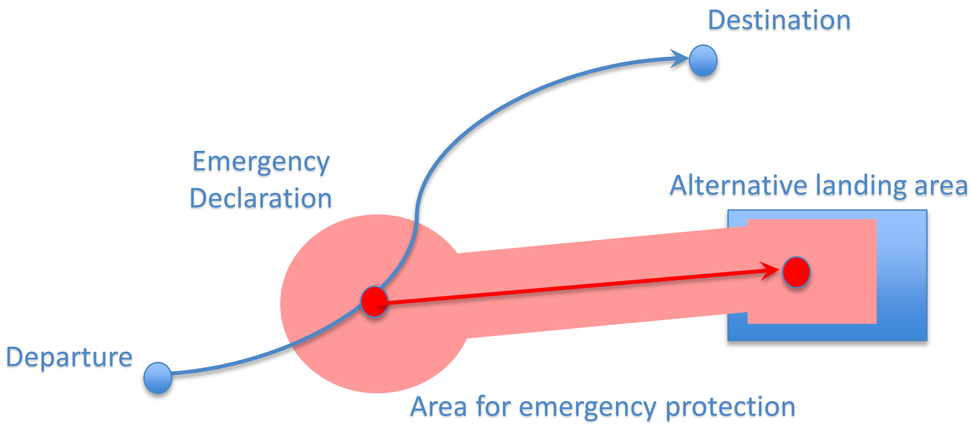

Figure 13: Visualization of the activation of an emergency with contingency plan to land in an alternative drone port.

If no contingency plan exists or it cannot be implemented, it is mandatory the declaration of a **no-fly zone in the area impacted by the emergency**. This process is performed by the Geo-fence Provision service which facilitates ad-hoc geo-fence changes to be sent to drones immediately. The drone must have the ability to request, receive and use geo-fencing data. The following figure shows the visualization of a new flight airspace restriction and four airborne drones within this region exiting the restricted zone [39]. New operation plans to the destination will be submitted by the Operation Plan Preparation service.

In general, processing of changes to airborne flights will be fast and not result in rejection - for example due to penetration of a geofence. Thus, these flights will be prioritized in the next steps of the DCB process.

Figure 14: New flight airspace restriction and drones within this region exiting the restricted zone

2. Calculation of demand prediction

This process is performed by the Dynamic Capacity Management service. When emergency is activated, this 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.

The outcome of this process 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.

3. 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 of 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. **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.

4. 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. 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**. A prioritization process will be launched.

Delays on ground is the other measure that can be implemented for those flights whose operations cannot take place due to the new restrictions, e.g., departing area is within the new no-fly zone.

5. 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 operation 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 safety and social indicators, hence whose removal would cause the largest overall reduction in risk or social impact.

6. 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. Slight horizontal/vertical changes to solve potential encounters should be solved 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.

The processes related to each approach are included in Table 17.

Table 17: Overview of potential DCB measure implementation options in the-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 *Similar to the strategic phase, see **Table 12**.*	**7b. Generation of "what-if" 4D trajectories** *Similar to the strategic phase, see Table 12.*
8a. Submission of new Operations Plans complying with the DCB measure *Similar to the strategic phase, see **Table 12**.*	**8b. Assessment of pair-wise collision risks of new DCB scenario** *Similar to the strategic phase, see Table 12.*
	9b. Implementation of DCB measure and pair-wise solutions *Similar to the strategic phase, see Table 12.*

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 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.

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.

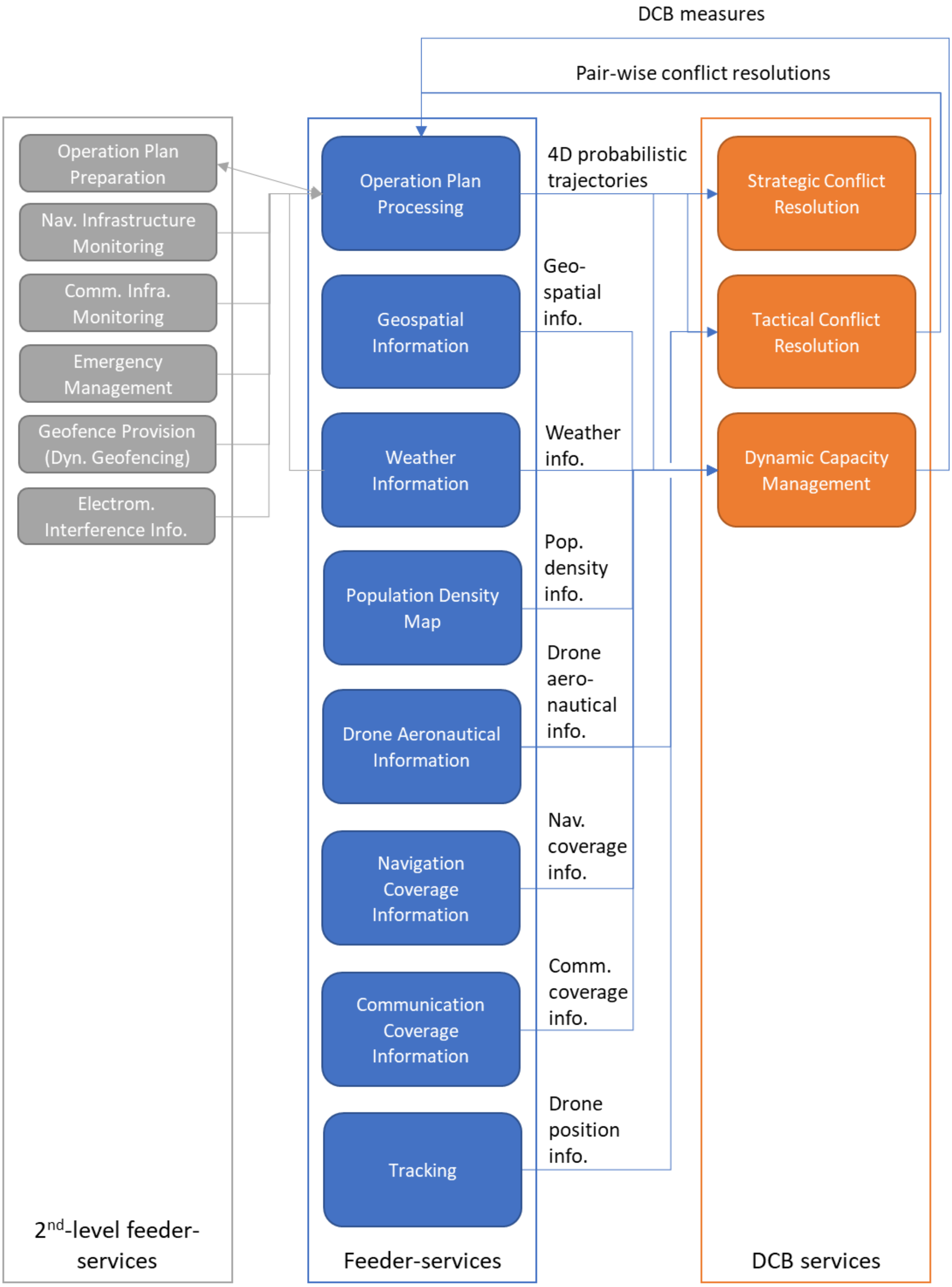

Figure 15: Overview of service interactions within the DACUS DCB solution.

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. For more information on the service interactions within these projects, please refer to Appendix C.

8.5 Potential U-space DCB measures

DCB measures can be classified in terms of their potential impact to the fulfilment of the mission objectives. 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 which must adhere to specific flight profiles.

The following bullets describe **potential DCB solutions** and their applicability:

- **Increasing CNS infrastructure** as a measure to increment the maximum number of drones which could be managed in a certain airspace. 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;

- 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;

- 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;

- 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;

- **Requesting higher individual aircraft operational performance requirements** in order to optimize the capacity utilization of the airspace [35]. 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;

- 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;
- **Increasing the operational ceiling of U-space airspace**. By definition, U-space designated airspace is linked to VLL airspace boundaries, which extend up to 400ft above ground level. However, as was highlighted in section 6.2, 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;
- **Imposing re-routings or delays on ground**. These are measures which could be highly impacting the fulfilment of the mission objectives and consequently, some of the missions could be at risk;
- **Rejecting 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".

9 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.

9.1 DCB 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. A detailed assessment of ATFCM today and the future solutions in SESAR is included in Appendix E.

9.1.1 ATFCM 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.

9.1.2 ATFCM 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 (taking the influence factors that are impacting both demand and capacity into consideration – see Appendix A) and the ATFCM measures that can be applied in each phase according to their effectiveness.

9.2 Overview 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.	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
	• Occupancy: Number of flights that can be handled at the same time. • Complexity: Quantification of the complexity of the traffic 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	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,

Notion	Air Traffic Management	U-space
	prior to operations, pre-tactical one day prior to operations and tactical as of the day of operations.	which may vary in time and location.

DCB measures	Within ATFCM, measures for managing air traffic imbalances come down to:
	
	1. Improving declared airspace/airport capacity (see Appendix E, E.1.2).
	2. Capacity optimization solutions (see Appendix E, E.2.1); or
	3. Application of ATFCM measures (see Appendix E, E.2.2).
		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.	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

Notion	Air Traffic Management	U-space
	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 selecting aircraft to be penalized (i.e., "cherry picking").	delivery – see priority list in [14]); as well as 2. The time of submission of the operation plan with respect to 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 18: Differences between ATM and U-space DCB processes

10 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.

10.1 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.

10.2 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.

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.

10.3 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.

10.4 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.

11 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.

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.

11.1 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 will try to address 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 or when unexpected events happen and change the overall demand or capacity view during the day of operations.

1. Contingency plans as part of the Collision Risk Model

The inclusion of contingency plans within the scope of the Collision Risk Model for UAS operations, which is the main model to determine the maximum number of drone operations in a certain urban area, is subject to further research.

Drone operation plans will contain the volumes of airspaces in which the UAS operator plans to conduct the operation under normal procedures and also those volumes of airspace outside the flight trajectory where contingency procedures are applied. The Collision Risk Model could use both of them, in the form of 4D trajectories, to calculate not only the envisioned level of risk under nominal circumstances but also how risk can change if contingency plans need to be implemented. Research on how to deal with these multiple sets of trajectories and the impact on the level of risk should be conducted.

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.

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.

4. Applicable DCB measures and their effectiveness

This U-space DCB concept redefines the set of DCB measures which are applicable in urban environments. Although previous research initiatives have analysed some of these measures and their expected benefits, there is a need of assessing consistently their effectiveness not only from the perspective of the network performances but also by assessing **how each measure will impact the diverse business models that will coexist in the cities**. This needs to be tested in a context in which "free-route" operations should be facilitated as a general principle.

As an example, one of the measures consists of allowing operations above VLL airspace (and below minimum operating altitudes for manned aircraft) in those areas where demand exceeds the capacity. However, we have identified that cellular network coverage decreases dramatically above VLL because network antennas are tilted down. Thus, this could be a limiting factor which constraints the effectiveness of the measure.

5. 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.

6. “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.

7. Prioritization of drone operations within the DCB process

The thinking in the U-space ConOps is that within any priority level, the selection of flights to act on for DCB or strategic conflict resolution, and how to act on them, should be driven by minimizing overall impact when all flights are considered. However, this raises the possibility that a particular flight is always considered the best target for change. Hence a draft of the ConOps proposed “Virtue Points” which would be awarded to operators whose flights were selected to be delayed or rerouted. These points would in future be used to raise the priority of a flight. The idea was explored further, and the proposal made that Virtue Points should also be awarded for other actions that maximise capacity – a very controversial question.

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

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

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

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

9. 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.

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

DACUS proposes 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 on the most suitable option should be obtained through further research.

11. 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.

11.2 Considerations for the scenarios

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

1. 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).

Assumptions on take-off and landing areas in cities should be addressed in the DACUS operational scenarios. In particular, it will be necessary to set the minimum number of areas to allow the management of contingencies during the tactical phase in a deterministic manner. This implies to take into consideration the constraints in the drone operations such as for instance, the autonomy of the drone due to the battery capacity or the failure of systems supporting Navigation, Communication and Surveillance.

2. 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.

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Appendix A On-going and previous research initiatives

This appendix summarizes several on-going and completed research initiatives on subjects considered relevant to drone demand and capacity balancing. The main conclusions of these projects were considered during the development of the DACUS concept and are listed in Table 19.

Table 19: Summary of main conclusions of other research initiatives of relevance to drone demand and capacity balancing, as well as associated research needs.

Project	Area	Conclusions relevant to DACUS	Research possibilities for DACUS
METROPOLIS	Capacity	• Capacity is evaluated by studying the variation of safety and efficiency metrics with demand. • Capacity can be inferred through the rate of change of the gradients of safety (conflict and intrusion numbers) and efficiency (distance travelled, work done) metrics with respect to traffic demand. • A sudden change in the gradient indicates that a capacity limit has been reached between the two corresponding densities.	• Potential to make use of the capacity models within the DACUS simulations.
	Future urban scenarios and traffic volumes	• The urban scenario definitions encompass population and city size, as well as traffic volume and city physical characteristics.	• Practical considerations to implement the scenarios in the simulation environment are relevant to be defined.
	Airspace structure	• The application of a "layers" concept to structure drone traffic based on headings has the lowest number of intrusions and lowest complexity of all common airspace structures. • Reducing airspace structure, combined with airborne separation leads better airspace utilization than a more centralized and highly structured approach. • Extreme traffic densities can be achieved by spreading the traffic	• Test combinations of the concepts addressed in METROPOLIS (mixed airspace structure) within an urban setting.

Project	Area	Conclusions relevant to DACUS	Research possibilities for DACUS
		over the airspace, while keeping structure relatively flexible.	
NextGEN CONOPS (USA)	DCB responsibilities	• ConOps places responsibility for DCB on the UAS Service Suppliers • USS Operator negotiation services should help resolve capacity problems. • No specific description is included relating to *how* USS might support these DCB services	• Look into USSP-based "decentralized de-confliction" as an option for the DACUS solution. • Simulate "decentralized de-confliction" concepts in the experiments.
Airbus UTM	UTM blueprint	• Introduce specific flight rules for drones: ○ Basic Flight Rules (BFR) for complete remote pilot responsibility (similar to VFR) ○ Managed Flight Rules (MFR) for shared remote pilot and UTM traffic management (similar to IFR) • Identification of stakeholder responsibilities at various levels of UTM implementation.	• The concept of corridors should be explored either to separate manned and unmanned aircraft or unmanned aircraft between them. • It could be interesting to assess the impact of a federated systems architecture on U-space services linked to DCB.
	UAV mission risk factors	• Depending on the applied system, separation standards for drones can vary between 2440m (for a TCAS-based system) down to 10m for a system utilizing random trees algorithms. • The most likely occurrences of UAV safety-volume infringements will occur on take-off and landing.	• Simulate a traffic mix of drones with varying separation requirements. • Incorporate higher navigation and manoeuvrability thresholds for drone take-off and landing areas in urban environments.

Project	Area	Conclusions relevant to DACUS	Research possibilities for DACUS
	Metrics for near-miss events	• The Airprox "Risk of collision" (class. A) and "Safety not assured" (class. B) are the most useful metrics to use in comparing near-miss events in a simulated environment.	• Utilize the Airprox A+B combination as a metric to quantify near misses in tactical traffic management.
	Metrics for dense airspace traffic	• "Minimum closing time" and "number of close aircraft" are measures that scale smoothly with increasing traffic density. • To increase the density in traffic volumes, it will be necessary for traffic management to by streamlining aircraft headings in volumes where the traffic will be concentrated. • Even at low traffic densities, a deconfliction service will be needed since flights interact often enough that it becomes a problem without.	• Increasing density of operations within a specified area by requesting increased aircraft collision avoidance capabilities. • Analyse the risk of cascade effects caused by avoidance manoeuvres. • Identify how traffic patterns and DCB measures could increase traffic density.
	Drone flocking	• Vehicle flocking has the potential to greatly increase airspace capacity. • Flocking would require autonomous visual separation capabilities of the drones within the flock. • Flocking would be supervised by corridor control services or tactical separation services	• Identify Responsibilities of the Dynamic Capacity Management service and the Tactical Separation service to manage flocks.
	Noise mitigation	• Effective noise mitigation requires a combination of: ○ Source noise reduction ○ Noise abatement procedures ○ Operating restrictions ○ Land use planning and management	• Identifying best quantifiable noise metrics and researching new ones • Modelling of high-density drone noise footprint

Project	Area	Conclusions relevant to DACUS	Research possibilities for DACUS
		○ Managing community annoyance	• Ensuring flexibility of traffic management platform to implement noise abatement procedures. • Identifying noise hot spots in traffic management platforms • Studying effects of route concentration, and repeated close-proximity noise events
	Pre-flight deconfliction effectiveness	• Pure reliance on 2D pre-flight deconfliction works for low traffic volumes, but quickly become insufficient as traffic increases.	• Assess 4D deconfliction effectiveness. • Identify the impact of the use of corridors to funnel traffic in high-density regions
	Risk assessment models	• Introduction of a comprehensive pre-flight model for risk assessment that feeds holistic airspace optimisation and management.	• Assess overlaps of the Risk model With the DACUS solution
UAM ConOps	Urban Air Mobility (general)	• Urban Air Mobility (UAM) vehicles will operate under their own specific set of rules, procedures and performance requirements within corridors situated above 400ft above ground level.	• Assess whether to treat UAM-vehicles as separate entities (in terms of corridors, UAM rules, etc.) within the DCB process or to include them as a functional element of the entire traffic picture.

Project	Area	Conclusions relevant to DACUS	Research possibilities for DACUS
			• Incorporate the nominal and off-nominal UAM Use Cases, which could be a reference for the definition of operational scenarios in DACUS.
	UAM corridors	• Corridors will be established between frequent travel destinations for UAM traffic (such as between airports). No tactical ATC separation is provided. • DCB may apply to UAM due to corridor congestion as well as other factors such as origin/ destination aerodrome congestion.	• Address UAM corridor congestion management. • Consider origin/ destination location congestion within the DCB process. • Assess the applicability of UAM corridors as a mechanism to increase the capacity of the airspace. • Elaborate on the connection between DCB and CBRs, which implies active participation of users and providers of UAM services in the decision-making processes.
	UAM separation	• UAM separation is achieved via shared flight intent, shared awareness, strategic deconfliction of flight intent, and the establishment of procedural rules.	• Compare these ambitions with the DACUS DCB solution for separation management.
New era of digital aviation	Real-time risk assessment	• The paper identifies the need of real-time risk assessment and monitoring, as well as new risk analysis methodologies, which should be focused on the type of	• Identify if the real-time risk assessment and monitoring is something to be done by the

Project	Area	Conclusions relevant to DACUS	Research possibilities for DACUS
		operations and their interactions rather than on pre-defined safety target for the whole airspace.	Dynamic Capacity Management service in the tactical phase.
	Interoperability	• The paper put the focus on the interoperability between service providers, between vehicles and operation types i.e., how entry and exit points are treated for operations that traverse multiple types of airspace and interact with multiple types of service providers, between countries or with the ATM systems.	• Identify in Dynamic Capacity Management should be a centralized system covering a local area or a wide airspace, and the potential needs to interoperate. Maybe interaction with ATM should be taken into consideration, in particular to define the boundary conditions to enter or exit the UTM airspace.
VUTURA	Use Cases	• The VUTURA project demonstrated a series of realistic business cases for drones (Rural smart farming, urgent medical deliveries, BVLOS delivery services and high priority emergency surveillance)	• Use these use cases as templates for the DACUS studies.
	Use of tactical de-confliction	• In the demonstration of Strategic Conflict Resolution and Tactical De-confliction it was noticed that if the first one was well performed, there wasn't any need of the second one.	• Refer to strategies employed within VUTURA to see whether the same result can be achieved within the DACUS studies.

A.1 METROPOLIS

The METROPOLIS project investigated radically new airspace design concepts for scenarios of traffic density, complexity and constraints. Focused primarily on personal air vehicles and unmanned, autonomous flying cargo vehicles.

The analysis has identified the following overlaps which are relevant to DACUS project goals:

- An **estimation of airspace capacity**, so as finding an accurate capacity metric.
- A **description of future urban scenarios with future traffic volume**s, distribution in urban areas and considering different air vehicle types (UAVs, PAVs).
- The **design of new airspace structure concepts** to accommodate future demand.

These goals were tested through a series of simulations.

A.1.1 Airspace capacity estimation

The project analysed airspace capacity by calculating the expected number of vehicles by looking at the limits of airspace capacity. One main observation is that the flow structure is a key factor which impacts capacity.

A.1.1.1 Airspace capacity calculation

In METROPOLIS, capacity is one of the four metrics used to measure the operational differences between the four different airspace structure concepts. The other operational metrics are safety, stability and efficiency.

Influence of Safety and Efficiency Metrics

One of the main research goals of the project is to investigate the airspace structure-capacity relationship. The traffic scenarios of increasing traffic demand have been defined to study this relationship. Similar to other transportation systems, airspace capacity is difficult to define explicitly, however, it is clear that that both safety and efficiency must be considered when evaluating the structure-capacity relationship. Therefore, it is proposed that capacity be measured indirectly by considering the relationship of the safety (average conflict percentage) and efficiency (traffic demand/scenario) metrics with respect to the (prescribed) demand of the four traffic scenarios. Furthermore, by analysing the gradient of the safety and efficiency metrics with respect to demand, it may be possible to detect **capacity limits**.

Traffic Density vs. Traffic Demand

Another way to evaluate capacity is to measure the extent to which traffic density matches the predefined traffic demand for each scenario. It is possible that for high demand scenarios, the departure metering used to prevent conflicts during take-off may limit the maximum number aircraft that can enter the airspace. The ratio between the number of aircraft that took-off and the number of spawned aircraft during the logging hour can be used to measure this relation:

$$R = \frac{n_{ac_{takeoff}}}{n_{ac_{spawn}}}$$

A running total of the number of 'actual' take-offs can be used to log *n_actakeoff* during the logging hour. The number of aircraft spawned during the simulation hour, *n_acspawn*, is known in advance of the simulation. If the ratio between density and demand is below a prescribed threshold (for example

75%), or if there is a significant reduction of the ratio between two scenarios, a **capacity limit** may be identified.

A.1.1.2 Conclusions on airspace capacity estimations

The safety related metrics used for the evaluation are **conflict und intrusion numbers**. On the other side the efficiency related metrics are distance travelled and work done.

- It should be noted that the **limited number of scenarios** used in this project may make it difficult to arrive a conclusive capacity limit for all concepts.
- Capacity can be inferred through the rate of change of the gradients of safety and efficiency metrics with respect to traffic demand.
- **Safety related capacity**: Full Mix and Layers concepts deteriorate slightly with density; no capacity limits were found for the densities considered in this project.

Unlike safety metrics, there is almost no variation of the efficiency related metrics with density. The only concept that shows a slight degradation of efficiency with density is Tubes. This is a surprising result and suggests that there is only a **weak relationship between efficiency and capacity for the densities considered in this project.**

A.1.2 Future urban scenarios and traffic volumes

For the experiments, four urban scenarios were defined based on population and traffic growth as well as a description of the experimental areas used in the simulation. The project analysed certain relevant aspects impacting the definition of the urban scenarios:

- Characteristics of the urban region: Analysing demographics of region at certain point of time and use this as baseline for future scenarios, based on growth rate and population density.
- Traffic volume estimates: derived by extrapolating the current levels of road traffic in Paris to the population size:
    - PAVs: Estimation of volume of PAVs per hour under certain assumptions
    - UAVs: Estimation of number of UAVs needed per hour to deliver packages.
- Distribution of traffic: by time of day taking into account the effect of rush hours.
- Traffic types: four types are considered (varying between residential-commercial types).
- Vehicle Modelling
    - PAV: fixed-wind VTOL, Gyrocopter, Tilt-rotor (range 190-700NM)
    - UAV: quadcopter

Definition of experimental areas

- Estimation of minimum area necessary for experiments: impacting the minimum number of vehicles to be simulated.
- Shape of experiment area: trapezoidal shaped area to cover all region types.
- Average and instantaneous (1 hour) traffic volume for experiment area.
- Urban street and building layout: grid-like city layout is adopted. Variation of building heights.

Distinction between commercial and residential zones: definition of focus points.

A.1.2.1 Description of urban scenarios and traffic volumes

Table 20: Projected Metropolis population and size for four future scenarios

	Scenario 1			Scenario 2		
	Population	Pop. Density [/km^2]	Area [km^2]	Population	Pop. Density [/km^2]	Area [km^2]
City Center	2,690,278	23,292	116	3,458,929	29,947	116
Inner Ring	5,196,515	6,878	756	6,681,233	8,843	756
Outer Ring	6,113,207	453	13,500	7,859,837	582	13,500
Total	*14,000,000*	*974*	*14,371*	*18,000,000*	*1,253*	*14,371*
	Scenario 3			Scenario 4		
	Population	Pop. Density [/km^2]	Area [km^2]	Population	Pop. Density [/km^2]	Area [km^2]
City Center	4,227,580	36,602	116	4,996,231	43,257	116
Inner Ring	8,165,952	10,808	756	9,650,670	12,773	756
Outer Ring	9,606,468	712	13,500	11,353,098	841	13,500
Total	*22,000,000*	*1,531*	*14,371*	*26,000,000*	*1,809*	*14,371*

Table 21: Future Traffic Volume Estimates for Entire City

		Population	TF-X	PAL-V	MTAV	UAV	Total
Scenario 1	City Center	2,690,278	3,939	288	336	174	4,737
	Inner Ring	5,196,515	7,608	557	650	336	9,151
	Outer Ring	6,113,207	8,951	655	764	395	10,765
	Total	14,000,000	20,498	1,500	1,750	905	**24,653**
Scenario 2	City Center	3,458,929	5,064	371	432	224	6,091
	Inner Ring	6,681,233	9,782	716	835	432	11,765
	Outer Ring	7,859,837	11,508	842	982	508	13,841
	Total	18,000,000	26,355	1,928	2,250	1,164	**31,697**
Scenario 3	City Center	4,227,580	6,190	453	528	273	7,444
	Inner Ring	8,165,952	11,956	875	1,021	528	14,380
	Outer Ring	9,606,468	14,065	1,029	1,201	621	16,916
	Total	22,000,000	32,211	2,357	2,750	1,423	**38,741**
Scenario 4	City Center	4,996,231	7,315	535	624	323	8,798
	Inner Ring	9,650,670	14,130	1,034	1,206	624	16,994
	Outer Ring	11,353,098	16,623	1,216	1,419	734	19,992
	Total	26,000,000	38,068	2,785	3,250	1,681	**45,784**

A.1.2.2 Conclusions on urban scenarios and traffic volumes

- Traffic volume estimates only for two mission purposes (UAV parcel delivery and PAV transportation)
- Definition of urban scenarios only for specific time (2050).

A.1.3 Proposed airspace structure concepts

Several airspace structure types were proposed and tested to find the most adequate one. These are described in more detail below:

Structure 1: Full Mix

In this design, all vehicles share the same airspace, without any structure or non-physical constraints, in which via a prescribed airborne separation assurance algorithm, supported by automation, the vehicles avoid each other while flying an optimal route. UAVs and PAVs are mixed. This is a static airspace design, which does not require adjustments based on demand.

- No separation between PAVs and UAVs
- Adopts the principles of Airborne Separation Assurance (ASA).
- Conflict Detection & Resolution divided into short term (minimum look ahead distance of 250 meters), long term (applying priority rules), emergency (based on TCAS system).

Figure 16: Fully mixed airspace structure.

Structure 2: Zones

Based on the principle of airspace design today, different zones for different types of vehicles, speed ranges as well as global directions were defined to aid the separation by the structure of the airspace. UAVs and PAVs each have their own zones and are mostly, if not completely, separated. A dynamic adjustment of zones based on demand or observed densities, is an option with this design.

- Higher levels of metropolitan airspace, above UAV airspace, are assigned to PAVs.
- Operations and flow management: Routes are issued by ATC and the “First-Come, First-Served” (FCFS) principle is applied to UAVs.
- Different rules and traffic management strategies can be applied depending on urban areas and vehicle types.

Figure 17: Airspace structure divided into zones.

Structure 3: Layers

In this design, every altitude band corresponds to a heading range in a repeating pattern. The aim is to allow maximum freedom of routing while lowering the relative speeds, facilitating the separation and increasing the safety. A limit to the ceiling of UAVs will be an option on this design. This is a static airspace design, which does not require adjustments based on demand.

- A segmentation of the airspace into layers of 300 ft vertical dimension with cruising layers (8)
- Conflict Detection & Resolution applying a mathematical potential algorithm (Modified Voltage Potential)

- Flow management: FCFS principle
- Demand Capacity Balancing over Time: allocate flight directions to layers in dependence of the expected traffic distribution. Introduction of a time dependent departure / landing fee system.

Figure 18: Airspace structure divided into layers.

Structure 4: Tubes

As a maximum of structuring of airspace, tubes were defined to provide a fixed, but dense, route structure. Different directions, speeds and vehicle types will use different tubes ensuring safety by separating potentially conflicting traffic. UAVs and PAVs each have their own tubes and are completely separated. A dynamic adjustment of zones based on demand or observed densities, is an option with this design.

- Air vehicles within a tube all fly at equal speed. A tube can only contain one air vehicle within a timeslot.
- Separation: Minimum separation will be ensured based on time.
- Abnormal situations: closing of tubes as no-go areas appear.

Figure 19: Airspace structure using tubular route structures.

A.1.3.1 Variables used to measure the concepts

A series of variables were identified and utilised to measure the effectiveness of the proposed concepts. A consolidated list of these variables is provided in Table 22.

Table 22: List of variables used to measure the different airspace structure concepts.

Demand	Expected number of vehicles
Capacity limits	• Minimum altitude • Maximum altitude • No-fly areas
Capacity	Studying variation of safety and efficiency metrics with demand
UAV requirements	• Flight times • Required distances • Fuel costs
Quantity of stream flow	• Units of vehicles per day • Vehicles per hour
flow	Measurement at a point on the roadway over time
Traffic volume	Average and instantaneous (1 hour) traffic volume in specific urban area. Divide volume in different time spans during the day (rush hours, evening)
Traffic complexity	Characterizing the geographical distribution of aircraft in the given volume of airspace
Loss of separation	Loss of separations occur if the minimum separation requirements are violated
Conflicts	Predicted intrusions; if the track of an intruder is expected to pass through the protected zone when both aircraft trajectories are extrapolated over a pre-defined 'look-ahead' time
Operational efficiency	• Route Efficiency • Relative Delay Absorption Capability • Departure Delay • Arrival Sequencing

A.1.3.2 Main conclusions on the airspace structure concepts.

The simulations of the airspace structure provided a series of results which are summarized below:

- In terms of safety, the number of conflicts and intrusions simulated increased proportionally with traffic density for **all the concepts**, even for the Tubes concept, where conflict-free trajectories should have been pre-planned.
- The **Layers concept**, which resulted in the lowest number of intrusions simulated, was also found to have the lowest complexity of all concepts. This indicates that the high safety observed for the **Layers concept** is a result of, in general, lower aircraft proximity and convergence. The opposite was found for the **Tubes concept**, which displayed the lowest safety while exhibiting the high traffic concentrations and complexity.
- From an efficiency standpoint, increasing airspace structure seems to negatively impact energy consumption.

- Reducing airspace structure, combined with airborne separation leads better airspace utilization than a more centralized and highly structured approach.
- A good way to structure high-density traffic would be one that suffices, i.e., one that aids in traffic separation, without unduly affecting system efficiency. While the segmentation into aircraft with similar headings, as seen in the **Layers concept**, still shows a beneficial effect when compared to the unstructured case (i.e., the **Full Mix** concept), the strict structuring as employed in the **Zones and Tubes concepts** only reduces performance without any gains in safety, nor any other metric.
- For both nominal and non-nominal experiments, the **Layers concept** was found to be the best balance between organizational, operational and environmental metrics.
- Extreme traffic densities can be achieved by spreading the traffic over the airspace, while keeping structure relatively flexible.
- For a spatially spread demand, such as provided by e.g., personal air transport or delivery drones, a Layered concept is optimal.

A.2 NextGEN Concept of Operations

A.2.1 Background/Summary

With the release of an initial concept of operations (ConOps) in 2018, which provided an initial high-level overview of how Unmanned Aircraft Systems (UAS) Traffic Management (UTM) could be deployed in the US, the FAA Nextgen Office provided a vision of how such operations could be safely supported in the very low airspace domain. The original document provided details of operational and technical requirements considered necessary to support UAS operation within an open and equitable, community-based UTM ecosystem.

Following a series of validation exercises, analysis of more complex operating environments, a variety of field demonstrations and operating initiatives carried out in partnership with other agencies and industry partners and other research programs in the USA such as the UTM Pilot Program (UPP) or the UAS Integration Pilot Program (IPP) demonstrations, the agency has recently released the FAA UTM Concept of Operations V2.0 (March 2020) which further expands the concept, associated services, UTM architecture, roles and responsibility.

This annex provides a high-level summary of the main components of the latest concept of operations.

A.2.2 The need for UTM

Given the wide range of functions and services that are expected to be supported through the use of low altitude unmanned air vehicles in the near future, and the projected growth in the number of operations, FAA and its partners identified the need to define a management process for UAS operations which could be accessible to all types of potential user in a safe and equitable manner. The predicted number of low altitude operations involving UAS is currently predicted to be at a similar level as existing manned air traffic operations, if not greater. However, to support operations of unmanned or remotely piloted vehicles, especially in the very low altitude environment and including both *Visual* and *Beyond-Visual Line-Of-Site* operation (VLOS/ BVLOS) in a safe and equitable fashion provides a variety of new challenges.

Furthermore, in many cases the very low-level airspace (defined as below 400 feet AGL by FAA) in which these operations are expected is typically uncontrolled (Class G) airspace in the USA, with only those areas in the vicinity of (major) airports being controlled (Class B, C, D or E[surface]).

While FAA already provides appropriate certification/licensing for VLOS operation (regulation 49 U.S.C 44809(c) and code 14 of the CFR) and a limited number of specific waivers provided to commercial operators (VLOS and BVLOS - under Part 135/137 and 91 licenses) or on a case-by-case basis, as the frequency of these operations is increasing rapidly (up to 2-3 million by 2023) a mechanism to support safe, secure, efficient and equitable access for operations of all types within U-Space. Moreover, suitable solutions will also be required to protect areas where such operations might be restricted or even prohibited (permanently, such as in the vicinity of major airport runways, or nuclear facilities, or dynamically, such in the case of emergency medi-vac operations or when large-scale public events are in progress).

In response to these, and other, evolving requirements FAA UTM ConOps envisages a range of community-supported products and services which are able to provide an accessible and scalable range of services and operational support functions to users of all types from those that will operate entirely in ‘uncontrolled’ airspace to those which may transit or even operate entirely within existing controlled airspace regions.

A.2.3 The evolution of UTM in the USA

Following the release of a conceptual framework for UTM (NASA 2013) and subsequent US Agency-Industry workshops and working groups, the FAA/NASA UTM Research Transition Team (RTT) developed a roadmap for the implementation of UTM in both controlled and uncontrolled airspace in the USA. This initiative has been further supported by a series of concept development and prototyping exercises as well as large-scale demonstrations to define a UTM ecosystem that will be capable of providing management services to very large-scale operations in areas where ATC services are not supported. The UTM ecosystem is designed to provide a federated set of targeted services in a community-based architecture to support the cooperative management of low altitude UAS operation for multiple operators in a variety of operational scenarios. From an early stage in the process, FAA has adopted the approach of UTM services being provided by authorised third-party providers or UAS operators themselves, supported by additional FAA managed information systems (using the Flight Information Management System [FIMS], which is part of the FAA Enterprise Architecture Cloud Services [FCS]). The use of FIMS supports information exchange between UTM operators and FAA systems both to promote situational awareness and provide access to historical review/audit in case of incidents.

In 2017, FAA deployed an initial application with the UTM ecosystem (the UAS Low Altitude Authorization and Notification Capability [LAANC]) as a prototype for testing UTM oriented services, before being officially deployed later in 2018. Initially, LAANC was limited in scope to regions located either within existing controlled airspace or close to existing airport facilities and is currently available at around 400 ATC facilities covering about 600 airports.

Following the deployment of LAANC, the FAA was requested by the US congress to expedite the development of UTM as well as to investigate additional security and transparency requirements based on Remote Identification (RID) capabilities for UAS operating in the US airspace, where RID could be used for operations ranging from the public identification of a UAS and who is operating it, to supporting federal investigation or security agencies if a UAS is operating in an unsafe or unauthorised manner.

With the release of v2.0 of the UTM concept of operations, the FAA Nextgen office provides a more detailed description of how UTM will be implemented, operational practices and the supporting services and architecture that will be made available to ensure its successful implementation.

A.2.4 UTM Scope

The scope of the v2.0 UTM ConOps includes all operations that are executed below 400 feet (AGL) and considers increasing levels of complexity in both uncontrolled and controlled airspace regions as illustrated in the figure below.

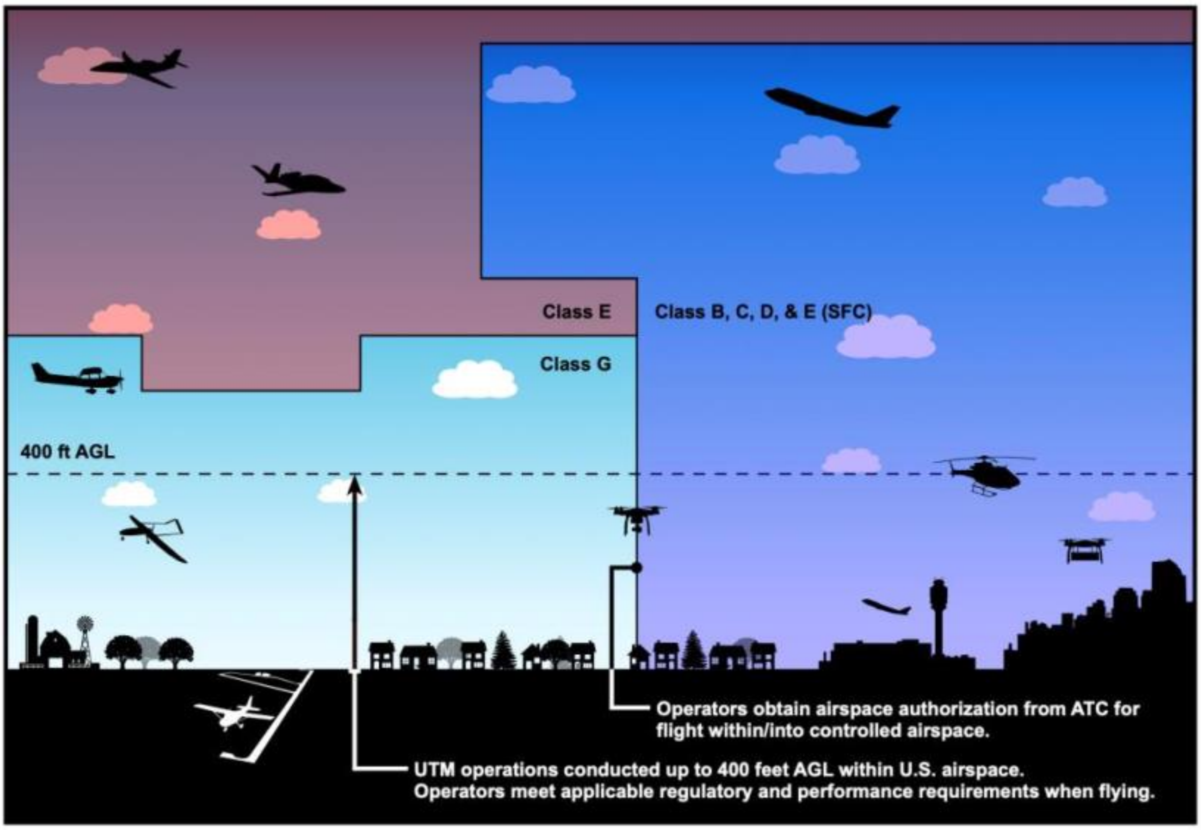


Figure 20: UTM Operations and Airspaces.

A.2.5 UTM Operational Concept

In the scope of the latest FAA/Nextgen ConOps from March 2020, UTM is the method through which the FAA will support UAS operation in the low altitude airspace. However, in practice, it is not foreseen that FAA will provide to associated support and services to UAS operators. Instead, FAA will act as the 'regulatory authority' and will license suitable partners to supply those services as part of a community-based multi-layered traffic management system.

UTM is designed as a set of systems and services based on the principles of information sharing and data exchange at all levels, including operator to operator, vehicle to vehicle and operator to service provider/FAA. Under this paradigm, FAA provides the regulatory guidance for UAS operation, while authorised UTM service providers or the operators themselves provide the necessary support services using the available UTM infrastructure.

The system is based on a suite of federated services, essentially a set of services that are used to support all aspects of UAS operation planning and execution through a group of connected systems and networks that can operate in a suitable connected environment using standard protocols to share essential data to ensure safe and equitable access to the available airspace, as well as to protect against unauthorised or unanticipated use of airspace where operations are not authorised for any reason.

Services are provided by certified UAS Service Suppliers (USS) and are separate from, but complementary to, ATC services – which continue to be provided by the FAA. They are based on the operators sharing information relating to their proposed operations including, but not limited to:

- Flight operations planning information;
- Communications and performance capabilities;
- Remote Identification information (public and enhanced – for use by security services);
- Airspace (access) requests and authorisation(s);
- Separation (strategic and tactical) requirements;
- Flight intent, operational and potential weather constraints;
- Mitigation strategy in case of unexpected event/emergencies;
- etc.

Operators share flight intent (flight plans) with one another, via the available network or networks, in order to support the coordination and de-confliction of proposed trajectories which are expressed as a series of time-constrained operating volumes (described later). Flight plans may be shared as a single airspace volume within which the operation will be performed between the specified times, or as a sequence of connected volumes, where consecutive volumes are linked in time and may vary according to the performance characteristics of the given UAS and/or operator license(s).

Service providers are able to assess the requested flight plans against the available airspace, other planned operations (to support strategic de-confliction if needed), airspace constraints (e.g., access to controlled airspace segments, prohibited areas, dynamic restrictions, weather etc.) and when the requested operation is accepted, authorisation is provided to the operator to allow them to perform the proposed flight.

UTM establishes the regulatory framework within which UAS operations shall be performed but relies on a combination of the UAS operators and USS to ensure that operating rules and performance requirements are sufficient to respect the operating rules and environment. The underlying network and distributed information architecture provide the necessary support for the sharing and coordination of key operational data to ensure situational awareness for all actors in the system (operators, USS, FAA, security agencies, general public etc.). UTM operators are responsible for the type of operation that is requested as well as to ensure that they meet any authorisation or performance requirements that have been established to allow them to perform it in a safe, predictable and efficient manner. USS are able to provide additional support to help operators in conformance assessment should that be required.

Nevertheless, as the federal authority that is in charge of all operations in airspace, the FAA maintains the responsibility to ensure that UTM and its federated services and providers meet the requirements for all types of operation in the airspace volumes/routes where they are performed.

Thus, to establish UTM, the FAA is:

- developing the regulatory framework to support UAS and traffic management that complies with the proposed technology for UTM deployment;
- Adopting an 'authorise and assess' approach to allow operation use of UTM systems and services in an event-based approach which is scalable as operations density increases;

- Promoting an approach which is sufficiently flexible to address changes in the nature of the supported operations, some of which may not yet be known, or which may be impacted by other, potentially unknown, external factors;
- Supporting the evolution of the associated UTM technology in line with a jointly agreed development plan to provide tested products and information services that meet both FAA standards and the needs of the UAS community; and
- Evolving UTM requirements to match new and innovative operating needs in particular when BVLOS operations are proposed in the system.

A.2.6 Target Benefits

In the scope of the latest ConOps, the FAA Nextgen office has identified a set of potential benefits listed as follows:

- UTM provides an innovative approach to meeting service requirements based on the provision of commercial services that will help reduce the 'time to market' for new capabilities due to market forces and business incentives to meet customer needs;
- The deployment of services via certified *commercial* partners (UAS operators, USS etc.) reduces the infrastructure and manpower burden on government agencies;
- The proposed solution offers a safe and stable environment that is based on shared situational awareness within an operational framework that respects standards, regulations and common protocols agreed by FAA and other partners;
- UTM will support a flexible and extensible solution that is better able to adapt as the marketplace for UAS operations evolves and matures; and
- UTM is based on a paradigm which allows FAA to maintain its overall authority for the airspace while allowing industry to manage operations in areas that are authorized for low level unmanned operations in a safe and conformant manner.

A.2.7 Notional Architecture

As mentioned previously, while FAA retains the regulatory and operational authority for UAS operations in the very low airspace (all categories), the delegation of its management to operators and/or USS providers relies on an architecture that can support a set of federated and potentially overlapping services that are made available to the U-space community. In order to allow those services to be easily accessed, and to ensure interoperability among the various commercial providers the notional system architecture illustrated below is proposed by the FAA NextGen office.

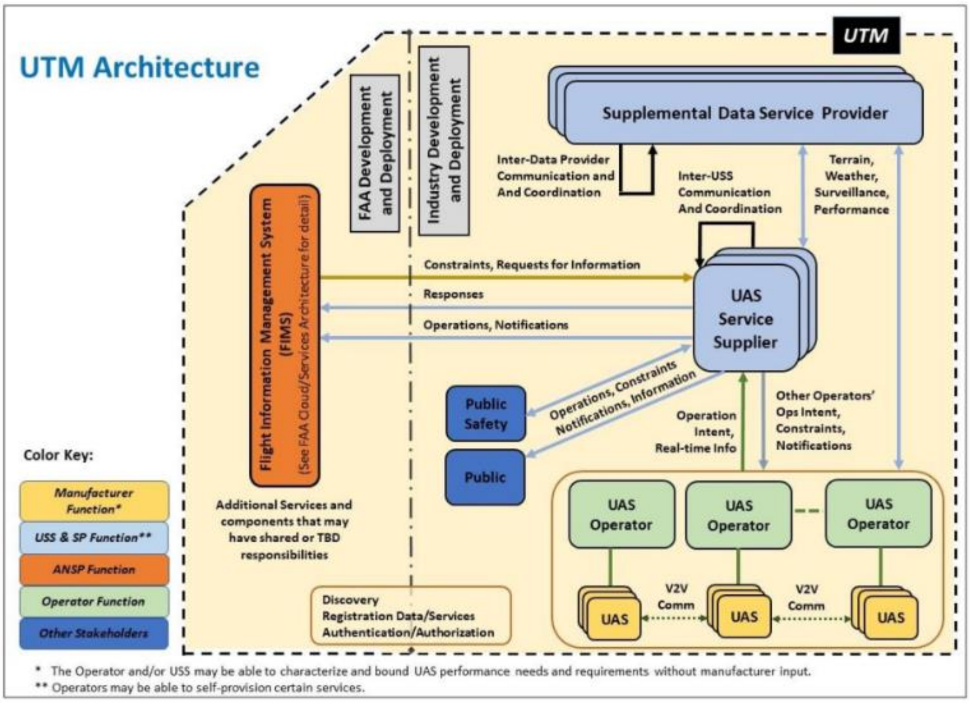


Figure 21: Notional UTM Architecture

UAS operators are able to connect to UAS service providers in order to publish their operational intent, exchange real-time information or gather up to date intelligence about the potential operating conditions or constraints. USS are able to validate operation requests and provide airspace authorisation(s), support strategic de-confliction or provide other operational services to help expedite the safe and efficient use of the available airspace resources, as well as to gather and distribute forecast and real-time weather, surveillance, demand, performance or constraint information and share that data with connected subscribers. Dedicated access portals are available to allow public or restricted access to key information relating to proposed or on-going UAS operations and all of the key information is continuously shared and archived via the FAA Flight Information Management System (FIMS) located in the FAA Cloud Services (FCS). Moreover, where UAS operations are expected to include flight segments which enter, traverse or are fully contained within controlled airspace areas, the federated solution, connected with FIMS is able to share planning and operational data with FAA ATC systems and units.

Additionally, through the connection with FIMS and the FCS, USS and UAS operators are also able to access any National Airspace System (NAS) data or resources that are authorised for sharing, should that be required.

A.2.8 Roles and responsibilities in the proposed UTM ConOps

The UTM solution proposed by the FAA Nextgen office foresees a community-based set of federated systems and services which is primarily supported by commercial partners that are given different roles and responsibilities for the planning and management of the available airspace resources in response to a given set of operational demands. Within the community, each of the partners has a clearly defined role, although in some cases, roles or responsibility can be shared between different partners (e.g., the USS providers and/or certain advanced UAS Operators).

Currently, the main participants are described as follows:

- FAA – it the federal authority responsible for the safe and equitable operation of aircraft in the NAS as well as the body responsible for regulation and oversight. In UTM, FAA provides the regulatory and operational framework under which UAS operations are authorised. FAA is also responsible for the provision of airspace constraint data (e.g., fixed and/or dynamic restrictions to UAS operations, specification of minimum performance requirements, provision of facility maps for ATC units, definition of Special Activity Airspace, Certification for operation etc.);
- Operator – is the entity that is responsible for all aspects of the operation of a given UAS vehicle with the designated airspace and in accordance with the authorised flight plan. In some cases, when appropriately equipped, the Operator may also be able to provide its own UTM services. Note also that in the case that a manned aircraft elects to operate in an airspace that is managed by UTM, this is also considered to be a UTM 'Operator' unless specifically treated otherwise;
- Remote Pilot – The remote pilot in command is the person responsible for the safe operation of the specific UAS vehicle when operating in the UTM airspace. The remote pilot is responsible for the execution of the proposed operation in line with the requested and authorised plan and must respect all of the allocated constraints (performance, weather, environment, flight restrictions etc.) during execution of the flight;
- UAS Service Supplier (USS) – the USS is an authorised entity that assists UAS operators in meeting the operational requirements and constraints for a given operation to ensure that it is executed in a safe and efficient manner. The USS acts as the communications bridge between the operators and other USS within the UTM network to support the sharing of information to ensure a shared situational awareness for all connected stakeholders. The USS also provides the necessary information about other planned operations in or around operating airspace volumes to allow the operator to determine whether the desired operation can be executed in a safe and efficient manner, or to allow them to adapt the planned operation in order to ensure its safe execution. USS also provide the facilities to archive operational data, furnish key public or confidential information to appropriate consumers (e.g., public access, security agency etc.) and to exchange/archive data with the FAA FIMS system.
  USS providers are also able to support services that enable UTM stakeholders to discover active USS across the network, subscribe to services that can allow vehicle owners/operators to register their UAS data in the UTM network (e.g., RID), and access support services for the planning, authorisation, strategic de-confliction etc. of a given UAS operation.

A.2.9 UAS Operations

Operators in UTM are expected to abide by the operating rules, regulations and policies that are applicable to the proposed operations regardless of whether those operations are VLOS or BVLOS. FAA considers that the services provided by USS within the UTM network of services is sufficient to allow the operator and vehicle to perform a sufficient level of performance to satisfy the operator mission in a safe and efficient manner without entering any prohibited airspace area and maintaining safe separation from all other traffic for the entire duration of those operation(s).

UTM operators are able to subscribe to and utilise a set of services provided by the USS and/or other entities in the UTM network in order to exchange appropriate information relating to their intended operation, and to promote shared situational awareness for all other users of UTM. Operators are able to request authorisation through the use of services supported by the various USS, in order to ensure the legitimate and conflict free access to the desired airspace in conformance with their own performance and airspace access rights.

In performing the requested operation, UAS are expected to conform to the agreed airspace profiles and timing constraints in order to ensure all operations can be performed in a safe and efficient manner.

In the event of an unexpected issue (e.g., Loss of communication, technical issue etc.) the expected action that will be taken by any given UAS should also be shared with the USS and other stakeholders connected to the UTM network.

The UTM operational framework fully supports the issue of authorisation to perform a given operation in line with any requirements that may be placed on it, provides airspace authorisation to allow an operator to utilise a given part of the airspace system in a given time window, supports functions for the planning of operations (and validation against other know plans) and is able to provide information on any static or dynamic constraint which may impact the operation being requested. In general, USS will also provide support services that identify strategic conflicts with other known operations, and which offer strategic solutions that can de-conflict the requested operation.

A.2.10 Authorisation to operate

The FAA approach to ensuring safety in the NAS is based on an assessment of the ability for aircraft operators Communications and Navigation capabilities combined with its own Surveillance (CNS) [and increasingly aircraft positional reporting capabilities such as ADS-B etc.] to operate in conformance with its published navigational performance capabilities. Operations in UTM will rely on the same approach as tradition flight operations, where the authorisation to operate will be based on

- Certification - Obtaining the appropriate 'license' to operate a given vehicle(s)
- Performance – where the requested operation is executed in a given airspace region and the UAS/Operator is able to perform in accordance with minimum performance criteria, and
- Airspace authorisation – where the location of the requested operation is carried out in airspace volumes for which the UAS/Operator has been authorised to use.

One of the key roles of the USS is to validate that each and every requested operation complies with the authorisation requirements, prior to any additional strategic or operations planning support that may be provided. If any of the required authorisations are not able to be provided, then the requested operation should be rejected or adapted to ensure full conformation to all criteria.

Note also that, in the event that a requested operation will result in execution that is either partially or fully contained in controlled airspace additional authorisation (from ATC / ATC systems) is also required before the UAS is permitted to operate.

A.2.11 Planning of Operations

In the FAA/Nextgen ConOps, the notion of an 'Operational Plan' is described as the submission of flight intent for sharing with other UTM operators (usually via the federated USS providers). The main objective is to support situational awareness between operators, rather than to share and propagate the plan to the various ATC actors or automation systems present in the 'classical ATM system'.

The 'Operational Plan', as described in the ConOps is developed before any authorised operation and provides a four-dimensional (4D) volume of airspace within which the requested operation should be performed. The plan also includes times and location of any other key events related to the proposed operation that are considered as important and may include:

- Launch details;
- Recovery information;
- Segmentation of the trajectory over time (e.g., multiple, connected airspace volumes used to segment the operation over different time windows);
- Contingency management actions (e.g., in case of an operational failure).

Depending on the type of operation, a larger single volume may be sufficient (e.g., in the case of a drone operating in a given airspace volume to make a series of aerial photographs where a single airspace reservation may suffice) whereas a UAS that is planned to take off from a delivery centre, go to one or more delivery address, drop of the payload and then return to the centre, a series of time reserved 4D segments would be more appropriate.

Once the plan is available, analysis services can help identify it may be impacted by other known operations (e.g., by identifying overlapping airspace volumes that are expected to be in use in the same timeframe).

Similarly, any additional constraints such as static or dynamic airspace restrictions, fly over permission issues (e.g., for a sporting event or a large public gathering) or weather/obstacle issues can be identified by the USS and notified to the user.

In the event of such notifications, the user is responsible to adapt the proposed plan and strategically de-conflict it, supported by an appropriate USS system/toolset if necessary.

In general, it remains the responsibility of the UTM operator to adapt the proposed plan to resolve any separation issues (with other aircraft, weather, restricted areas, obstacles etc.) strategically by adapting the proposed plan in advance of execution and by updating the plan accordingly.

Naturally, situations may occur where the execution of the proposed operation is unable to conform to the original (and potentially strategically de-conflicted) plan so additional contingency exists to support dynamic (tactical) resolution of any issues encountered during flight operation (e.g., separation issues with other UAS, unexpected changes in weather, unplanned airspace restriction due to medi-vac or security reasons etc). However, in general this is expected to be carried out by the operator as early as possible, in coordination with other operators and with the support of USS tools and services if needed (e.g., to identify those situations and potential solutions that could be considered.) Longer term solutions also foresee the use of on-board Detect and Avoid capabilities, but these are not described further at this stage.

A.2.12 Security

The ConOps also includes a substantial amount of information relating to the security of operations in UTM. In general, this refers to both unauthorised activities by a given UAS, but also to other types of threat such as cyber security issues, privacy, RID spoofing etc. and is considered to be out of the scope of this high-level overview of the current FAA/Nextgen UTM Concept review provided in this annex.

A.2.13 Use-cases and operational scenarios.

The FAA Nextgen ConOps also provides a set of typical operational scenarios in which the actions performed by each of the different participants is described in more detail. These are not included in this summary but in the event where the reader is interested to find out more, it is recommended to consult the original Concept document.

A.3 Airbus UTM and white papers

Airbus, through its numerous entities, is a company providing materials and services in the fields of aeronautics and space. It is mostly known for its activity in civil and military aircraft manufacturing.

The last recent years, Airbus has been developing an expertise in the field of drone and U-space Traffic Management (UTM).

This has been mainly characterized by the edition of the Blueprint document dated on 2018, explaining Airbus' view of the U-space, and the project skyways, which is an urban air delivery by drone demonstration, in Singapore.

Today, Airbus's offer includes, in the field of UTM, flight tools such as mission planning, flight briefings and flight authorization to the attention of the drone operator/pilot, and several additional data services, such as weather, maps, terrain information, just to name a few.

A.3.1 Airbus Blueprint

In 2018, Airbus A3 team published "Blueprint for the sky, the roadmap for the safe integration of autonomous aircraft". With the aim to keep safety as the most important criteria, Airbus proposes a roadmap for collaboration and cooperation in order to develop technological advancements.

The future air traffic management will enable manned and unmanned aircraft to fly together.

Observations show that the current organization of air traffic management, human- centred, has already difficulties to manage the current manned aircraft activity in constant growth. Given the expected amount of drone flights, it will be mandatory to include digitalization and automatisms in the order to manage this traffic, as human won't be able to manage such an amount of traffic. This new system is called UTM for UAS Traffic Management, Unmanned Traffic Management in the Airbus Blueprint.

UTM, also known as U-space in Europe, is a collection of services (and also systems).

Gathered by the common goal to maintain safety, even better to improve it, Airbus identifies several users of the airspace, such as hobby drones, general and commercial aviation, helicopters, state aircraft, but also all the professional drones which will take the place of manned aircraft for specific missions. These stakeholders will occupy the airspace from very low to very high altitudes, for missions from leisure to imaging and analytics, including transportation of goods and people, and much more.

Airbus has divided the operational environment into four different categories: airspace, systems, regulation and stakeholders.

Airspace

First of all, the airspace is defined with the following characteristics:

- Accessible;
- Shared;

- harmonized worldwide.

And the UTM managing the traffic in the airspace must be flexible, scalable and allow autonomous flights with the same level of safety that we know today.

The structure of the airspace, including arrival and departure procedures, will probably have to be refined taking into account the new missions performed by the drones, with several take-off and landing locations, potentially spread everywhere. Free routings look like to be the best way from point to point, but conflicts with other drone or other users of the airspace or obstacles may need some arrangements such as for instance corridors (e.g., in high demand area, with usage requirements) or fixed routes, depending on the infrastructures available (CNS) and the traffic density.

As a complement to the Instrument and Visual flight rules in effect in manned aviation, Airbus suggests two additional flight rules adapted to drones and helicopters so that they fit with their missions and the future way of flying autonomously: BFR and MFR.

- Basic flight rules for independent flight where the remote pilot is responsible for the safety, probably in low traffic density airspace;
- Managed flight rules in airspace where a traffic management service providing separation is available, probably where the traffic density is too high to be entrusted only to the remote pilot. Other services will help manage the airspace, owing to weather conditions information, control instructions, or basic information to pilot or autopilot about regulation or nearby traffic.

Systems

Depending on the location of the operations, requirements of the traffic management system will not be the same. In urban environment for instance, traffic density, obstacles or radically different aircraft characteristics will define the traffic management system capabilities and the CNS infrastructure required for safe navigation performances.

All the systems will provide the users with required micro-services, some of them may be certified. The possible architectures for UTM are the following:

- Federated: multiple providers exist for most services and each aircraft can choose between entities;
- Centralized: single entity provides services to all users;
- Hub and spoke: multiple entities exist in an airspace, but each drone receives services from one supplier;
- Peer to peer/ closest peer: no entity provides services; aircraft communicates locally with nearest neighbours;
- Distributed: no entity provides services, vehicles communicate globally and directly, relative to flight plan.

A system manager could provide a single and authoritative system to coordinate digital traffic services.

Regulation

Risk assessment is central in the manned aviation safety culture. New types of aircraft, sometimes flying autonomously, in different environment (e.g., urban, close to the ground) require new risk assessment methodology. A common methodology should be used in order to compare risk assessments between services.

In terms of security, the potential huge amount of service providers and the architectures of the systems may increase the cyber-security issues.

The certification and licensing policies should follow the same form as today in manned aviation. Leisure remote pilot, with lower training requirements compared to commercial remote pilot, may be excluded from flying in certain airspace classes such as CTR. It could be the same for drones with lower performance requirements and not certified to fly, for instance, above urban area. Regulatory agencies will be responsible for certification and licensing.

Finally, standards will be required to ensure interoperability between suppliers, in, for instance: communication, aircraft performance metrics, conflict resolution, emergency procedures, etc…

Stakeholders

Airbus sees the development and deployment of the required infrastructure, onboard equipment and procedures in 6 levels, from no automation to full automation, each allowing more complex flight in more complex environment.

The Blueprint identifies four different groups of stakeholders with the following roles along the level implementation, in the table below:

Table 23: Overview of stakeholder responsibilities at various levels of UTM implementation according to the Airbus UTM blueprint.

Stakeholder	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Operation enabled	Visual line of sight (VLOS), commercial drone operations	Improves safety for VLOS commercial drone operations and Beyond Visual Line of Sight (BVLOS) operations	Autonomous BVLOS operations in low-density airspace	Safe integration of BVLOS in controlled airspace	Fleet operations at moderate scale	On-demand autonomous operations in dynamic, high-density airspace.
Policy makers and regulators	VLOS Flight Rules (e.g., US Part 107, NZ 101/102)	•Waiver program •VLOS pilot licensing	•Authorization policy Registration •ID equipment requirements •Emergency and priority access	•Basic & Managed Flight Rules •Pilot/System rating •Flights over people •Equitable access provisions	•Autonomous certification •Detect and Avoid certification •Fleet operating certification •Risk-based approval	Third-party accreditation for certification services

Stakeholder	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Technical providers and standard bodies	Wireless command and control	•Basic sense and avoid (ex. ACAS-X) Basic surveillance (ex. ADS-B)	•Vehicle-to-infrastructure comms •Security requirements •ID surveillance equipment	•Navigation and DAA performance requirements •Traffic Manager accreditation •Risk assessment	•Service-to-service coordination •Corridor control accreditation	•Vehicle-to-vehicle information sharing •Multi-modal transport coordination
Airspace operators (ANSP and regulators)	•Published aeronautical charts •No fly zones •Altitude restrictions	•PinS Procedures •VFR corridors •Altitude restrictions •Automated geofencing and altitude limits	•UAS tracking •Expanded Instrument Procedures •Automated approvals	•Unmanned procedures •Corridor configuration	High-density controlled airspace established	Dynamic and performance-based rules for access to airspace
Airspace and unmanned service providers	Flight plan filing • Aircraft and pilot registry	SWIM	Network Manager • Operator flight planning • Unmanned Aeronautical Information Service	Digital Traffic Managers • ATM-UTM coordination • Info Service Providers • High assurance IT infrastructure • Service provider marketplace	Corridor control services • Specialized traffic management	ATM integration • Congestion avoidance

Ever since the publication of the blueprint, Airbus has been continuously publishing papers summarizing their progress and insights on UTM-related topics. These insights of relevance to drone demand and capacity balancing are summarized in their individual sections below.

A.3.2 Airbus UTM white paper: Understanding UAV Mission Risk

This paper [4] explores where risk model fits in the larger realm of UAV risk assessment:

- Discussion of the overall approach to developing the risk model and what the resulting model may look like (at the time of publishing, the risk model was not yet complete. An overview of the complete risk model is provided in section A.3.8);
- Identification of several high-level challenges, along with approaches planned to take in tackling them;
- Review of existing research literature in crash severity, vehicle separation, human factors, vehicle reliability and flight into known icing;
- Understanding of UAV risk assessment industry efforts;
- Provision of an overview of the fault tree analysis to target the efforts.

What Will the Risk Model Look Like?

The risk model developed by Airbus covers the following categories and types of risk:

1. **Vehicle reliability, equipage and redundancy.** Not only failure rates for mechanical components, but predictive battery performance and quantifiable mitigation for redundant systems, navigation…
2. **Communications protocols and infrastructure;**
3. **Operator training, experience and performance;**
4. **Airspace usage and rules.** Airborne collision risk increases in more congested airspace. But risk is not merely a function of airspace class or average traffic volume: it varies significantly based on exact location with regard to approach paths, departure corridors, traffic patterns and other factors unique to each area;
5. **Environmental factors.** Weather and terrain interactions can have a significant impact on the safety of a mission;
6. **Population density, land use patterns and building/obstacle height/density patterns**.

Literature Reviews

A series of literature reviews were performed on research relevant to quantifying the risk of drone collisions. The ones relevant to DACUS include:

Literature Review: Separation Standards

How vehicles might deconflict themselves from each other, and how to quantitatively determine appropriate separation standards.

Wiebel [5] **uses Traffic Collision Avoidance System (TCAS) alerting criteria as a baseline to determine well-clear standards using conditional collision probabilities.** The modelling allows the separation standard to vary based on what regulators determine to be an acceptable boundary risk level of a near-mid-air collision (NMAC) occurring. The author proposes a conservative requirement of 8,000 feet (2,440m) ahead and 3,000 feet (914m) to the side and behind, since most TCAS proximity events involve head-on/converging operations. However, these distances do not account for the flight dynamics of multirotor UAVs, which are generally very manoeuvrable and capable of making abrupt trajectory changes.

At the other end of the spectrum, Balachandran [6] demonstrates **how UAVs can use Rapidly Exploring Random Trees to perform their own conflict resolution with other aircraft and obstacles.** The author assumes that 10 meters would constitute an acceptable well-clear standard between UAVs, or 0.5% of Wiebel's forward well-clear spacing. The research is intriguing because it shows how a vehicle with suitable onboard computational resources can resolve its own conflicts in as little as 0.2 seconds, without having to rely on external ATC instructions, operator commands or collaborative resolution advisories from the other vehicle.

Research and testing of **Airborne Collision Avoidance System X (ACAS X) indicates that it may also be useful for resolving conflicts between UAVs**, in addition to its originally intended use as an upgrade and replacement for TCAS [7]. Whereas TCAS uses a fixed set of rules to determine how to resolve a conflict between two aircraft, ACAS X also considers aircraft performance and probabilistic models to predict aircraft positions.

Lin [8] **simulated crash field dynamics for small UAVs in various wind conditions to determine the largest ground footprint over which the UAV might fall.** The results could be applied to low-risk path planning algorithms to determine acceptable overflight areas in built environments.

Homola's [9] findings from testing near Reno, Nevada indicated that **the most likely times for a UAV to blunder outside of its assigned protected airspace volume were during take-off and landing.** This is an important discovery, since it suggests that vehicles may need to meet precise navigation and manoeuvrability thresholds if they are allowed to operate near one another in busy terminal environments.

Literature Review: Human Factors

Human factors will continue to be a source of errors, even in increasingly autonomous flight regimes. These errors may take different forms than we are accustomed to today, whether in vehicle maintenance, fleet management practices or the ability to react to unusual situations in a timely and effective manner.

Literature Review: Vehicle Reliability

Because off-the-shelf UAVs are not subject to airworthiness certification criteria like manned aircraft (and therefore, independently verifiable end-to-end manufacturing quality control processes), there may be large variability in the reliability of components across different examples of the same vehicle model.

A.3.3 Airbus UTM white paper: Metrics for Near-Miss Events

This paper [10] compares existing metrics for near-miss events and identifies the most adequate one for the application on drones. There is **no publicly available global metric** for comparing air traffic safety events in which two aircraft engage in a near-miss incident. **Three separate and overlapping terms exist**, and different air navigation service providers (ANSPs) may report and classify those events in separate ways.

Airprox (Air Proximity Hazard)

ICAO defines an Airprox as an event in which either a pilot or a controller feels there was an increased risk of collision between two aircraft.

Airprox **reports are categorized by severity**, after the fact, using a **qualitative process** and whatever information is available from controllers and pilots. This may include radar and audio replays, as well as written voluntary safety reporting program (VSRP) entries. **No specific distance between aircraft is established.**

Each Airprox, under ICAO guidance, receives one of the following four classifications:

- **A - Risk of collision.** The risk classification of an aircraft proximity in which serious risk of collision has existed;
- **B - Safety not assured.** The risk classification of an aircraft proximity in which the safety of the aircraft may have been compromised;
- **C - No risk of collision.** The risk classification of an aircraft proximity in which no risk of collision has existed;
- **D - Risk not determined.** The risk classification of an aircraft proximity in which insufficient information was available to determine the risk involved, or inconclusive or conflicting evidence precluded such determination.

Airprox events that are categorized as A or B are considered "risk bearing", while the Category C and D events are considered to have no or unknown actual risk of collision, respectively.

NMAC (Near Mid-Air Collision)

The FAA, by contrast, counts NMACs as those events in which the **proximity between aircraft was less than 500 feet,** and the pilot making the report considered there to be a collision hazard. Each event is then reviewed against specific criteria to determine severity. Based on published definitions, a **Critical NMAC is equivalent to a Category A Airprox**, and a **Probable NMAC is equivalent to a Category B.**

Inadequate Separation and Separation Minima Infringements (SMI)

EUROCONTROL maps its event severity categories to comparable ICAO categories. In the case of separation minima infringements (equivalent to losses of separation), those instances marked as **Serious or Major Incidents in EUROCONTROL** terminology **correspond to Airprox Category A and B**, respectively. However, EUROCONTROL states that not all Serious and Major SMIs are investigated as Airprox events.

Conclusions

Airprox A+B is the most useful metric to use in comparing near-miss events in a simulated environment with the real-world because of the way it systematically evaluates and categorizes event severity. But **current rates of near misses**, regardless of the metric, **may result in an undesirably high number of mid-air collisions if extrapolated to the much higher volumes and densities of urban air mobility traffic expected in the coming years.**

A.3.4 Airbus UTM white paper: Metrics to characterize Dense Airspace Traffic

The paper [11] defines and tests two metrics to determine when the traffic in flight is “dense” for drone operations. These metrics are based on the idea that “*density matters when the vehicles in flight interact with each other*”.

The first metric is the ***minimum closing time***, how close the closest aircraft is on average. This is computed by looking at all aircraft in the airspace, measuring their closing time and selecting the smallest. The second metric is the ***number of close aircraft***, how many aircraft are in the immediate vicinity on average.

Results show that both measures scaled smoothly with the number of aircraft in flight. Thus, the paper recognized that there was no obvious knee in a curve where the limit can be declared.

Results suggest that traffic can become “dense” at low traffic volumes, including levels much lower than anticipated demand in urban areas by 2030. In general, the more that all drones are on similar headings the better these metrics are and consequently, more drones can coexist in the same airspace. In case of random traffic, for 250 flights in an area of 10 Km x 10 Km x 300 m (density of around 25 drones/Km2), TCAS collision avoidance should be almost continuously alerting. In case of stream pattern, drone operations in the area can be increased by ten (around 250 drones/Km2). As a conclusion, the more that all aircraft are on similar headings, the better these metrics of the effect of density are. These results suggested the need of employing traffic management mechanism in the airspace to **reduce the entropy in the traffic flow in volumes where the traffic will be concentrated**. In addition, the paper explains that the behaviour of a dense air traffic flow is very sensitive to perturbations such as wind gust, intruding aircraft or an aircraft that experiences a failure. **Traffic management systems must consider these sensitivities** and build resilience into traffic flows.

The paper also estimates how much of the time the drone will spend manoeuvring around potential conflicts if no deconfliction service is provided. With a density of 50 drones/Km2, passenger-carrying UAVs will be flying normally 29% of the total flight time in case of random traffic, and 75% of the time in case of stream pattern. Even at very low densities, flights interact often enough that they spend more than 10%[10] of their flight time manoeuvring to avoid collision. Thus, the **need of a deconfliction service that organized the flows seems to be very necessary** according to this report.

Assumptions

- The *closing time*, the amount of time required for other aircraft to reach ours, is computing a single distance and speed rather than making separate measures horizontally and vertically as in TCAS measures. In addition, the second condition of TCAS, which is based solely on distance, is not taken into consideration;
- An aircraft is considered a close aircraft if the closing time is less than 15 seconds. This is based on the current TCAS resolution advisory at 1000 ft,
- Drone speeds are uniformly randomly between 2 and 40 m/s.

[10] This is assumed the limit according to the TCAS system performance in the US reports.

Limitations and next steps

- Definition of *Density* in the document can be better understood as *Complexity,* so Density matters when the Complexity of the traffic is high;
- The paper explains that the new metrics grow almost linearly with the number of operations and thus, it is not obvious to define the maximum number of operations based exclusively on these metrics;
- Drone models need to be further analysed. Collision manoeuvre will depend on the type of aircraft and reaction time need to be determined for different cases. One of the most critical one could be probably the remotely piloted fixed-wing UAV being operated using VLOS rules at the extreme of visual line-of-sight distance.

Potential applicability in DACUS

- New metrics, which can be part of the performance framework to characterize the density and/or complexity of the operations as a factor to limit the demand (task 05.04 DACUS Performance Framework);
- The 15-second parameter might change by using collision avoidance mechanisms with a tighter tolerance. Thus, requesting the increase of aircraft capabilities in a certain area will allow increasing the density of that area;

  Research question: Flexibility to request the increase of aircraft capabilities in flexible areas within a certain airspace. This could imply that drones with pre-approved flight plans should be rejected when increasing the requested capabilities.

- In other work, they have found that collision avoidance systems reduce overall system safety if density goes above a threshold where one avoidance manoeuvre causes a cascade of other manoeuvres in response;

  Research question: Need to clarify if this cascade effect needs to be taken into account in the calculation of the time parameters for the collision avoidance systems for drones.

- Traffic patterns or DCB measures that could allow increasing the density metrics (T05.01 Airspace Structure and Rules).

  Research question: Identification of the most suitable DCB measures that organize the traffic patterns.

A.3.5 Airbus UTM white paper: Applying Visual Separation Principles to UAV Flocking

In this paper [12] Airbus UTM states that establishing a set of UAV behaviours based on rules of formation flight and visual separation - taking advantage of on-board equipment and V2V communication links - will be crucial tools for autonomously managing future airspace density and capacity constraints.

In formation flying today, the flight leader is responsible for the formation, including ensuring that all other aircraft are in the correct positions. Only the flight leader talks to the air traffic controllers and communications within the formation perform on a dedicated radio frequency separate from any air traffic controllers' frequency. Formations fly together under visual flight rules, where no prescribed separation minima exist.

The paper wonders if the UTM service would pass all instructions to a flock through a single lead vehicle or the UTM service would continue to send instructions to each vehicle. In the first case, all vehicles would need to meet the same communications and performance requirements.

The ability to have vehicles "flock" has the potential to greatly increase airspace capacity, especially if all vehicles within a flock are able to maintain spacing between each other that is a fraction of any other separation requirement. Depending on the airspace needs and vehicle abilities, a flock may be created by a UTM service managing an area of particularly congested airspace or may be proposed by a drone operator. The paper makes two proposals about how the UTM service could use the flock. Two proposals are explained, being both of them applicable independently or in combination:

- Option 1:
  1. A Corridor Control Service recognizes an upcoming period of congestion that would exceed its maximum capacity;
  2. It proactively creates a flock sending instructions to each vehicle about its position in the flock and rallying point outside of the corridor to create the flock;
  3. Capacity Management Service requires that the entire flock traverse over a waypoint within a given amount of time.
- Option 2:
  1. The Tactical Separation Service, which is tracking an existing flock, identifies a single vehicle that could benefit from joining that flock;
  2. The service communicates information about the joining vehicle to the flock's lead aircraft;
  3. The **Tactical Conflict Resolution service gives the vehicle routing instructions to join the flock**;
  4. When vehicles need to leave the flock, the lead aircraft advises the separation service;
  5. The aircraft leave the flock following breakaway instructions received from the lead aircraft and shared with the separation service.

Assumptions

- The paper assumes that existing technologies such as cameras or infrared sensors can be used for ***autonomous visual separation*** within the flock.

Limitations and next steps

- Need to analyse the impact of UAV flocks to manage contingencies, and in particular, those cases in which UAVs are in conflict with manned aviation;
- Need to test the concepts in the paper through simulations, in particular the process that a UTM service shall use to assemble the flock, the optimal spacing between vehicles or the benefits of this measure in comparison with the creating of stream patterns.

Potential applicability in DACUS

- Functionalities of the Tactical Separation Service that go beyond the obvious functionalities of separating drones two by two (T3.4 Dynamic separation minima based on collision risk models, separation intelligence allocation and CNS performance);

Research question: Responsibilities of the Dynamic Capacity Management service and the Tactical Separation service to manage flocks.

- Solutions to be used by the Dynamic Capacity Management service to increase the capacity in a certain area. These solutions could be tested in the DACUS simulations (T1.2 DCB concept).

A.3.6 Airbus UTM white paper: Managing UAS Noise Footprint

This white paper [27] identifies gaps in current research on the generation and the effects of drone noise on the population, and propose an approach to mitigate them.

Current issues with noise modelling

One main point that is mentioned is that the approach towards addressing drone noise concerns should be proactive, rather than reactive. Traditionally, noise impacts are not considered by operators or regulatory agencies until after they have become a problem, causing distrust and annoyance within the wider community. Thereafter, attempts to mitigate noise impacts typically involve long and comprehensive noise studies, which lead to noise abatement procedures. Such a process can take up several years, lacks clearly quantifiable goals or deadlines and creates uncertainty within the community. The approach should therefore leverage today's technology and data-driven decision making to drive favourable implementation policies.

The report goes on to list some key findings from manned aviation that could affect drone operations in terms of noise footprint:

Repeated noise events, regardless of measured sound levels, present an opportunity for annoyance.
The longer the noise exposure duration, the greater the potential for annoyance.
Spectral characteristics affect the perception of noise. Specific tonal ranges are generally more annoying than broadband noise.
We react differently to sound levels depending on our relationship to regulators and operators. If we hold a favourable view toward drones, we are likely to be less annoyed by the noise.
Acoustic properties of sounds are different depending upon weather and topography
Most noise disturbance reports received by airports are from communities outside the significant noise exposure area.
An increase of 5-6 dB in noise exposure is clearly noticeable and can result in high annoyance levels.
Summer months can expose you to more noise by having open windows.
Background noise at night is lower than during the day.

Concerning individual noise levels, the report highlights that many commonly used vehicles are in the perceptible "loud" range at relatively low altitudes. Thus, in order not to bother noise-sensitive areas or underlying residence, they would need to be routed away from them entirely (at least at low altitudes). When looking at the cumulative noise impact, that is, the long-term noise exposure of communities due to several drone flights per day, the impact thereof is much more difficult to quantify. Current means to measure long-term annoyance are inadequate for modelling such annoyances, largely due to the fact that they are not specifically aimed at drones, and thus require the development of new metrics. For instance, the noise of a drone played at the same volume as that of a car is generally seen as more annoying, making the assumption that community opposition to drone noise would be similar to that of car noise irrelevant.

Noise mitigation

Drone noise mitigation will rely on a combination of methods, which are detailed below.

Figure 22: Overview of methods for noise mitigation of drone flights.

Table 24: List and summary of individual methods to reduce the noise impact of operations

Method	Description
Reduction of noise at the source	Potentially one of the most effective means of noise reduction lie in mitigating drone noise emitted by the vehicles themselves (such as through passive noise cancellation and design changes). These will likely be regulated through standards and certification.
Noise abatement operational procedures	**Preferential routes:** Use of routes with specified headings, altitudes and effective hours can reduce noise footprint in sensitive areas. **Optimized arrival and departure procedures:** The use of vertical take-off and landing (VTOL) procedures reduces exposure of the population on the arrival and departure paths. **Dispersing operations:** Instead of concentrating routes to increase operations, efficiency, safety and predictability (as is common in air traffic control), dispersing operations over noise sensitive areas can be part of a solution to remove noise hotspots.

	Alternating routes: Alternating high-usage routes can mitigate the amount of noise exposure. **Hovering:** limiting the amount of hovering time of an aircraft can also reduce the noise exposure.
Operating restrictions	**NOTE:** the paper specifically points out that, although mentioned, the feasibility of these restrictions is unproven. **Curfews:** Time-based curfews to mitigate noise exposure at night **Movement limits:** Capping of movements by limiting the number of flights within a given area (analogous to “slot control” at airports) **Noise quotas:** A limit to the total number of operations per operator within a specified area. **Non-addition rules:** Rules that prohibit certain drone types based on noise certification standards. **Non-scheduled flights:** Restrictions on flights without a flight plan to specific areas. **Enforcing restrictions and limitations:** Use of geofences in combination with registration, identification and tracking methods to ensure compliance with operating restrictions
Land use planning and management	Compatible land use can be achieved by basing operations hubs according to their noise exposure. This could limit the selection of drone hubs (i.e., on top of parking garages, highway interchanges or other infrastructure close to the communities intended to be served). Similarly, noise sensitive areas such as schools, parks, hospitals or places of worship would need to be classified as no-fly zones up to a certain altitude. En-route traffic might also need to be confined to industrial and commercial areas as well as existing road infrastructure, which in turn may have negative effect on overall airspace capacity.
Managing community annoyance	Noise problem topics should be proactively addressed in conjunction with the wider community, follow best practices, use common terminology, use data-driven approaches, understand community needs and find means to engage them.

Future research

The white paper concludes with a list of research areas on drone noise pollution:

- A comprehensive examination of noise from drones;
- Reduction of rotor noise;
- Defining drone noise certification and other standards as they relate to noise mitigation;
- Identifying best quantifiable noise metrics and researching new ones;
- Modelling of high-density drone noise footprint;
- Ensuring flexibility of traffic management platform to implement noise abatement procedures;
- Identifying noise hot spots in traffic management platforms;
- Studying effects of route concentration, and repeated close-proximity noise events;
- Conducting community noise exposure survey studies on annoyance levels and mitigation effects;
- Generating noise dose-response curves of drones and comparing it to other transportation modes;
- Addressing community involvement;
- Researching compounding effects of aircraft, road and drone noise.

A.3.7 UTM white paper: Effectiveness of Pre-flight De-confliction in High-Density UAS Operations

In high-density environments, loss of separation events increases linearly with the effective flight rate, and while pre-flight de-confliction techniques decreased the loss of separation rates, they also decreased the effective flight rate in a region.

This document focuses on effectiveness of pre-flight de-confliction techniques; but relying only on simple pre-flight de-confliction rules and allowing flights to operate without having to use traditional airspace structures (e.g., altitude separation, one-way routes or charted arrival procedures) simply does not provide a path to safe airspace usage.

Study design and assumptions

16 different scenarios have been modelled. The scenarios are different combinations of flights per hour (100, 250, 500 and 1,000 flights per hour) and airspace regions. Each airspace region is 10 nautical miles (18.5km) square, with the following characteristics:

• Uniform: Flights take-off and land at points distributed randomly throughout the airspace;

• Gaussian: Flights are concentrated at one node at the centre of the region, with the likelihood of a flight originating at a location decreasing with the distance from that point;

• Bimodal: Two Gaussian-distributed nodes with their centres 5km apart;

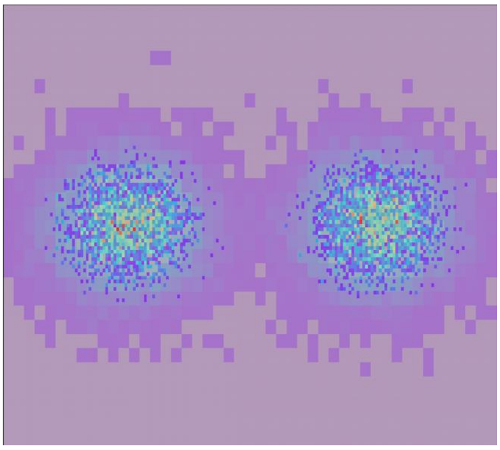


Figure 23: Study design using two Gaussian-distributed nodes.

• Shenzhen: Publicly available population data was used to create a simple, scaled model representing the Shenzhen, China region, which has some extremely dense neighbourhoods and some very sparsely populated areas within short distances of each other.

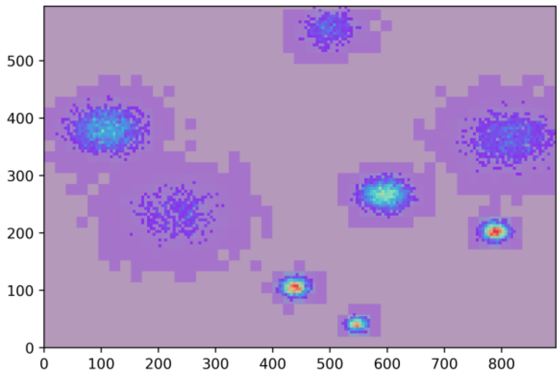


Figure 24: Scaled model of the Shenzhen metropolitan area.

Several assumptions were made to simplify the modelling of the simulated airspace. In all scenarios, vehicles have identical performance characteristics:

- relatively short vertical take-off and landing (VTOL) ascent and descent phases;
- cruise speed is at 20m/s (39 knots) at the same altitude;
- 10m (33ft) across (about the size of an urban air mobility vehicle).

Finally, there is no vertical de-confliction between them.

The methodology

The de-confliction methodology includes three steps:

- the simulator generates a flight plan;

- a few seconds before departure, the planner looks at all other flights that it expects to be in the air and tries to adjust the route of the vehicle not yet airborne, if a conflict is detected;
- modifies the new flight plan's horizontal routing around any traffic conflicts, based on their predicted positions at each one-second interval.

The goal is to maintain at least 500 feet between all vehicles. There is no other measure to reduce the number of conflicts, nor time-based metering system in place, which helps provide order and predictability in today's airspace.

The simulator's planner performs horizontal de-confliction as it receives flight plans using a geometric path planning methodology to perform de-confliction based on [29]. It will add a path segment either to the left or right of the region in which it expects the first vehicle to be flying, but it is blind to that vehicle's direction of travel. As a result, it may choose the less-optimal solution of turning to fly ahead of and in front of the first vehicle. Having successfully generated a new path segment around the conflicting vehicle, it repeats these steps all the way to the destination. However, there is no guarantee of a conflict-free route, especially in instances with many vehicles in conflict with each other, or difficult-to-resolve encounters at shallow convergence angles.

In addition, a flight plan filing service, which double-checks each route before approving the flight, in the seconds before departure, was tested. The filing service is able to detect if a new flight plan will conflict with a previously approved route. In those cases, it denies the flight plan, preventing it from departing.

The filing service was tested both as a standalone function (no other de-confliction applied), and in conjunction with the pre-flight de-confliction algorithm. In the latter instance, the filing service acts as a second check on the de-confliction algorithm's work. This is particularly useful when the de-confliction algorithm was unable to resolve all conflicts along a flight's route. When this occurs, the filing service is able to catch those plans that are not properly de-conflicted and reject them.

To establish a baseline point of comparison, was ran all of the scenarios described above with no de-confliction at all.

The combination of four flight rates, four different regions, and four airspace management strategies (including the baseline without any form of de-confliction or conflict check) yielded 64 unique configurations. To ensure statistical significance of pairwise loss of separation rate comparisons, we ran each of the 64 configurations for 120 hours. The combined simulator run time was 7,680 hours, or the equivalent of 320 days.

The simulator's analysis script counts each instance of a loss of separation and normalizes that to a rate per flight hour. As a loose proxy for the Airprox A+B ICAO metric, we also count those loss of separation events in which 25 percent or less of the required separation was maintained. Any proximity event of less than 10m is counted as a collision (recall that each vehicle has a diameter of 10m, and therefore a radius of 5m).

The results

Tukey's multiple comparison adjustment factor was used to construct an assortment of pairwise confidence intervals which were used to compare competing de-confliction methods. The method provides a simultaneous 99% confidence for all intervals for a given deconfliction comparison and a particular rate of event.

In general:
• Safety event rates for pre-flight de-confliction alone tend to be significantly less than baseline;
• Rates for the filing service alone tend to be significantly less than pre-flight de-confliction alone;
• Rates for when both pre-flight de-confliction and the filing service were enabled tend to be significantly less than scenarios with only one of those tools applied;
• Collision results at low traffic volumes were not statistically significant because of the small number of events observed.

Several observations were found using the above described deconfliction method:

- In complex airspace, a greater proportion of flights were rejected than in simpler airspace;
- This approach may be sufficient at very low traffic volumes, but even at only 100 flights per hour in a region about the size of the city of Frankfurt, loss of separation rates are 10,000 times higher than what we see today.

Conclusion

The results show that both pre-flight de-confliction and the flight plan filing service, even working together, do not guarantee a sufficient level of safety, even with 100 flights per hour in the considered area. But as a reminder, only the horizontal de-confliction measure was used.

Future work will need to emphasize four-dimensional pre-flight path planning, the implementation of one-way corridors and inflight rerouting.

A.3.8 Airbus UTM white paper: A Quantitative Framework for UAV Risk Assessment

The report [30] begins with an initial overview of risk assessment in aviation, such as through the development of a safety management system (SMS), and then goes on to explain the Specific Operations Safety Risk Assessment (SORA) methodology. Furthermore, they list an extensive list of use cases for operator interaction with this system, including: Current and future UAV operator use cases, insurance use cases, regulator use cases and air navigation service provider (ANSP) use cases.

The risk models

The main part of the paper focuses on the risk models that Airbus UTM has developed for drone operations. In the future, these models will combine to provide risk-based capacity management services.

Pre-flight risk model for present-day missions

The pre-flight model is aimed at facilitating the flight approval process for ANSPs, by providing guidance and context to understand the risk levels of planned missions. The model calculates the risk of a certain event through a series of input categories. These have been summarized below and represented graphically in the architectural diagram:

Risk of loss of control resulting in a crash or collision	Chance of fly away. Likelihood of an airborne collision. Likelihood of killing someone on the ground
• Flight location, time, duration, etc. • Vehicles make, model and performance characteristics • Operator experience • Wind and weather conditions • Vehicle maintenance • Battery performance	• RF spectrum and comms. link characteristics • GNSS coverages, obstacles/terrain that result in degraded navigation accuracy. • Historical flight track information • People density and exposure

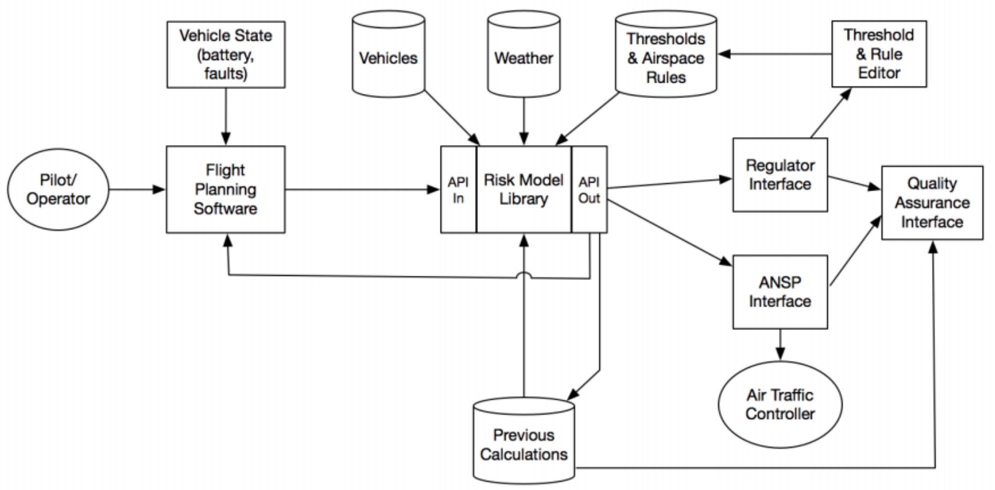


Figure 25: Schematic overview of the pre-flight risk model.

This is the most basic model that Airbus UTM proposes, aimed to be used in the pre-flight phase, but allegedly being able to handle risk calculations just before take-off. The time-horizon it will be used for will depend however on ANSP requirements for handling flight plan requests. The model itself is expected to grow in complexity as its use is more widespread. This could lead to enhancements with additional variables and shift from a purely advisory role to an automated flight approval role. Lessons learned from the development of the simple model will eventually evolve towards the comprehensive pre-flight model.

The comprehensive pre-flight model

As more data becomes available through the integration of the models into UTM ecosystems, a comprehensive pre-flight model is envisioned which takes advantage of this wealth of data. This model is to be used in a UTM environment with higher levels of process automation and will provide outputs that can be used to optimize a vehicle's route and perform deconfliction actions prior to take-off. In addition to the previously described risk factors, the comprehensive model will include the following:

Dynamic air risk calculations

- Real-time weather conditions reported from vehicles and weather stations.
- High-res mapping of terrain, buildings, obstacles and urban canyons
- Fine-grained information about the environment, land use and population density
- Communications signal availability
- Navigation reliability, GNSS availability, accuracy and local augmentation
- Surveillance coverage requirements
- Current/historical airspace usage data

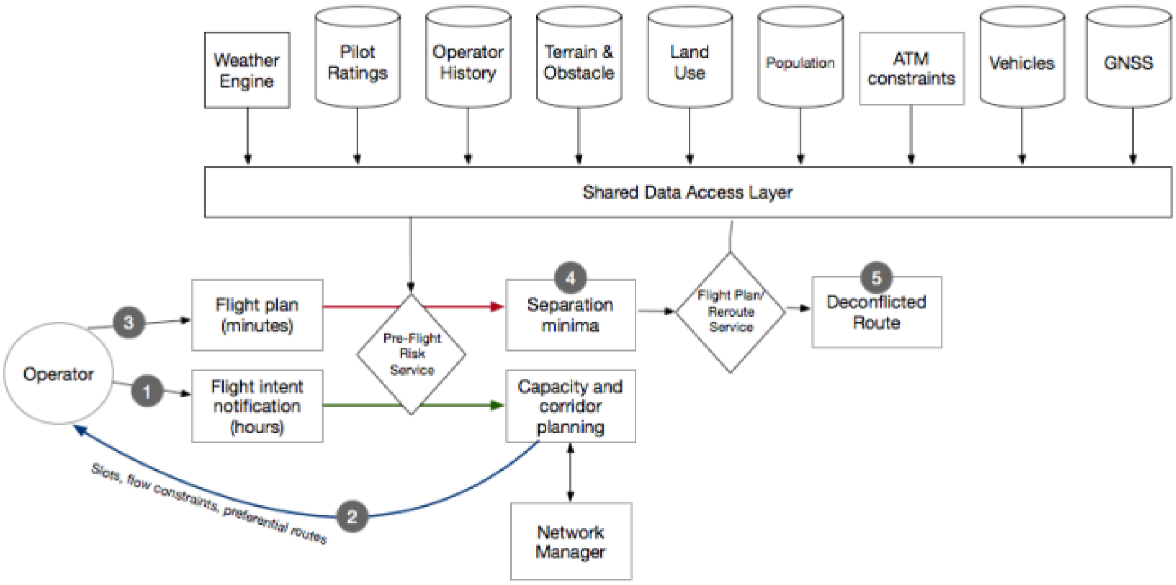


Figure 26: Schematic overview of the comprehensive pre-flight model.

This advanced pre-flight model would run on each individual flight plan, thus requiring algorithmic queries on a large variety of real-time information sources, potentially too computationally heavy for use in tactical inflight deconfliction. In order to do so in real-time, a shared data access layer needs to be established. Furthermore, it would service two types of flight planning information.

1. Flight intent submission several hours in advance:
   - Contains basic elements of the flight plan, but limited information to perform the complete risk calculation.
   - This information is enough to inform demand & capacity management services and create preferential routes and time-based slots.
2. Detailed 4D flight plan submission a few minutes before departure:
   - Contains all information relevant for a complete risk calculation.
   - This allows the risk service to perform calculations at a more granular level.

Inflight and Capacity Management Models

This model is very similar to the comprehensive flight planning model. Its use is more tailored toward a holistic airspace optimization, when hundreds of vehicles operate at any given time. The model works by combining individual risk model instances into a complete set:

- A pre-flight risk service handles factors unique to an individual vehicle and its mission and route;
- An airspace risk service looks at how the interactions among large numbers of vehicles affect total airspace risk. Its outputs affect capacity management, "corridor" management or time- or distance-based flow management;
- An inflight risk service plays a critical role in helping tactical deconfliction services decide how to resolve the inevitable inflight conflicts that will emerge. This model will feed tactical deconfliction services.

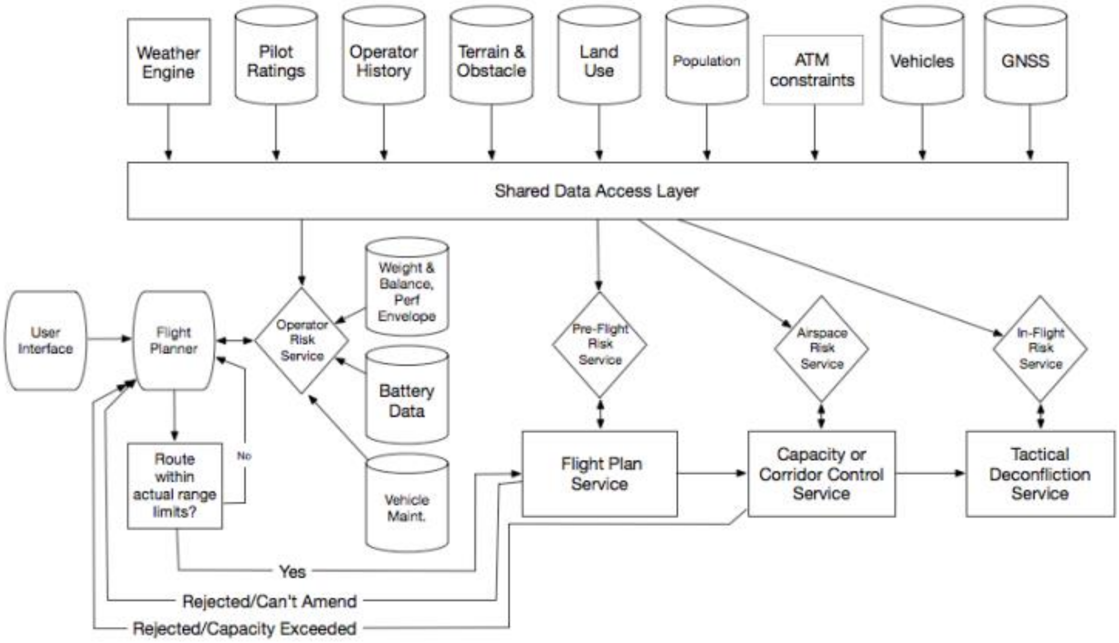


Figure 27: Schematic overview of the in-flight model.

One underlying advantage of this holistic model is that overall airspace risk can be seen as a changing surface with peaks and valleys across which vehicles fly. Well equipped vehicles may traverse "higher" parts of the surface whereas less equipped vehicles will be "pushed away" from those areas.

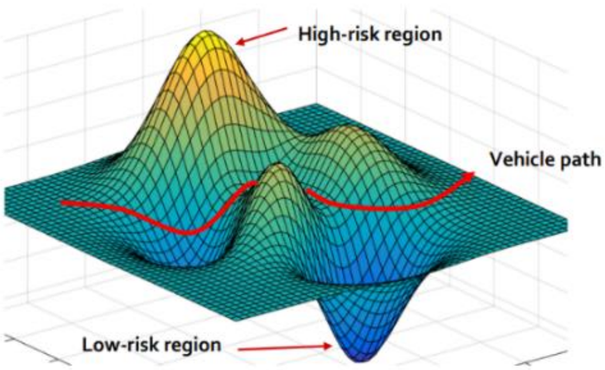


Figure 28: Graphical example of how the risk model may be navigated by a drone

A.4 UAM Concept of Operations by FAA

A.4.1 Summary

V1.0 of the Urban Air Mobility (UAM) Concept of Operations was published by the FAA on June 26, 2020. The purpose of the UAM is to create an environment in an urban area where both passengers and cargo can be transported. UAM is a subset of the Advanced Air Mobility (AMM) initiative to develop an air transportation system between local, regional, intraregional, and urban places previously not served or unserved using new aircraft. UAM focuses on urban and suburban environments.

UAM defines corridors where the drones will operate under UAM specific rules, procedures and performance requirements. The following figure shows UAM, UTM and ATM operating environments as they are proposed by the UAM ConOps.

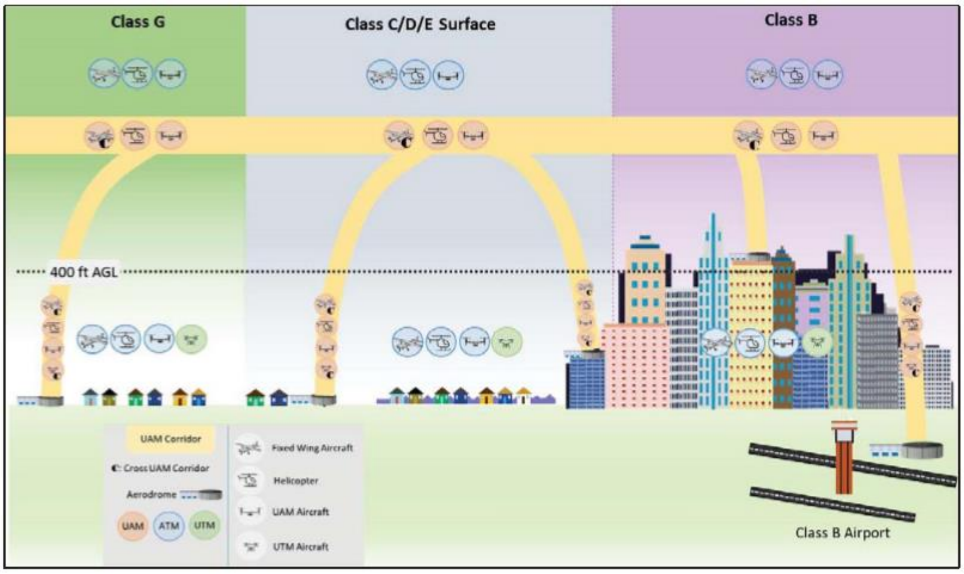


Figure 29: UAM, UTM, and ATM operating environments.

The evolution of UAM operations is characterized by these key indicators:

1. Operational tempo: density, frequency and complexity of operations;
2. UAM structure: complexity of infrastructure and services that support UAM. Structure evolves from current helicopter routing to UAM-specific corridors and associated performance requirements and procedures that reduce operational complexity;
3. UAM driven regulatory changes: regulations may evolve to address the needs for UAM;
4. UAM Community Business Rules (CBRs): This set of UAM operational business rules developed by the stakeholder community will probably augment the UAM regulations to establish the expectations of operators and Providers of Services for UAM (PSUs) which are entities that assist UAM operators with meeting UAM operational requirements to enable safe and efficient use of UAM corridors and aerodromes. These service providers share operational data with stakeholders and confirm flight intent;
5. Aircraft automation level: The evolution will be the following one:
    1. Human-within-the-Loop (HWTL);

2. Human-on-the-Loop (HOLT);
3. Human-over-the-Loop (HOVTL);

6. Location of the Pilot in command (PIC): physical location of the pilot in command.

On the other hand, the concept has illustrated a subset of UAM operations and interactions during specific nominal and off-nominal operations. The Nominal UAM use case explores a UAM operation at a high-level including operations within a UAM Corridor, strategic deconfliction and information exchanges between operators and information needs. The Off-Nominal UAM use case explores conformance monitoring and situations in which operations are non-conforming with planned flight intent, and also explores contingency situations.

A.4.2 Assumptions

- The concept assumes that UAM corridors enable safe and efficient UAM operations without tactical ATC separation. The operation starts in an UAM aerodrome (A), continues through the UAM corridor and finishes in the destination UAM aerodrome (B). Initially the corridors will connect two known aerodromes (A, B) to support point-to-point operations. As UAM operations evolve, these corridors may be segmented and connected to form more complex and efficient networks;
- DBC applies when it is not possible to support the intended demand. DCB business rules are part of FAA approved CBRs. Sometimes the excessive demand may not be due to UAM corridor capacity but due to other factors such as congestion at the aerodrome. The application of DCB will be consistent with access, equity, safety, and security;
- UAM separation is achieved via shared flight intent, shared awareness, strategic deconfliction of flight intent, and the establishment of procedural rules. The strategic deconfliction will be exercised by the PSUs while the operators will remain responsible for the safe conduct of operations including operating relative to other aircraft, weather, terrain, and hazards and avoiding unsafe conditions.

A.4.3 Potential applicability in DACUS

- The concept states relevant assumptions with respect to the UAM operations in the future. Some of these assumptions could be considered within DACUS, in particular:
  - Differences in the aircraft automation level. The level of automation will impact on the separation minima and also on the maximum number of drones which are acceptable in a certain area;
- The applicability of UAM corridors as a mechanism to increase the capacity of the airspace;
- The connection between DCB and CBRs, which implies active participation of users and providers of UAM services in the decision-making processes;
- The consideration of aerodromes as an element that can also be congested;
- The Nominal and Off-Nominal UAM Use Cases, which could be a reference for the definition of operational scenarios in DACUS.

A.5 New era of digital aviation by Airbus and Boeing

A.5.1 Summary

The objective of this paper is to showcase how UAS Traffic Management (UTM) can contribute to the safe and efficient advancement of future airspace, as well as to raise awareness on the need for new global standards and regulations to enable seamless and interoperable progress.

New aircraft will introduce an advanced mix of flight profiles and capabilities. Airspace will need to accommodate a multitude of new operations with differing performance standards and priorities. For example, small UAS and mobility vehicles in urban areas will need to be flexible in nature. Air taxis and drone delivery vehicles will increasingly fly on-demand and require a flexible traffic management system within these low altitudes.

Interoperability and compatibility are critical for stakeholders with interests in all parts of the airspace. Interoperability enables safe and efficient coordination, and directly supports the safety and efficiency needs of UTM. Compatibility means that multiple providers sharing the same airspace can coexist, without causing negative consequences for users.

The paper states the UTM principles, being safety of the key drivers. The diverse mix of new operations places additional importance on the ability to effectively calculate and manage risk for new operations with different risk profiles. New risk analysis methodologies will focus more on the type of operations (and their interactions) rather than a defined safety target for the airspace as a whole.

UTM should be designed with features like real-time safety performance data monitoring, conformance monitoring and predictive hazard analysis. Real-time risk assessment and monitoring will allow instant identification of any degradation in service provision, or conformance.

A.5.2 Potential applicability in DACUS

- The paper identifies the need of real-time risk assessment and monitoring, as well as new risk analysis methodologies, which should be focused on the type of operations and their interactions rather than on pre-defined safety target for the whole airspace.

> *Research question: Identify if the real-time risk assessment and monitoring is something to be done by the Dynamic Capacity Management service in the tactical phase.*

- The paper put the focus on the interoperability between service providers, between vehicles and operation types i.e., how entry and exit points are treated for operations that traverse multiple types of airspace and interact with multiple types of service providers, between countries or with the ATM systems.

> *Research question: Identify in Dynamic Capacity Management should be a centralized system covering a local area or a wide airspace, and the potential needs to interoperate. Maybe interaction with ATM should be taken into consideration, in particular to define the boundary conditions to enter or exit the UTM airspace.*

Appendix B Detailed analysis of influence factors on capacity and demand

This appendix provides an in-depth overview of the influence factors on capacity and demand which have been identified throughout the development of the DCB process. The information provided in this section is the result of an extensive literature review (see Appendix A) as well as a workshop with experts on specific subject areas.

B.1 Identification of influence factors

An extensive list of potential influence factors on DCB captured from literature and from results of an internal workshop are listed here.

The influence factors listed here are divided into several groups depending on the classification of their influence factor type:

- Airspace Design (AD)
- Business Model (BM)
- CNS (CNS)
- Environmental (Env)
- Geographical (Geo)
- Operational (Ops)
- Regulatory (Reg)
- Risk (Risk)
- Societal (Soc)
- Traffic (TR)

Each influence factor is provided with a quick description, its expected influence and effect on urban airspace capacity or demand, an estimation of the expected impact, a series of parameters which quantify it and a list of metrics through which it can be measured. Furthermore, each influence factor type can be split into whether the information is “Static”, essentially serving as a time-invariant boundary condition, or “Time-variant”, making it a factor worth monitoring over the course of the drone operational lifecycle.

Table 25: Overview of influence factors on U-space demand and capacity balancing

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
AD.01	Airspace Volumes	Airspace volumes to be found in VLL airspace including geographical zones.	Capacity	**The implementation of airspace volumes with a defined spatial size and limits will affect directly the capacity.** Depending on its characteristics (see metrics), the operational efficiency could increase. Efficiency is regarded as how well the airspace is utilized. This factor is time-variant, assuming that some design parameters like	H	• Size • Limits (altitude) • Service being offered. • Types of operation • Access requirements • Static restrictions • Dynamic restrictions • Weather/air conditions	• Percentage of individual airspace utilization	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				limits and size can change rapidly.				
AD.02	Route Structure	A route structure concept includes design elements like flow management, separation, conflict management, operational restriction and procedures.	Capacity	**The implementation of route structures for VLL airspaces significantly influences the capacity**. On one side it could reduce the operational efficiency but at the same time increase the operational safety. Efficiency is regarded as how many drone operators can fly as they would like to meet their business needs.	H	• Separation criteria • Operational restrictions (speed) • Equipment requirements • Applicable procedures	• Traffic flow efficiency • Number of conflicts per route structure • Percentage of drone user business needs covered	Static
AD.03	Conflict Management	The conflict management in a particular	Capacity	Conflict management will affect capacity due	H	• Service provisions of each layer	• Number of conflicts	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		airspace consist of four layers: strategic deconfliction, pre-tactical deconfliction, tactical separation provision and collision avoidance.		**to the resulting measures in conflict situations.** Effective conflict management could both increase the operational safety and efficiency.		• Connectivity between aircraft		
AD.04	Separation	Concept for keeping aircraft outside of a minimum distance from each other to reduce the risk of a Mid-Air Collision.	Capacity	The definition of separation concepts has a direct influence on capacity as it will impact the **minimum allowed spacing between drones as well as drones and manned aircraft**. Having defined separation between drones could increase the	H	• Separation minima • PBN requirements	• Number of losses of separation	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				operational safety in the airspace. Safety can be measured here in terms of loss of separations.				
AD.05	Airspace Access Rules	Rules that describe the operational practices that a pilot/operator is subject to access and follow in a particular airspace volume.	Capacity	The particular **rules valid in a certain airspace** have an influence on the capacity in the way that the operational safety of this could be increased.	H	• Entering permissions (i.e., in certain levels) • Priority schemes for using the airspace		Static
AD.06	U-space Service Availability	The number and type of U-space services provided in a specific airspace	Both	The **number and types of U-space services**, as well as **the types of U-space service providers** (USSPs) **available** will define which operations will be possible in any	H	• U-space Service type • USSP type • U-space coverage • Service performance	• Number of U-space Services per given area • Types of U-space Services per given area • Number of USSPs per given area	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				given airspace. This affects demand and capacity. **Capacity** will be affected by the types of services supporting Dynamic Capacity Management. It is expected that the **fidelity and performance of the U-space services** directly **influences the separation requirements among drones**: The higher the capability of services, the more effective the utilization of the airspace and as			• Types of USSPs per given area	

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				such the higher the capacity. **Demand** will depend on the USSPs available within a certain area of airspace. The **more USSP that service a given area**, the **more likely** it will be for **drone operators to perform specific mission types**. Reciprocally, **demand for drone services** will also **drive the number of USSPs** made available in the demanded area. This aspect is however linked to a more long-term				

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				development than the previously mentioned ones.				
BM.01	Required Flight Profile	Flight profile necessary to complete a specific mission	Demand	Certain drone **missions may be linked to a specific type of flight profile** (either for achieving mission objectives or due to flight restrictions). This affects **demand of drone** operations in certain areas given the flight restrictions or requirements associated to them.	H	• Timeframe of operation • Spatial trajectory • Mission objectives • Operating restrictions	• Number of restrictions per geographical area • Number of missions carried out per geographical area. • Types of missions carried out per geographical area	Time-variant
			Capacity	The **flight profile will also affect capacity of the airspace**. For instance,	H	• Spatial trajectory	• 4D space occupied by spatial trajectories	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				considering take-off and landing procedures, vertical take-off and landing requires less spaces than taking-off and landing with a sloped gradient.				
BM.02	Required Departure / Arrival Locations	Departure and arrival locations of the drone operations	Demand	Drone **mission completion might be linked to very specific departure and arrival points** (launch pads, airports, vertiports, etc.). The number of the points that are available as well as the number of operations from each specific point affect the demand	H	• Geographic references of departure/ arrival locations • Type of location	• Number of operations to/ from this location	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				of vehicles within a specific area.				
BM.03	Perception of Delivery Method	Public delivery points vs direct to end-destination delivery and type of delivery method	Demand	Customer is buying a product or service and is not very concerned about the method of delivery. More **demand for to the door delivery** than to a public delivery point. Not taking this into account can affect demand significantly - meaning - drone operations might be the safest and most economical	M	• Number of drone deliveries requested	• Percentage of drone deliveries out of all delivery types	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				ways to deliver a product or service, but the demand is not related to the delivery method - if no alternative method is available this might reduce demand. This factor is considered static for DCB timeframes; however, it must be considered that public perception is prone to change over time.				
BM.04	Cost vs. Volume of Business Model	High-cost low transaction (hospital deliveries) or low-cost high	Demand	If **regulations limit operations** to lifesaving or high cost / high value operations, then	M	• Service type • Cost of transaction	• Sold transactions vs avg. transaction value	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		transaction (food deliveries)		building up demand can be hard. The **types of services provided in a given area** can significantly affect demand and therefore requirements for DCB.				
BM.05	Break-Even Impact	When break-even point is hit demand increases significantly	Demand	As soon as it is common perception that drone deliveries are cheaper from both capital expense and operational expense perspectives than alternatives, a number of	H	• Capital expense. • Operational expense • Category of payload • Weight of payload	• Categorize break-even points based on weight / payload. • Number of operators in the market	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				different operators will want to enter the market. This might be different depending on payload size and ranges. **Each new category of size / payload hitting break-even will significantly increase demand and appetite for investing in capacity.** This factor is considered static for DCB timeframes, but it is noteworthy that				

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				categories will enter break even points at various times.				
BM.06	Mission	The mission that the drone flight is aiming to achieve	Both	The drone mission is an **integral part of the entire drone operational lifecycle**, and dictates how the drone must fly and when, which vehicle is to be used, how it is to be used and the payload it needs to carry. As such the drone mission has a **great influence on the DCB process as a whole**.	H	• Mission aim • Time of operation • Flight profile of operation • Vehicle requirements • Payload requirements		Static and Time-variant
Env.01	Weather conditions	Atmospheric conditions that have influence on the demand for	Demand	The presence of **weather phenomena which the general public**	H	• Spatial weather characterization • Prediction time	• Demand increase/decrease factor	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		drone services, as well as on flight safety or the efficient and effective conduct of the mission.		**perceives as "unpleasant"** (e.g., cloudy skies, rain or wind) can potentially increase the **demand for services** such as "door-to-door delivery", which may be conducted by drones.		• Prediction quality • Prediction uncertainty • Seasonal weather characteristics • Atmospheric conditions • Wind speed/velocity • Precipitation • Time of operation demand • Location of operation demand	caused by weather	
			Demand	On the other hand, **difficult or extreme weather conditions** will have substantial effect on the possibility for	H	• Spatial weather characterization • Prediction time • Prediction quality	• Number of cancelled flights due to weather • Number of drone operating	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				vehicles to fly. The expected influence of such weather on drone operations, and subsequently on demand, can be summarized in one of two means: (1) **Mission purpose cannot be fulfilled** due to weather conditions, e.g., aerial imaging in foggy environment. **Decreases spatiotemporal demand**. (2) Weather conditions exceed **the operating limitations of**		• Prediction uncertainty • Seasonal weather characteristics • Atmospheric conditions • Wind speed/velocity • Precipitation • Mission purpose • Technical capabilities of the drone • Time of operation • Location of operation • Drone operating limits related to weather	limits breached due to weather. • Number of flight plan changes per business model	

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				the vehicle. May result in a No-Go decision by the operator, which **reduces demand**. Or may require re-routing, which **shifts demand** from one region to another.				
			Capacity	Finally, the inclusion of **weather conditions into the tactical management** of drone traffic within the DCB process may also have an effect on capacity. One example could be the mitigation of risk caused by	H	• Spatial weather characterization • Prediction time • Prediction quality • Prediction uncertainty • Seasonal weather characteristics • Atmospheric conditions	• Number of separation distance changes due to weather	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				weather hazards on the traffic within an area through the use of DCB measures - e.g., **higher separation** - which would **decrease capacity** within the affected area.		• Wind speed/velocity • Precipitation • Time of operation • Location of operation • Separation specifications for given weather characteristics		
Reg.01	Legal Operational Pre-requisites	Minimum requirements for drones to operate legally within a region	Both	Regulators will specify the **pre-requisites** under which drone operations can take place (such as flight authorizations, maximum operating altitudes, operation permissions, types of vehicles	M	• Minimum operating requirements • Area of requirement applicability		Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				allowed, maximum vehicle weights, the utilization of U-space, permitted levels of autonomy). These conditions will **affect the entirety of the DCB process** and its provision within U-space.				
Reg.02	Rules of the air	Rules which drone operators must adhere to when flying	Capacity	Depending on the type of operation of any flying vehicle, specific rules of the air must be adhered to. U-space specific "**Low-level Flight Rules**" (LFR) may be put in place alongside the **general flight rules**	M	• Low-level flight rules • General flight rules		Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				applicable to all airspace users (right of way, priorities, interception, etc.) These rules will define how drones will fly, and thus have an impact on the capacity of the airspace.				
Reg.03	Spatial Flight Restrictions	Operational restrictions imposed by authorities concerning the location and altitude of drone operations.	Capacity	Regulatory aspects can limit the volumetric areas where drones are allowed to operate. These affect the capacity of the airspace. First and foremost, the airspace will need to be a **designated U-space airspace.** Then, even within	H	• Coordinates of exclusion zones. • Geographic U-space service coverage	• Number of operating restrictions per operational area	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				U-space airspace, drones may only operate outside of **exclusion zones** (public buildings, crowds, power stations, airports, prisons etc) defined by the regulator or local authority. As such, restrictions may apply in accordance with the **availability of specific U-space services and U-space airspace class definitions** within the operational area.				
Reg.04	Temporal Flight Restrictions	Operational restrictions imposed by	Demand	Similar to manned aviation, temporal operating	H	• Curfew activation times	• Number of flight restrictions	Static and

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		authorities concerning when drones are allowed to operate		restrictions may be imposed. These can be both static and time-variant. Static: **Curfews** may be put in place for assuring low drone disturbance to the general population at evening and night times, on specific days or time intervals. Time-variant: Flight restrictions at specific time intervals may be imposed on drones in case of **higher-priority operations** (public events, state-operations,		• Locations of higher priority operations and activation times	imposed due to higher priority operation	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				national security, etc.).				
Reg.05	Drone System Restrictions	Operational restrictions imposed by authorities concerning drone system functionalities and performances.	Demand	EASA classifies drones in **three main categories: "Open", "specific" and "certified"**. The types of drones subject to DCB measures will likely be of the "specific" and "certified" category. Either category may have different restrictions based on their vehicle capabilities. It is expected that **more operating restrictions will apply to drones of the "specific"**	M	• Drone vehicle category • List of restrictions per category	• Ratio of numbers of drones per category • Average number of restrictions per flight within each category	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				category than those of the "certified" category. The **severity of the restrictions** in place concerning drone capabilities will ultimately **determine the quantities of "specific" or "certified" drones** operating within a certain airspace. These may include restrictions due to: • Vehicle performance (flight envelope) • Environmental and meteorological				

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				performance limitations				
Reg.06	Standard Scenarios	Standard scenarios for UAS (Unmanned Aircraft Systems) operations in the 'specific' category.	Demand	Standard scenarios (STS) are predetermined drone flight operating scenarios that are provided so that drone operators can fly without having to wait for an operational authorisation and to harmonise drone operations throughout Europe. As such, it is expected that, especially in the short-term, **most drone operations will follow the**	L	• Air and ground risk mitigation provision • Contingency procedure definitions	• Airspace class demand per STS	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				standard scenario format, which pre-defines a set of risk mitigations. These will likely affect which type of airspace is demanded.				
Reg.07	Stakeholder responsibilities	Delegation of responsibilities and authorizations in the DCB process to different stakeholders	Demand	The structure of the responsibilities and authorizations of different stakeholders involved in the DCB process (e.g., government, cities, public safety and security agencies, USSPs, competent authority) will affect demand. Demand will be affected depending on the rigorousness and	M	• List of stakeholders and associated responsibilities/ authorizations	• Number of different stakeholder authorizations per flight approval	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				complexity of the flight permission process. The more stakeholders are involved, the more complex the process will be and thus demand might be decreased as applicants are deterred from participating in the process. As such there is a need **to minimize multi-level authorizations for flights** from various stakeholders.				
Risk.01	Third-Party Risk	The third-party risk indicates the probability that a person is fatally	Capacity	Minimizing the operational risk of fatally harming third parties (people) will be the highest priority.	H	• Mean Population Density (the most important factor) • Contingency procedures	• Probability of fatality/flight hour • Probability of collision/flight hour	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		harmed by drone operations.		**Minimizing risk through ensuring sufficient separation** is the main reason for a capacity limit. The **amount of people exposed to UAV operations** is **depending on the time of day/day of the week/time of year**. E.g., in summer, more people will be out in the open than in winter, more on the weekends than during working days, etc. This influences the third-party risk, and therefore also the capacity. It could be assumed that the **capacity**		• Shelter factor (refers to the protection of persons against drones falling over them) • CNS Infrastructure • UAV size/weight and Flight Termination System • Airspace Design • Drone Infrastructure (Landing points, etc.) • Aircraft Features/Performance • Dynamic Population Density • CNS Infrastructure availability	• Probability of collision/hour • Probability of collision/drone	

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				increases with lower third-party risk and thus less ground movement of people.		• Airspace configuration • Real Aircraft equipage (CNS, DAA…) • Drone Infrastructure availability • Emergencies & Abnormal Situations • Contingency procedures		
			Capacity	The **amount of other air traffic (manned)** also influences the capacity, meaning **the more manned traffic is expected the lower the capacity for drones** will be.	H	• Typical Traffic Mix • Real Time Traffic Mix	• Probability of collision/flight hour • Probability of collision/hour • Probability of collision/drone	
			Capacity	**Weather will increase the third-party risk**, as it	H	• Weather forecast (changing the		

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				increases the operational risk in general and thus reducing capacity.		time/day of operation) • Climate • Weather		
			Demand	Third-Party Risk can also **influence demand**, in case **the technical requirements to fly in a certain airspace** (due to high TP risk) are so stringent that many operators cannot achieve them.	M	• Aircraft equipage requirements (CNS, DAA...)		
Risk.02	UAV Features	Size, weight, dangerous load	Capacity	The **greater the dimensions, the larger the risk of lethality** in case of an UAV falling over a person.	M	• Size (LxWxH) • Weight (kg)	• Cumulative ground risk per area due to drone features	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
Risk.03	UAV Altitude	Altitude of UAV operations above ground level	Capacity	The **greater the height, the larger the risk of lethality in case** of an UAV falling over a person. The altitudes of UAV operations may also affect the **physical space available for drone operations**, and the **types of manoeuvres** they are allowed to perform, thus influencing the capacity of vehicles at various altitudes	M	• Altitude (m)	• Altitude influence on ground risk • Altitude influence on manoeuvring space • Altitude influence on manoeuvres	Static
Soc.01	Consumer Behaviour	The behaviour of consumers of drone services on the demand for services.	Demand	The consumer behaviour is the essential factor for the demand. The **economic situation** will	M	• Consumer economic situation / purchasing power.	• Number and time of requests per operational area	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				consequently influence the consumer behaviour. When people increasingly buy goods and order it via a drone service, the demand consequently will increase. The same might be true for other use cases **with increased purchasing power, people are able and willing to spend more on new and innovative services.**		• Distribution over geographical area		
Soc.02	Population Density and Distribution	The number of people potentially exposed to UAV operations and	Both	A **high population density can lead to an increasing demand**. Simultaneously in	H	• Distribution over geographical area (Persons/km2) • Location of people	• Number of requests per population density value	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		how they are spread throughout the area.		areas of high population density a **high amount of people is exposed** to the impact of a potential UAV crash, therefore **can reduce the capacity**. **Bad Weather can cause less people to be exposed** in the open, and thus reducing the third-party risk and thus increasing capacity		• Inside/ outside • Horizontal/ vertical distribution • Recreational/ business	• Probability of a person to be covered/protected. • Cell phone connections	
Soc.03	Public Acceptance	The acceptance of the public towards UAV operations	Both	A **low public acceptance will reduce or retain the demand of UAV operations**. Additionally, it **might be necessary to reduce the**	M	• Number of drone operations requested. • Public feedback on drone operations	• Public acceptance level	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				capacity to maintain public acceptance.				
Soc.04	Noise Impact	The noise emitted by drone operations will affect the local community.	Capacity	Noise mitigation procedures will affect overall urban airspace capacity due to potential **noise abatement procedures** and **operating restrictions** on **specific types of air vehicles**. The extent of these restrictions could be subject to real-time **community annoyance measurements**.	H	• Actual noise levels • Duration of operation • Ecological impact • Community annoyance feedback • Vehicle noise classifications • Number of movements • Area noise level	• Number of noise abatement procedures per area • Number of operating restrictions per area • Number of noise/ operating restrictions per vehicle type • Community annoyance feedback • Meteorological effects on noise impact • Acceptable noise level per area	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
							• Area classification	
TR.01	Complexity of the traffic.	This factor takes into account how the traffic evolves within a time span and the interrelations between a specific drone and other drones or manned aircraft.	Both	The idea of **traffic complexity is directly taken from the ATM domain**. It intends to **capture the variability and the difficulty to manage the expected traffic**, within a time span (day, hour) and in a specific area, taking into account the number of drones, their trajectories, airspace structure, air traffic flows, relative speeds, sector dimensions, etc.	H	• Height changes defined in flight plan. • Size of the area affected by the drones under consideration. • Density of drones • Number of expected vehicles. (vehicles per day/hour) • Air traffic flows • Time spans during the day (rush hour, evening, etc.) • Distribution over geographical areas. • Number of crossed areas.	• Traffic complexity and variability over time	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				This factor has a direct impact on capacity and tries to capture all the **characteristics of the flight plans directly related to the variability over time** and area of these characteristics. An operator could be **reluctant to operate** their drone(s) if the traffic situation in the area is too complex. This has an **impact on overall demand.**		• Number of geocaged flight plans over the total of flight plans. • Instantaneous traffic volume in a) specific urban areas (flow streams), b) time spans during the day (rush hour, evening, etc.)		
TR.02	Mix of Traffic	Characteristics of the drones and/or manned aircraft in a	Capacity	This factor addresses the different characteristics of all aircraft	H	• Maximum speed • Maximum Take-off Mass • Vehicle type	• Variability in safety distances assigned to drones	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		specific area and time span.		(manned and unmanned) that have planned their missions in an area. It has an impact on capacity, taking into account that great differences in the **characteristics of the involved drones/manned aircraft will increase the required safety distance among them** and it will cause a capacity reduction.		• Vehicle manoeuvrability • Variance of the MTOM. • Variance of the maximum speed. • Number of multicopters versus number of fixed wing drones. • Variance in drone capability due to on-board equipment		
TR.03	Drone Swarms	The existence of drone swarms would impact on the definition of other flight plans and trajectories within the area	Both	Once the flight plan of the swarm has been submitted, the **capacity of the surroundings is reduced due to the presence of a high**	H	• Purpose of the swarm (mission) • Number of vehicles in the swarm. • Dimensions of the swarm	• Number of swarms per area • % of area occupied by swarm	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
		affected by the swarm.		**number of drones** in the area. **Impact is higher in capacity than in demand**. If a drone swarm is defined within an area, the capacity in this area is strongly reduced due to the inherent complexity of the swarm. However, the impact in demand is lower, since the existence of swarms is established as an increase in demand, but it doesn't impact in the demand by itself.		• Swarm complexity		

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
TR.04	UAV Performances	Speed, manoeuvrability, etc.	Capacity	The **speed and manoeuvrability impact on the collision risk with other UAV and manned aircraft**	M	• Size (LxWxH) • Weight (kg)		Static
TR.05	Proximity To Manned Aircraft	Proximity to manned aircraft in the area of operation	Capacity	If UAV are **operating in the same area than manned aircraft** or very close to them, there is an **Air Risk, reducing capacity**. This factor is considered time-variant, however, may be some airspace may be static for some areas.	H	• Area of operation of manned aircraft • Position and altitude of manned aircraft • Number/Density of manned aircraft in the area	• Air risk classification	Static and time-variant
TR.06	UAV Density	Density of UAV in the area of operation	Capacity	The **larger the UAV density, the greater the risk of collision**	H	• Distance between UAV operations	• Number/Density of UAV in the area	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
Geo.01	Geographical Organization of the Urban Area	This factor is addressing how the cities are organized and how they are progressively growing in size	Capacity	Changes in the **organization and distribution of areas within and around the urban areas**, e.g., new residential areas in the surrounding, will imply changes both in the demand and the capacity. In any case, these changes take place in years and consequently, they are not dynamically impacting demand or capacity. They **can be considered boundary conditions for the calculation of both**.	M	• Urban area classification • Geographical features of the area	• Number of buildings under construction per square meter in a certain urban area. • Population density per hour of the day.	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				Impact is higher in capacity than in demand. The fact of doing new buildings or houses directly impact on the capacity because the existence of new areas with cranes that probably needs to be taken into account to deviate the traffic. On the contrary, demand increase implies that the population has changed in that area (once buildings are done).				

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
Geo.02	Geographical Location of the Urban Area	This factor is addressing the impact of the geographical area where an urban area is located.	Capacity	The geographical location, e.g., altitude above sea level, is associated with specific climatological aspects which will impact the performances of the drones operating in the area. Consequently, this could impact the separation minima standards, and thus, the capacity. This implies that the **geographical location should be taken on board to customize specific parameters included in the DCB process**.	L	• Geographical coordinates of the city. • City elevation • Drone performance envelope		Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
Geo.03	Urban Layout	The geometrical properties of urban environments.	Capacity	Large buildings, towers and narrow streets create additional obstacles which increase the collision risk. Furthermore, navigation performances can be affected in urban canyons.	M	• Three-dimensional map profile • Obstacle database • Urban canyon database		Static
Geo.04	Urban Area Classification	The classification of urban areas and associated operational limitations on drones.	Capacity	Depending on the flora, fauna or physical infrastructure present at any specific location within an urban environment, certain operating limitations on drones may exist (i.e., noise-	M	• Classification (industrial, residential, etc.) • Distribution over geographical area	• Number of operating restrictions per urban area classification	Static

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				sensitive areas). As such, a **classification system which links operating restrictions to geographical locations** may be put in place, which will affect the capacity of the airspace within those areas.				
CNS.01	Navigation Performances	Navigation accuracy, integrity, availability and continuity of service	Capacity	The navigation performances determine the ability of the aircraft to follow the planned trajectory and identify undesired deviations. In structured airspaces, **the better the**	M	• Accuracy: Horizontal (m 2Drms)/ Vertical (m rms) • Integrity: probability of exceeding the alert limit (risk per hour) • Continuity of service:	• Average navigation performance per area	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				performances, the lower the collision risk, increasing therefore potential capacity.		probability of outage (risk per hour) • Availability: probability of navigation source not operative (risk per hour)		
CNS.02	Communication Performances	Communications update rate, latency, availability and continuity of service	Capacity	The communications service is the link to provide UAV real time data (position, speed, etc.) to the U-space Service Provider and receive alerts in case of conflict. **The better the performances, the lower the collision risk, increasing therefore potential capacity**.	M	• Latency: time to receive a message (msec) • Update rate: time between communications (sec) • Continuity of service: probability of outage (risk per hour) • Availability: probability of navigation source	• Average communication performance per area	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
						not operative (risk per hour)		
CNS.03	Surveillance/Tracking Performances	Surveillance/Tracking accuracy, integrity, probability of detection, false alarm rate, availability and continuity of service	Capacity	The surveillance/tracking service allows to calculate real time drone position by the U-space Service Provider, as an initial stage to determine conflicts. The **lower the uncertainty, the lower the collision risk or required separation minima, increasing therefore potential capacity**.	M	• Accuracy: Horizontal (m 2Drms)/ Vertical (m rms) • Integrity: probability of erroneous data (risk per hour) • Probability of detection: probability of detecting a target in each update (%) • False alarm rate: probability of identifying a target which does not exist (false target/cell) • Continuity of service:	• Surveillance uncertainty per area	Time-variant

ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
						probability of outage (risk per hour) • Availability: probability of navigation source not operative (risk per hour)		
Ops.01	Skilled Workforce	Help decide the drone routes, schedule drones, etc.	Capacity	Without skilled workforce not only in flying, but also in route-planning, risk analysis, regulation and licensing, compliance and reporting, reaching capacity is hard. This factor is considered time-variant, assuming training and	L	• Nr of certified operators • Approvals / Licenses • Flight hours		Time-variant

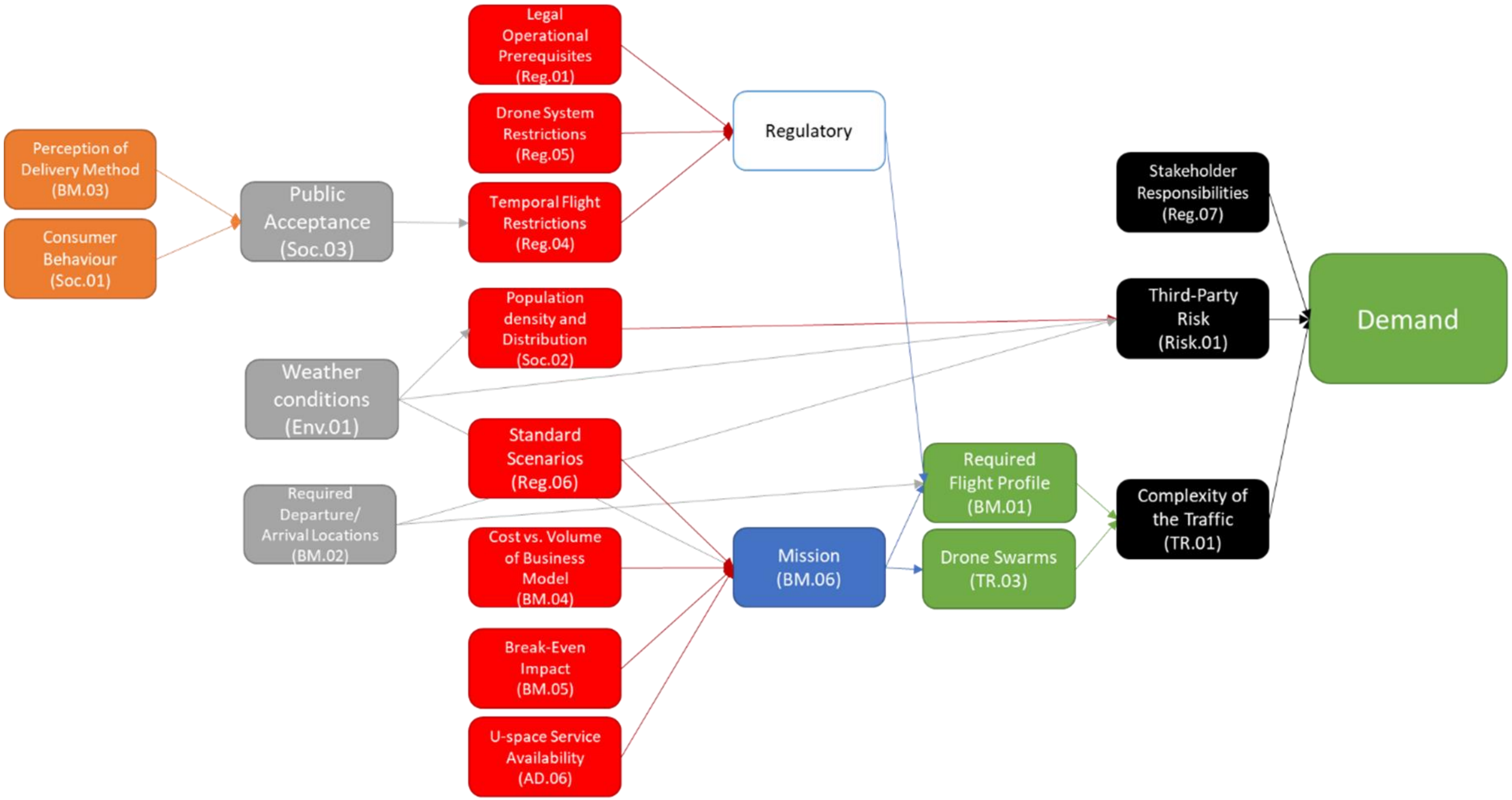
ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				experience takes time				
Ops.02	Drone port Setup	The setup of the take-off / landing area needs to be proper	Capacity	Multiple factors related to the location and actual work area around the drones affects capacity: • Right tools for maintenance • Charging facilities • Area for maintenance and safety management. • Time delay of spare parts to geographical location • Required size of take-off area (VTOL or airstrip)	M	• Drone port geographical properties • Drone port equipment • Nr of operable days per year in location. • Maintenance and staff requirements	• Time from fault to return to operation. • Max drones in flight from location. • Time from decision to first take-off • Time from last landing to close down.	Time-variant

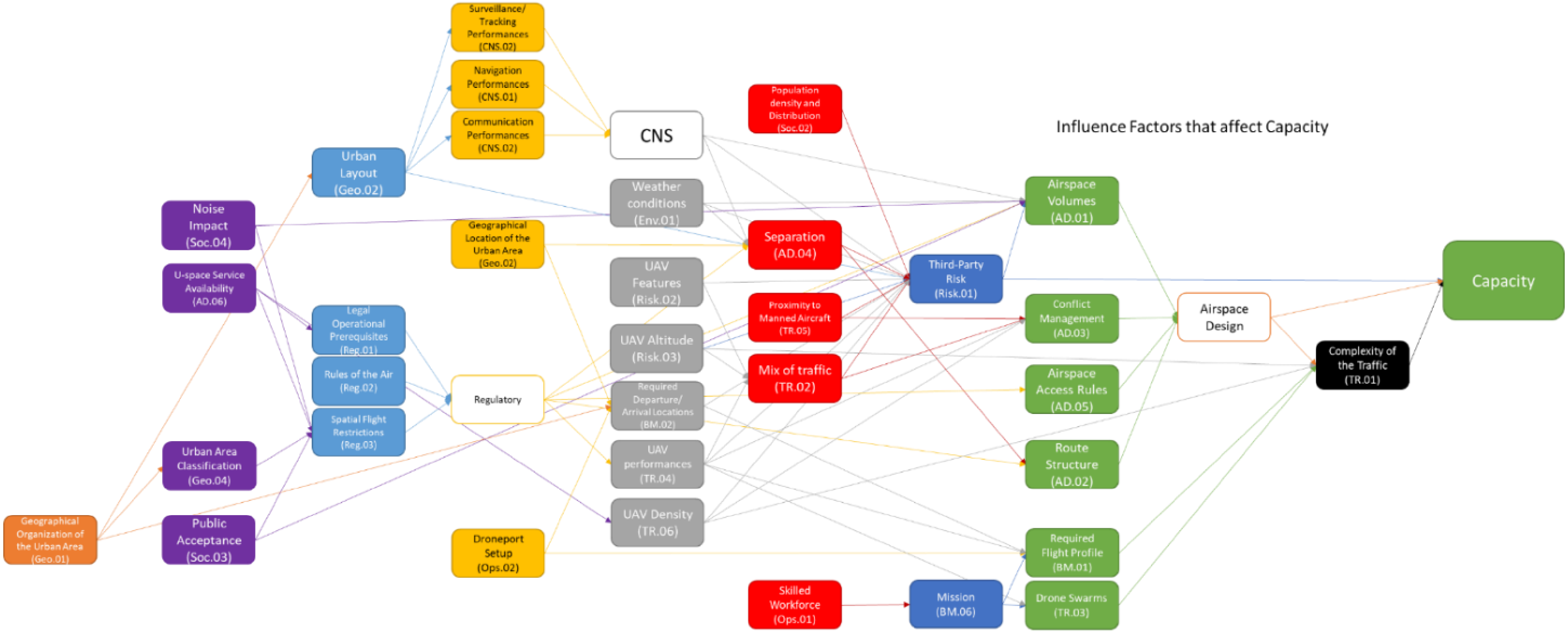
ID	Influence factor	Description	Effect on	Expected influence on DCB	Estimated impact on DCB	Parameters	Metrics	Variance
				• Necessity of landing or not • Access to maintenance knowledge • Weatherproofing location • Access to power, staff This factor is considered time-variant, assuming setup takes time.				

B.2 Interrelations between the Influence Factors

Reading the Influence Factors, it becomes apparent that there seem to be dependencies in between individual elements, as well as some hierarchical process behind them. This section graphically depicts individual dependencies between the Influence Factors and how they are organised. However, it is important to note that the links only refer to highlighted dependencies from the Table in the previous section, rather than "means-ends" relationships. Furthermore, as Influence Factors are modelled in higher detail, dependencies may change or be amplified. Each Influence Factor is a complex construct which cannot be fully graphically depicted. The images below show high-level links among the identified Influence Factors and their relation to demand or capacity.

Influence Factors that affect Demand




Influence Factors that affect Capacity
Surveillance/ Tracking Performances (CNS.02)
Navigation Performances (CNS.01)
Communication Performances (CNS.02)
CNS
Population density and Distribution (Soc.02)
Urban Layout (Geo.02)
Weather conditions (Env.01)
Airspace Volumes (AD.01)
Noise Impact (Soc.04)
Geographical Location of the Urban Area (Geo.02)
Separation (AD.04)
U-space Service Availability (AD.06)
UAV Features (Risk.02)
Third-Party Risk (Risk.01)
Capacity
Legal Operational Prerequisites (Reg.01)
Proximity to Manned Aircraft (TR.05)
Conflict Management (AD.03)
Airspace Design
UAV Altitude (Risk.03)
Complexity of the Traffic (TR.01)
Rules of the Air (Reg.02)
Mix of traffic (TR.02)
Airspace Access Rules (AD.05)
Regulatory
Required Departure/ Arrival Locations (BM.02)
Spatial Flight Restrictions (Reg.03)
Urban Area Classification (Geo.04)
UAV performances (TR.04)
Route Structure (AD.02)
Geographical Organization of the Urban Area (Geo.01)
Public Acceptance (Soc.03)
UAV Density (TR.06)
Droneport Setup (Ops.02)
Required Flight Profile (BM.01)
Skilled Workforce (Ops.01)
Mission (BM.06)
Drone Swarms (TR.03)

B.3 Influence Factor Modelling

As part of the refinement process of the original list of influence factors, a specific set of factors was selected to be elaborated in further detail. The selection of factors was linked to the expected impact on the DCB process, as well as their relevance in support of WP3 and WP5 activities. The elaboration itself was performed during a virtual workshop with subject matter experts from within the consortium. This section provides a summary of the influence factors that were refined, as well as some general comments on the models which they aim to support.

B.3.1 Demand modelling

It has been recognized that the main factor for demand model of the project could be mission types (derived from business models and their link to operational areas in urban environments), the impact of weather conditions and weather prediction.

Special focus for demand modelling was therefore placed on weather-related aspects. Prevailing weather conditions have a large influence on drone operations, but weather predictions are just as interesting to the DCB process in the strategic phase. Knowledge about weather phenomena is important at every phase of the DCB process (strategic, pre-tactical and tactical). Weather prediction will have a higher impact in the strategic and pre-tactical phases, whereas actual weather observations would affect tactical decisions.

Results from the workshop with experts also highlighted some important considerations regarding weather predictions which should be considered within the DCB process:

- The timeframe of the weather prediction model should be aligned with the DCB timeframe.
- Consider the weather picture created in the strategic phase for the decisions in the tactical phase. For instance, based on weather predictions there will be a higher implication of weather factors in certain services, like the tactical de-confliction service.
- Required prediction time for the most state-of-the-art weather models is around 6-12 hours. One month could be too difficult to predict. One week is a better starting point in the strategic phase. One-day timeframe has the most relevance for weather prediction in the pre-tactical phase.
- Technical capabilities should be matched with the weather predictions.
- Further external data sources that will feed the demand model need to be defined.

Table 26: Further details on demand modelling.

ID	**Env.01**	**Influence Factor**	**Weather conditions**	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
Factor applicability and impact on DCB	Weather prediction	Demand ()	Demand () Capacity ()	Demand (low) Capacity (low)
	Weather observation			Demand (high) Capacity (high)
Parameters	Spatial weather characterization	X	X	X
	Prediction time		X	X
	Prediction quality			
	Prediction uncertainty	X		
	Seasonal weather characteristics			
	Atmospheric conditions			
	Wind speed/velocity			

ID	Env.01	Influence Factor	Weather conditions	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
	Precipitation			
	Mission purpose			
	Technical capabilities of the drone			
	Time of operation			
	Location of operation			
	Separation specifications for given weather characteristics			
	Drone operating limits related to weather			
Metrics	Demand increase/decrease factor caused by weather			
	Number of cancelled flights due to weather			
	Number of drone operating limits breached due to weather			
	Number of flight plan changes per business model			
	Number of separation distance changes due to weather			
Sources	User-relevant data	X	X	

ID	Env.01	Influence Factor	Weather conditions	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
	Local observations			X
	Captured data from drones themselves			X
	Data from areas of high drone activity			X

B.3.2 Risk modelling

The group discussions performed during the workshop on influence factors showcased that some of the factors identified in the global list contain other factors within them as their own parameters. This particularly applies to Third-Party Risk, which was found to be rather a measure of capacity which results as a consequence of other Influence Factors.

The Influence Factors that contribute to "Third-Party Risk" are **dynamic population density (Soc.02)**, **traffic mix (TR.02) and density (TR.06)**, **weather (Env.01)**.

It is considered necessary to classify the parameters (which are really the Influence Factors) with respect to two criteria:

- Type of risk impact: Barriers (reduce Severity) & Precursors (affect Probability)
- Persistence: Scenarios (pre-existent, cannot be modified) & Contributing Factors (can be modified, for example, choosing the timeslot)

In terms of Capacity, the impact of Third-Party Risk will affect all DCB phases: Strategic, Pre-tactical and Tactical, although with different parameters. The impact of Third-Party Risk in Demand will be mostly strategic (linked to stringent technical requirements) but depending on the dynamicity of the scenario it could also affect the Pre-Tactical Phase. The metrics have to consider the individual risk of each drone (marginal risk), not exceeding certain limits, as well as the global risk in the scenario.

Results from the workshop also revolved around some important considerations concerning risk modelling for DCB in U-space:

- The DCB timeframes in U-space will be more dynamic than in ATM and the proposed timing using (D-2, D-1 and D) is not applicable. This is reflected in the tabular summary below.

Table 27: Further details on risk modelling.

ID	**Risk.01**	**Influence Factor**	**Third-Party Risk**	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
Factor applicability and impact on DCB	Third-Party Risk	Demand (medium) Capacity (high)	Capacity (high)	Capacity (high)
Parameters	Mean Population Density (the most important factor)	X (Precursor/Contributing)		
	Weather forecast (changing the time/day of operation)	X (Precursor/Contributing)		
	Climate	X (Precursor/Scenario)		
	Contingency procedures	X (Barrier/Contributing)	X (Barrier)	
	Typical Traffic Mix	X (Precursor/Contributing)		
	Shelter factor (refers to the protection of persons against drones falling over them)	X (Precursor/Scenario)	X (Precursor)	X (Precursor)
	CNS Infrastructure	X (Precursor/Scenario)		

ID	Risk.01	Influence Factor	Third-Party Risk	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
	UAV size/weight and Flight Termination System	X (Barrier/Contributing)	X (Barrier)	X (Barrier)
	Airspace Design	X (Barrier/Scenario)		
	Aircraft equipage requirements (CNS, DAA,)	X (Barrier/Contributing)		
	Drone Infrastructure (Landing points, etc.)	X (Precursor/Scenario)		
	Aircraft Features/Performance	X (Precursor/Contributing)	X (Precursor)	X (Precursor)
	Dynamic Population Density		X (Precursor)	X (Precursor)
	Weather		X (Precursor)	X (Precursor)
	CNS Infrastructure availability		X (Precursor)	X (Precursor)
	Real Time Traffic Mix		X (Precursor)	X (Precursor)
	Airspace configuration		X (Barrier)	X (Barrier)
	Real Aircraft equipage (CNS, DAA…)		X (Barrier)	X (Barrier)

ID	Risk.01	Influence Factor	Third-Party Risk	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
	Drone Infrastructure availability		X (Precursor)	X (Precursor)
	Emergencies & Abnormal Situations			X (Precursor)
	Contingency procedures		X (Precursor)	X (Precursor)
Metrics	Probability of fatality/flight hour (notice that the larger the number of drones, the greater the number of flight hours; therefore, this can be considered an individual risk)	X	X	X
	Probability of collision/flight hour	X	X	X
	Probability of collision/hour (this would be a global measure, as it increases with the number of drones)	X	X	X
	Probability of collision/drone	X	X	X
Sources	n.A. (Depending on the Factor/Parameter considered)			

Traffic complexity was also addressed during the workshop, although given time constraints not to the degree of fidelity that was given to Third-Party Risk. Conclusions showcased that in ATM complexity is related to the presence of human in the loop, but in U-space, complexity would refer to the risk of the scenario. Complexity will depend on several factors (air space structure, traffic flows, relative speeds, sector dimensions, etc.).

Complexity of the traffic is linked to risk, and therefore to capacity. Although it could also affect demand, as an operator could be reluctant to operate if the traffic is too complex. Complexity could change in the tactical phase as contingencies can change the scenario.

In terms of capacity, the impact of complexity of the traffic will affect all phases: Strategic, Pre-tactical and Tactical, although with different parameters. The impact in Demand will be mostly strategic.

B.3.3 Societal modelling

For societal modelling two influence factors have been further elaborated on. The first being the density and distribution of the population, and the other being the impact of noise.

Population density just represents the average number of individuals per unit of area or volume. Often, individuals in a population are not spread out evenly. Population distribution describes how the individuals are distributed or spread throughout their habitat. It is expected that high population density can increase demand for UAV services but at the same time the capacity can be adversely affected as higher numbers of people can be exposed to third party risk factors. Weather and seasonal variations in distribution of the population can cause less or more people to be in the open and thus have an impact on capacity.

Like observations in other areas, the time frame of the DCB phases (strategic, pre-tactical and tactical) were deemed to be too wide. Most drone missions will likely be planned and executed within a short time frame. Weather and season will impact the density and distribution of the population but mostly the time frame is much shorter than in regular air traffic. Strategic planning is mostly depending on season and weather forecast while pre-tactical and tactical planning boil down to during and shortly (1H) before the mission.

Table 28: Further details on societal modelling (population density).

ID	**Soc.02**	**Influence Factor**	**Population density and distribution**	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
Factor applicability and impact on DCB	Population density and distribution	Demand () Capacity ()	Demand () Capacity ()	Capacity ()

ID	Soc.02	Influence Factor	Population density and distribution	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
Parameters	Distribution over geographical area (Persons/km2).	X	X	X
	Location of people		X	
	Inside/ outside		X	
	Horizontal/ vertical distribution	X		
	Recreational/ business	X		
Metrics	Number of requests per population density value	X		
	Probability of a person to be covered/protected	X	X	
	Cell phone connections			
Sources	Community	X	X	
	Social media			
	Mobile network	X	X	X
	Traffic management systems		X	X
	Surveillance cameras			

ID	Soc.02	Influence Factor	Population density and distribution	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
	Survey institutions			

Noise emitted by drones will affect the local community. The noise levels will affect overall urban airspace capacity due to potential noise abatement procedures and operating restrictions on specific types of air vehicles. Day-time urban environments are noisy but public perception of drones could be a factor in the community annoyance that could warrant a real-time measurement.

Table 29: Further details on societal modelling (noise impact).

ID	Soc.04	Influence Factor	Noise Impact	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
Factor applicability and impact on DCB	Noise Impact	Demand () Capacity ()	Capacity ()	Capacity ()
Parameters	Actual noise levels			X
	Duration of operation			X
	Ecological impact	X		
	Community annoyance feedback	X		
	Vehicle noise classifications	X		
	Number of movements	X	X	
	Area noise level	X		X
Metrics	Number of noise abatement procedures per area	X		
	Number of operating restrictions per area	X		
	Number of noise/ operating restrictions per vehicle type		X	
	Community annoyance feedback	X		
	Meteorological effects on noise impact			

ID	Soc.04	Influence Factor	Noise Impact	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
	Acceptable noise level per area	X		
	Area classification	X		
Sources	Manufacturers of devices	X		
	CAA	X	X	X
	Local authorities	X	X	X
	Police	X	X	X
	Noise measuring device	X	X	X

B.3.4 Airspace design

The workshop also addressed some elements related to the design of urban airspace, which was of relevance to work package 5. Two Influence Factors related to airspace design were discussed: “Airspace Volumes” and “Route Structure”.

Concerning route structures, the main question arose around the implementation thereof, such as if the need for a fixed route structure is warranted which might potentially to be replaced by defined no-fly zones or other concepts (such as layers).

Related to airspace volumes, the main problem highlighted during the discussions with experts were the different definitions of airspace volumes in Regulation (UE) 2019/947 [31], U-space ConOps [14] and an additional definition that could be: volume over you can calculate capacity. This difference has a large impact on how drones should fly in that airspace. As reference, definitions in Reg. 2019/947 and the U-space ConOps are included here.

Table 30: Summary of definitions of airspace volumes from two different sources.

Reg. 2019/947	U-space ConOps
a. Operational volume is the combination of the flight geography and the contingency volume. b. Flight geography means the volume(s) of airspace defined spatially and temporally in which the UAS operator plans to conduct the operation under normal procedures described in point (6)(c) of Appendix 5 to the Annex[11]. c. Contingency volume means the volume of airspace outside the flight geography where contingency procedures described in point (6)(d) of Appendix 5 to the Annex are applied[12].	a. Volumes differ in two ways; the services being offered and hence the types of operation which are possible, and their access and entry requirements. Three airspace volume types are identified and referred to as X, Y and Z. All the VLL airspace is either X, Y or Z. b. The most significant difference is in the provision of conflict resolution services: i. X: No conflict resolution service is offered ii. Y: Pre-flight (“strategic”) conflict resolution is offered only

[11] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02019R0947-20200606. English version. Pages 58 and 59.

[12] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02019R0947-20200606. English version. Page 59.

Reg. 2019/947	U-space ConOps
	iii. Z: Pre-flight ("strategic") conflict resolution and in-flight ("tactical") conflict resolution are offered

Concerning the impact of airspace volumes on the DCB process, they are expected to impact both demand and capacity. In the strategic phase, demand will be affected by the parameters of the airspace volume, such as **CNS requirements**, and capacity in terms of operation planning and environment linked to the airspace volumes. In the tactical phase, contingency situations surrounding airspace volumes will affect airspace capacity.

The concept for airspace volumes itself was split into two different ideas:

1. Restrictions:
    a. Technical restrictions **(Reg.05, CNS.01-03)**
    b. Non-technical restrictions (e.g., **noise (Soc.04)**, **ground risk (Risk.01)**, fauna)
    c. Regulatory restrictions **(Reg.01-04)**
    d. Security restrictions (e.g., no flight over buildings with security limitations)
    e. Privacy restrictions **(Soc.03)** (e.g., photography and videography)
    f. Restrictions related to **weather (Env.01)** (e.g., stability of the air, turbulence)
2. Enablers: technical elements that will drive the risk model and decide the size of the airspace volume or the available capacity.

There was no consensus regarding the definition of metrics to quantify this Influence Factor. There were some ideas, such as density or number of potential coincidences in 4D trajectories (X, Y, Z and time), but the group established that it would be **necessary to define an acceptable level of residual risk** before defining some metrics for this IF.

Two different sources were defined:

1. Technology: level of automation, precision of navigation, information exchange. The technology will define the level of uncertainty.
2. Operating methods: procedures, rules of air, services offered, process workflow, etc. All these ideas will impact the level of risk. Impact will be higher in strategic phase since in tactical phase the residual problem is resolved.

Finally, some considerations relevant to U-space DCB were highlighted:

- What defines the "scope" which bounds the limits on the number of vehicles which are allowed within a certain area? (safety? noise?).
- **It is necessary to define the risk model before considering the definition of Airspace volume.** (Define layers of risk as in ATM).

Table 31: Further details on airspace modelling.

ID	**AD.01**	**Influence Factor**	**Airspace Volumes**	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
Factor applicability and impact on DCB	Airspace Volumes	Demand (medium) Capacity (high)		 Capacity (medium - low)
Parameters	Service being offered	X		X
	Access requirements	X		X
	Static restrictions	X		
	Dynamic restrictions			X
	Weather/air conditions			X
Metrics		X		
		X		
			X	
		X		

ID	AD.01	Influence Factor	Airspace Volumes	
	Element	**Strategic**	**Pre-tactical**	**Tactical**
		X		
		X		
Sources	Technology	X		
	Operating methods	X	X	X

B.4 Required data and availability.

The following tables list a series of data required to measure the influence factors which affect the models developed in DACUS. Each data point shall provide a description of the information, link to the associated influence factor, describe how it affects the influence factor, an estimate of its availability and a link to the potential sources of information of the data.

B.4.1 Demand modelling

Table 32: Data requirements for demand modelling.

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D01	Spatial weather characterization	Micro weather localized in small urban	Weather conditions	Weather within small region may have significant variations due to topographical relief	M	Local weather

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
		region within a "city-like" region.		(wind, rain…) and urban fabrics (wind…).		
D02	Prediction time		Weather conditions	This time is the application time of the prediction;	H	Meteorological services
D03	Prediction quality	Data reliability given by the weather forecasting system	Weather conditions	Prediction quality is important for the use of this prediction in our model. In this case, the most important factor of quality is the prediction continuity.	L	Meteorological services
D04	Prediction uncertainty	Precision of the weather forecasting system	Weather conditions	Prediction uncertainty has an impact on the use of the prediction.	M	Meteorological services
D05	Seasonal weather characteristics		Weather conditions	It is a statistical parameter of the weather conditions.	H	Meteorological statistics
D06	Atmospheric conditions		Weather conditions	It is a parameter of the weather conditions.	H	Meteorological services
D07	Wind speed/velocity		Weather conditions	It is a parameter of the weather conditions.	H	Meteorological services
D08	Precipitation		Weather conditions	It is a parameter of the weather conditions.	H	Meteorological services

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D09	Mission purpose		Mission	Mission purpose is dependent the kind of drone used. It gives also information of the mission characteristics probability (location, time).	L	Demand study (no available data)
D10	Technical capabilities of the drone		Mission	Technical capabilities of the of the mission purpose it can be used for.	M	Manufacturer data
D11	Time of operation	Time and duration of operation	Mission	It is a characteristic of the mission.	L	Demand study (no available data)
D12	Location of operation	Initial and target location of operation, eventually waypoints	Mission	It is a characteristic of the mission.	L	Demand study (no available data)
D13	Separation specifications for given weather characteristics		Mission		L	
D14	Drone operating limits related to weather	Limit of weather conditions under which a	Mission	Drone operating limits related to weather will affect the mission feasibility.	M	Manufacturer data

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
		drone can operate.				

B.4.2 Risk modelling

Table 33: Data requirements for risk modelling.

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D15	Mean Population Density	Mean population density in a certain place	Third-Party Risk	Third-party risk is directly proportional to the population density. Once the UAV has fallen, the probability of impact with a third party depends on the population density.	H	Several Sources e.g., https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download
D16	Weather forecast	Prediction for the time/day of operation	Third-Party Risk	Bad weather conditions increase the chances of damage to third parties as there is a greater probability of collision with another aircraft or failure of the system itself. Once it happens, the lack of visibility can cause it to be difficult for third parties to spot the drone. However, on the other hand, good weather conditions can cause more people to be outside in the streets	H	Meteorological services
D17	Climate		Third-Party Risk	Climate would determine the likelihood of bad weather conditions in a certain month of the year, and so the potential risk of uncontrolled operations.	H	Meteorological statistics

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D18	Contingency procedures		Third-Party Risk	Contingency procedures would reduce the third-party risk, providing safe alternatives in case of emergency	L	Local Regulations
D19	Typical Traffic Mix	Drones' features: type (multirotor, fixed wing), size, speed, etc.	Third-Party Risk	The bigger the drones and the greater theirs speeds, the larger the collision risk and the impact on people on the ground,	M	Statistics and Demand predictions
D20	Shelter factor (refers to the protection of persons against drones falling over them)		Third-Party Risk	The higher the sheltering factor, the lower the third-party risk, as the likelihood of a person being struck by a drone would be lower	M	Topographical data (e.g., https://land.copernicus.eu/pan-european/corine-land-cover/clc2018)
D21	CNS Infrastructure		Third-Party Risk	Proper performance of CNS systems would reduce the risk of failures, collisions, etc, it is it would reduce the third-party risk.	L	Nominal GNSS performance values can be taken from the Performance Reports, e.g.: https://www.gps.gov/systems/gps/performance/ or https://www.gsc-europa.eu/electronic-library/galileo-service-performance-reports

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
						or https://egnos-user-support.essp-sas.eu/new_egnos_ops/documents/field_gc_document_type/monthly-performance-report-84 But for other services (e.g., LTE) they are not easy to obtain
D22	UAV size/weight and Flight Termination System		Third-Party Risk	The characteristics, configuration and performance of the aircraft would determine how much damage it can cause. A termination flight system like a parachute can considerably reduce the risk to third parties.	H	Information proportionated by the operator/manufacturers and considered in the models
D23	Airspace Design		Third-Party Risk	The design of the airspace would determine the probability of collision with other aircraft.	M/H	Local Regulations
D24	Aircraft equipage requirements (CNS, DAA…)		Third-Party Risk	Aircraft equipage requirements would determine how safe the operation is, as they can reduce the collision risk.	L	Local Regulations
D25	Drone Infrastructure		Third-Party Risk	Robust infrastructures would contribute to safe operations reducing the third-	L	

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
	(Landing points, etc.)			party risk, as they will limit the potential sites for landing and take off		
D26	Aircraft Features/Performance		Third-Party Risk	The aircraft features/performance would determine, at first instance, how secure it is flying. On the other hand, if a collision/failure had already occurred, the performance of the aircraft would be determinant in the severity of damage to third parties.	H	Information proportionated by the operator/manufacturer.
D27	Dynamic Population Density		Third-Party Risk	It is essential to calculate the third-party risk in real time. Thus, the authorisation of the flights would be more secure.	L	Complex population density models. High computer load.
D28	Weather		Third-Party Risk	Quality real-time information would allow to adjust the operating conditions to the circumstances, allowing to reduce third-party risk	M	Meteorological services
D29	CNS Infrastructure availability		Third-Party Risk	Quality real-time information would allow to adjust the operating conditions to the circumstances, allowing to reduce third-party risk	L	
D30	Real Time Traffic Mix		Third-Party Risk	Quality real-time information would allow to adjust the operating conditions to the circumstances, allowing to reduce third-party risk	M	

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D31	Airspace configuration		Third-Party Risk	Quality real-time information would allow to adjust the operating conditions to the circumstances, allowing to reduce third-party risk	M	AIP, NOTAM
D32	Real Aircraft equipage (CNS, DAA…)		Third-Party Risk	Quality real-time information would allow to adjust the operating conditions to the circumstances, allowing to reduce third-party risk	L	
D33	Drone Infrastructure availability		Third-Party Risk	Quality real-time information would allow to adjust the operating conditions to the circumstances, allowing to reduce third-party risk	M	
D34	Emergencies & Abnormal Situations		Third-Party Risk	Emergencies and abnormal situations would provoke changes in operating conditions (trajectories, schedules…). These last-minute changes would affect the risk to third parties as they are not the predicted conditions.	L	
D35	Contingency procedures		Third-Party Risk	Contingency procedures would provoke changes in operating conditions (trajectories, schedules…). These last-minute changes would affect the risk to third parties as they are not the predicted conditions.	L	Local Regulations

B.4.3 Societal modelling

Table 34: Data requirements for modelling social influence factors.

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D36	Distribution over geographical area (Persons/km2).	Mean population density in a certain place	Population density and distribution	It the population density.	M	
D37	Location of people	The arrangement, or spread, of people living in each area.	Population density and distribution	Location of people gives population distribution.	L	
D38	Inside/ outside	Whether the population is more likely inside or outside	Population density and distribution	The inside/outside parameter affects population distribution and how it can perceive drone flight. The visual and noise impact is bigger if people are outside.	L	
D39	Horizontal/ vertical distribution	Population distribution within the 3D space, including buildings height.	Population density and distribution	The highest people are localized, the more they are affected by drone flights.	L	

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D40	Recreational/ business		Population density and distribution	The recreational/business parameter affects population distribution and how it can perceive drone flight. Roughly, the visual and noise impact is bigger if people are doing recreational activities.	L	

B.4.4 Airspace design

Table 35: Data required for airspace modelling.

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
D41	Service being offered	Available U-space services per volume	Airspace Design	Capacity / Traffic Density / Operating Constraints / Traffic Management Need	H	U-Space Concept of operations; later: EASA
D42	Access requirements	Technical and operational restrictions to receive allowance to enter an airspace volume	Airspace Design	Capacity / Traffic Density / Transit Traffic Management / Demand	H	U-Space Concept of operations; later: EASA
D43	Static restrictions	General restrictions that are permanently	Airspace Design	Capacity / Traffic Density / Traffic Mixture / No-Fly Zones / Take-off and	H	National Aviation Authorities

ID	Data type	Description	Ass. IF	Expected impact on associated IF	Estimated availability	Source
		in place for a volume		Landing Zones / Corridors & Routing / Demand		
D44	Dynamic restrictions	Adaptive restrictions that can change over time and on demand	Airspace Design	Capacity / Traffic Density / Traffic Mixture / No-Fly Zones / Take-off and Landing Zones / Corridors & Routing / Operational Timeframes	H	National Aviation Authorities NOTAMs AIP
D45	Weather/air conditions	Weather conditions that turn into additional restrictions	Airspace Design	Capacity / Traffic Density / Traffic Mixture / No-Fly Zones / Take-off and Landing Zones / Corridors & Routing / Operational Timeframes / Demand	M	Local and Accredited Meteorological Service National Aviation Authorities

Appendix C DCB concepts from previous U-space projects

C.1 U-space CONOPS

The concept of operations for U-space describes the **Dynamic Capacity Management** service as the core element which defines when an airspace is deemed “full”. The CONOPS does not go on to specify the definition of “fullness”, other than that it will be related to a loss of safe separation as well as other characteristics of the airspace. Dynamic Capacity Management is to be invoked only when necessary (i.e., the airspace is declared “full”) and will aim to resolve DCB imbalances built on concepts such as “reasonable time to act” (RTTA) and priority. The details of the inner workings are not detailed in this section, but rather its links to other U-space services. According to the U-space CONOPS, the Dynamic Capacity Management service is invoked by the Drone Operation Plan Processing service only if the airspace requires it and is fed 4D probabilistic trajectory models to solve imbalances. The Drone Operation Plan Processing service is the means through which drone operators will interact with the wider U-space ecosystem and be informed of conflicts.

Conflict management involves several processes; however the core elements rely on Strategic and Tactical Conflict Resolution services. The former encompasses the process of detecting and resolving conflicts before the flight takes place, the latter during flight execution. **Strategic Conflict Resolution** is provided with probabilistic 4D trajectories by the Drone Operation Plan Processing service and examines them to identify pairs which have a reasonable probability of infringing separation minima. Once identified, the service will apply a set of viable solutions to resolve the conflict from a predefined list of options which are then proposed to the operator for resubmission. **Tactical Conflict Resolution** will make use of a real-time common airspace picture to identify and resolve real-time conflicts. It will use track data to predict losses of separation and provide advice or instructions to drone pilots to change their speed, level or heading as necessary. To make better predictions it should use aircraft flight envelope and characteristics models as well as be provided with drone operation plan information. As such it is a client of the Tracking service, Drone Operation Plan Processing service and the Drone Aeronautical Information Management Service. In the case that the Tactical Conflict Resolution service fails, on-board “Detect and Avoid” systems should be utilized as a back-up.

The image below depicts the services that directly affect the Dynamic Capacity Management and Conflict Resolutions services as well as 2nd-level links to prior services.

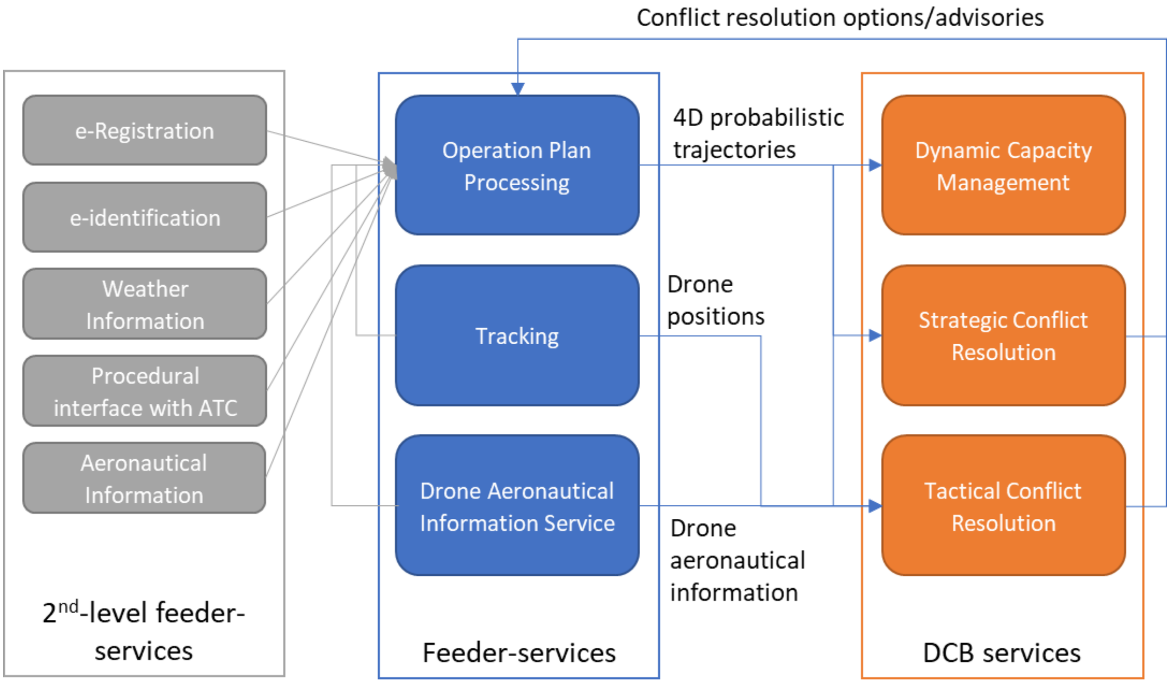


Figure 30: Schematic overview of service interactions of DCB services in the U-space CONOPS.

C.2 IMPETUS

The SESAR Exploratory Research project IMPETUS dealt primarily with the realization of drone information management based on microservices. The microservice architectural style is a dynamic and highly flexible way to develop a single application as a suite of small, independent and specialized services [42]. Given this focus, the project made some assumptions on the U-space architecture and service interactions within. This summary will focus on the interactions foreseen by the IMPETUS project on the **Dynamic Capacity Management** and **Deconfliction** services (i.e., Conflict Resolution services in the U-space ConOps terminology).

The project developed its assumptions around a federated architecture, in which safety-critical services related to the management of traffic (such as Dynamic Capacity Management and Deconfliction) would be overseen by a central authority. The gateway of this authority to the individual flight plans of the operators is through the Flight Planning Management service (i.e., Drone Operation Plan Processing service in the U-space ConOps terminology) which communicates with external U-space Service Providers [43].

Functionalities of the **Dynamic Capacity Management** service were directly tested in a series of simulated experiments, with the focus on testing architecture related challenges (such as scalability, reliability and failure modes) as well as service-relevant advancements beyond the state of the art. Dynamic Capacity Management will be active during planning and tactical phases. It interacts with the **Strategic and Tactical Deconfliction** services to limit the number of drones in each airspace. IMPETUS experiment results showed that these limits were predominantly dependent on the deconfliction services' abilities to resolve conflicts [39]. This means that the definition of airspace capacity for U-space, from a purely technical standpoint, would likely be linked to service performance rather that other external factors.

The novel aspects of the **Tactical Deconfliction** service specifically revolve around the application of dynamic separation criteria which adapt the size and shapes of the safety buffers around drones. These criteria are essentially a list of weighted parameters based on information about drone characteristics, flight plans and missions, priorities with respect to other drone flights, whether or not they are controlled by a human operator as well as knowledge of CNS coverage in the area of operation and weather observations. The higher the weight of each parameter, the larger the safety buffer and thus the higher the separation criteria of the drone. This information is to be provided by a series of services, which are schematized below.

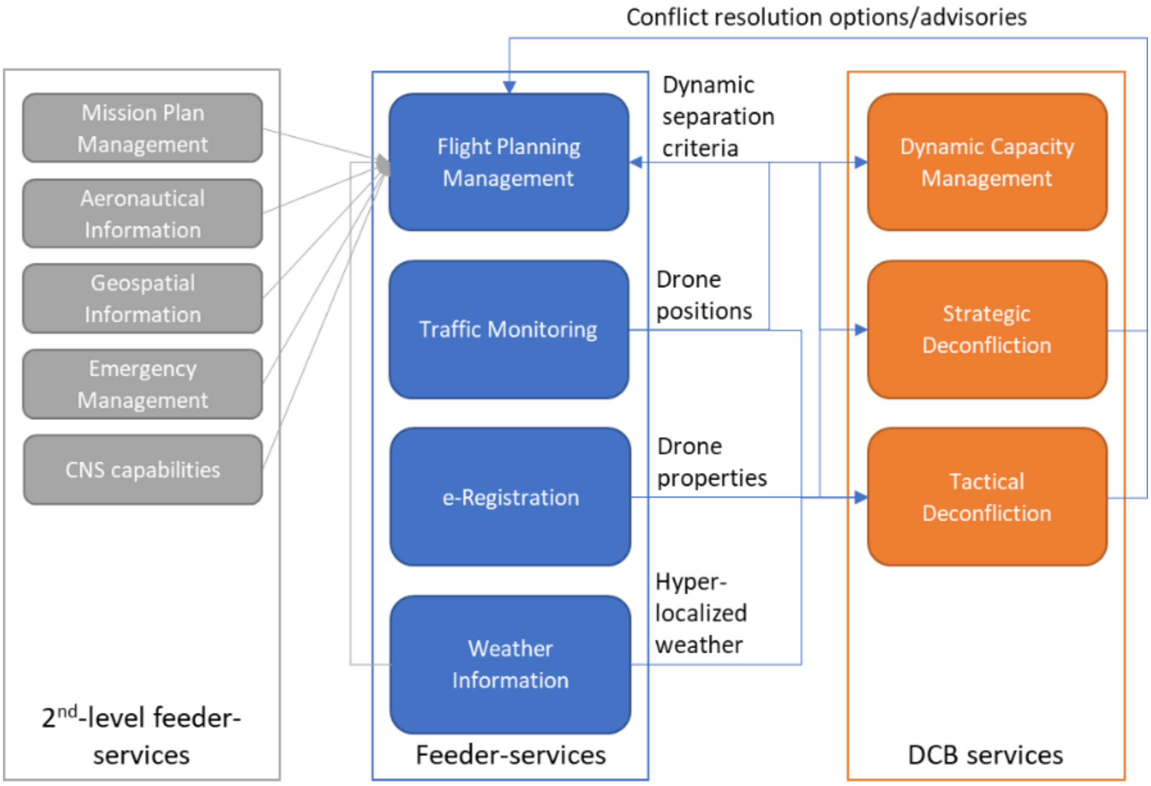


Figure 31: Schematic overview of service interactions of DCB services in IMPETUS.

C.3 DREAMS

DREAMS was an exploratory research project with a similar aim as IMPETUS, focusing on information management for drones. As part of their work, the consortium published a document outlining a series of scenarios which include capacity management and managing deconflictions [44].

Capacity management processes were exemplified through autonomous drone delivery routes within urban airspace. Like the IMPETUS approach, DREAMS defined a centralized controlling role for overseeing drone flights called the “U-space controller”. For every flight authorization, the U-space controller would request a capacity check from the Flight Planning Management service, which would be forwarded to the **Dynamic Capacity Management** service. If capacity is reached, the Dynamic Capacity Management service proposes an adequate time slot for the flight, and forwards it to the Flight Planning Management service, which in turn forwards it to the U-space controller. When the drone then takes off, Dynamic Capacity Management is notified and stores its flight plan for future reference.

Deconfliction management was showcased around the use case of a temporary restriction affecting a drone delivery mission in-flight. The Flight Planning Management service would work together with the **Strategic Deconfliction** service to identify any active flight plans affected by the restriction. The Strategic Deconfliction service then recalculates flight plans for all affected flying drones. Noteworthy here is the utilization of the Strategic Deconfliction service for tactical flight decisions involving flight restrictions. The **Tactical Deconfliction** service on the other hand was only specified to be used for resolving conflicts between vehicles. The document does not go on to specify the reason for the preference of the Strategic Deconfliction service over the Tactical Deconfliction service for this purpose. The Flight Planning Management service the requests flying users to change their flight plans accordingly or propose viable alternatives.

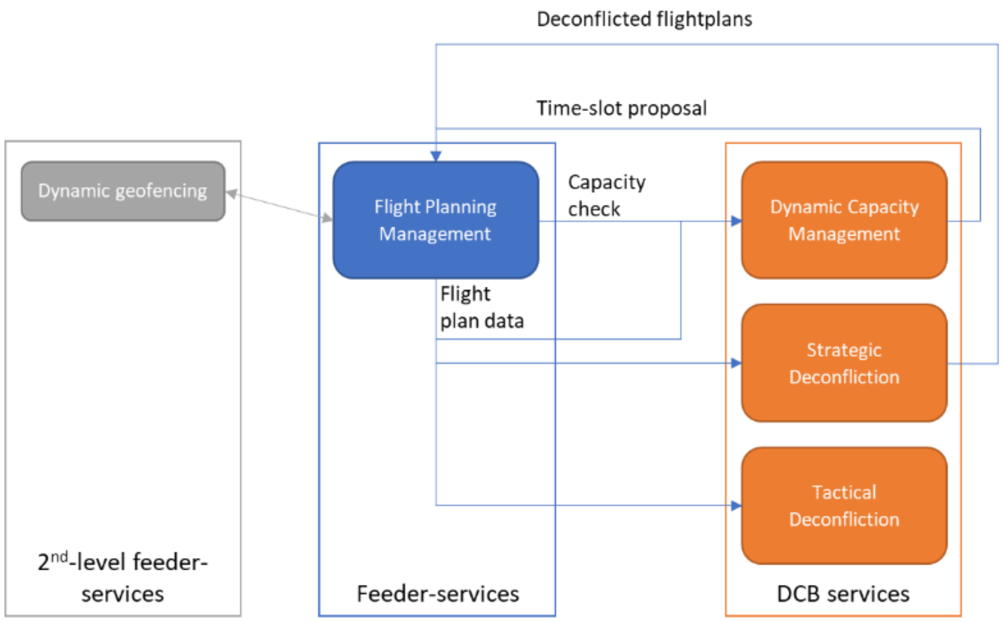


Figure 32: Schematic overview of service interactions of DCB services in DREAMS.

C.4 DOMUS

The DOMUS project was a very large-scale demonstration project for U-space. As part of the demonstration activities, several U-space services were developed and their interactions among them defined. This section highlights the services involved in demand and capacity management within the DOMUS demonstration architecture, which were – for validation purposes – limited to Strategic and Tactical Deconfliction.

The **Strategic Deconfliction** service identifies conflicts among the flight plans that it receives from the Flight Planning Management service as soon as it receives a request to do so. Conflict detection considers spatial and temporal conflicts among previously approved flight plans, as well as infringements of authorized access to airspace, airspace structure rules and restrictions. Therefore, it requires a link to Flight Planning Management as well as the Drone Aeronautical Information Management services. Conflict among drone flights is initially resolved by checking the flight priority levels [45] – higher priority flights will not be altered. Those flights that are subject to altering will receive variations on trajectory, time, altitude or volume. Deconflicted flight plans are then sent back to the Flight Planning Management service.

The **Tactical Deconfliction** service ensures safe separation of drones when flying, by checking for potential collisions from traffic data provided by the Traffic Monitoring service and calculating resolution to avoid conflict. Furthermore, information provided by the Tactical Geofencing service allows the Tactical Deconfliction service to evaluate eventual conflicts between inflight drones and geofences. Conflict resolutions are sent to the Traffic Monitoring service to be forwarded to the drone operator.

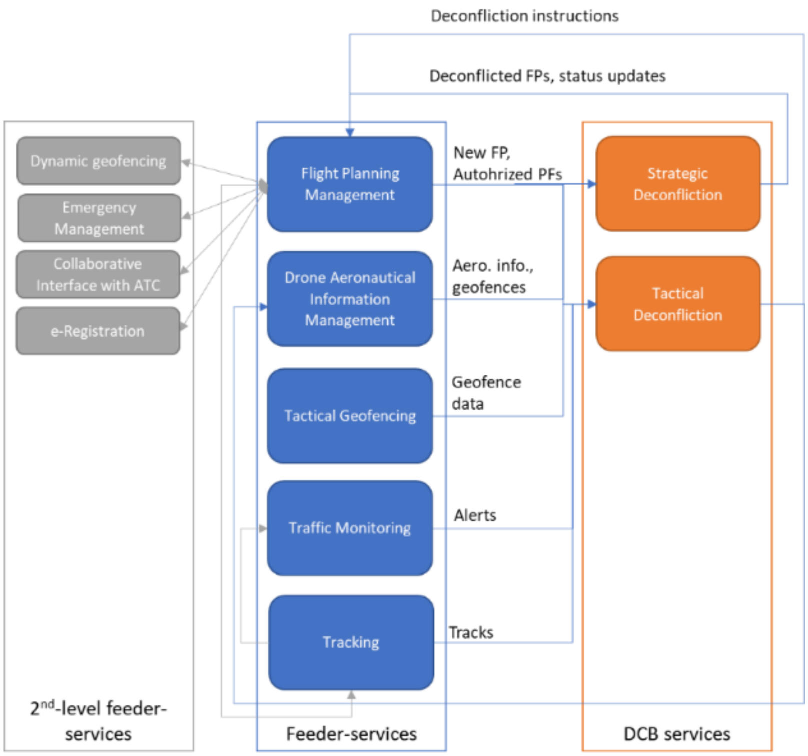


Figure 33: Schematic overview of service interactions of DCB services in DOMUS.

C.5 SAFEDRONE

Although not specifically addressed in the project, some conclusions on service interactions related to demand and capacity balancing were extracted from the documentation of the SAFEDRONE demonstration project.

The **Strategic Deconfliction** service receives flight plan data from the Flight Planning Management service and checks them for any overlap in all three dimensions within a specified period. Any overlaps are registered and sent back to the Flight Planning Management service for processing.

The **Tactical Deconfliction** service is in charge of identifying conflicts among drones and no-fly zone infringements with information received from the Monitoring service and returns appropriate alerts to be forwarded to drone operators.

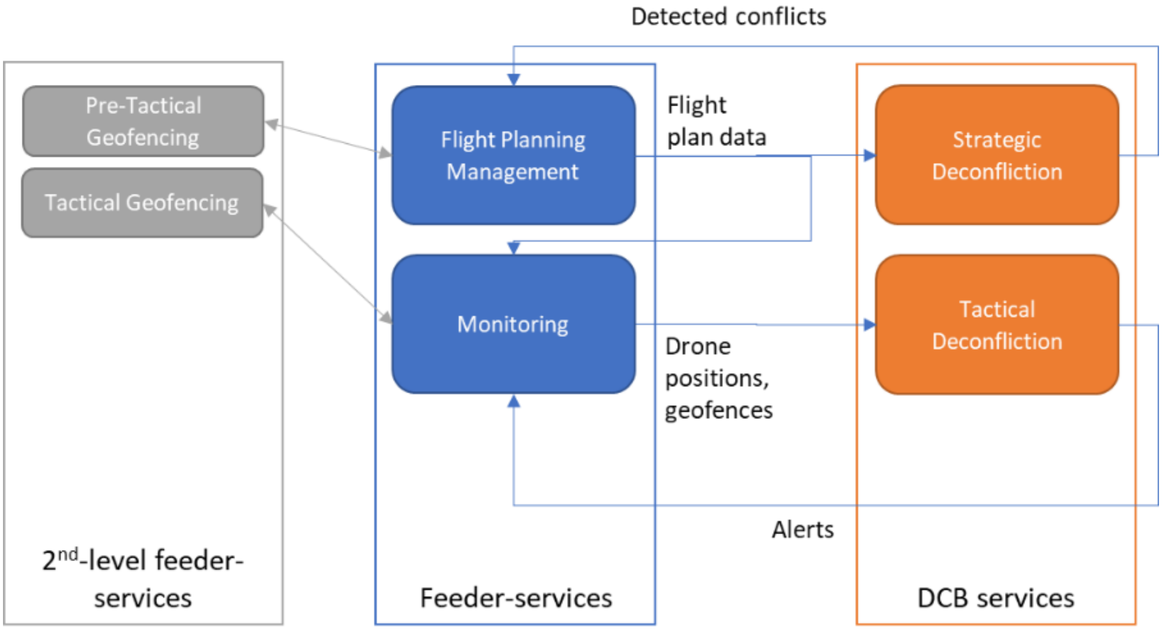


Figure 34: Schematic overview of service interactions of DCB services in SAFEDRONE.

Appendix D Overview of UAS capabilities

This appendix 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 Aerial Vehicle (UAV) – and its supporting Ground Control Station (GCS) as well as the capabilities of U-space Services and Air Traffic Services.

D.1 UAV capabilities

This section will describe the capabilities of a generic drone (UASV based on its elements and how they can affect to the Demand and Capacity Balancing process. The figure below shows the main elements of a UA.

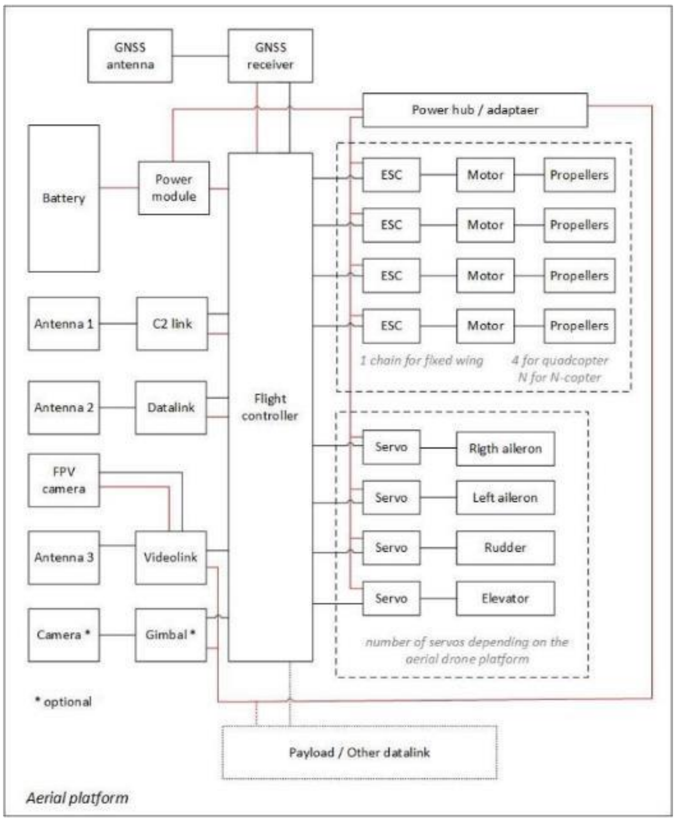


Figure 35: Typical elements comprising UAS.

The table below describes typical drone components and provides assumptions on their impact on the DCB process.

Table 36: Impact of general drone characteristics on the DCB process.

Component	Description
Aerial Platform	The structure that integrates the rest of the elements that make up a drone. There are five main types of aerial platform: • fixed wing, • multi rotor, • single rotor, • fixed-wing hybrid VTOL and • tethered drones.
Motor	Although there is the possibility of using gas-powered motors (especially in single rotor platforms), most drones use electric motors.
Electronic Speed Controller (ESC)	Electronic Speed Controllers connect the flight controller and the electric motor (each brushless motor requires an ESC). The ESC takes power from the battery and receives signals from the Flight Controller (with information about pilot's order) and makes the brushless motor spin.
Propellers	Propellers transform rotary motion into linear thrust. Drone propellers provide lift to the aircraft by spinning and creating an airflow, which results in a pressure difference between the top and bottom surfaces of the propeller. This accelerates a mass of air in one direction, providing lift, which counteracts the force of gravity. Propellers for multirotor drones are arranged in pairs, spinning either clockwise or anti-clockwise to create a balance. Varying the speed of these propellers allows the drone to hover, ascend, descend, or affect its yaw, pitch and roll.
Servomotors	An electrical device that rotates with high efficiency and great precision. Moreover, the output shaft of this motor can be moved to a particular angle, so they can define the required orientation of the flight controller surfaces.
Flight Control Surfaces	In fixed wing platforms (including fixed-wing hybrid VTOL), there are three main components in the drone airframe for its control. They are the ailerons, the rudder and the elevator, which control the roll, pitch and yaw, respectively.
Battery	The battery of a drone provides power to all its components. Although some drones can use gas (like single rotor platforms), most of them use electric batteries. The most popular are the Lithium-Polymer (LiPo) batteries, because they are generally robust and lightweight, which is important for a drone.
FPV Camera	First-Person View (FPV) camera is a device used to control a drone by the pilot showing what a pilot on board would see. This camera is usually integrated in the drone's platform and sends images to video link for its transmission to the pilot screen. This screen could be integrated in FPV glasses.
Gimbal	A gimbal is a support system that allows an object to remain horizontal regardless of movement around it. Drone gimbals keep an object in the same orientation regardless of drone movement.
Payload	Payload is the weight that a drone can carry. It is usually counted outside of the drone's weight and includes anything additional to the drone's general components: such as cameras (not FPV), sensors, microcontrollers, additional data links, or packages for delivery.

The next sections provide more detail on the most relevant drone components related to its remote control and positioning capabilities as well as navigation, communications and surveillance data provision. Each subsection concludes provides an overview of the expected influence on the DCB process.

D.1.1 Flight Controller

The most important elements of a flight controller are described below. Although they are presented separately, normally a Flight Controller (FC) has these elements integrated in the same device (in a single board), especially in commercial drones. However, it can be common for the GNSS receiver to be external to the flight controller.

- **Inertial Measurement Unit (IMU):** is an electronic device that measures and reports acceleration, orientation, angular rates, and other gravitational forces. It is composed of three (3) orthogonal accelerometers, three (3) orthogonal gyroscopes, and depending on the heading requirement – three (3) orthogonal magnetometers. That is to say, one per axis for each of the three vehicle axes: roll, pitch, and yaw.

    - **Accelerometers**: measure the velocity and acceleration of the drone.
    - **Gyroscopes**: physical sensors that detect and measure the angular motion of an object relative to an inertial reference frame.
    - **Magnetometers**: sensors used to determine the strength or direction of magnetic fields to provide bearing.

  Depending on the FC, the IMU will send this data to the FMU for processing or to an AHRS or INS system for pre-processing.

- **Attitude and Heading Reference System (AHRS):** An electronic device that acts as a motion sensor. It contains an IMU (3 gyroscopes, 3 accelerometers, and 3 magnetometers) and **adds a Central Processing Unit (CPU)** that embeds estimation filters (e.g., Extended Kalman filter). This allows to calculate highly reliable attitude and heading relative to magnetic north, in addition to roll, pitch, and yaw.

  AHRS can be connected to an external GNSS receiver to improve its performance. Indeed, GPS-aided AHRS delivers additional navigation. Usually, the system is then renamed Inertial Navigation System.

- **Inertial Navigation System (INS):** This electronic device combines:

    - An Inertial Measurement Unit (**IMU**). Can have more than one unit.
    - A **microprocessor** (CPU) that runs an enhanced on-board estimation filters to fuse in real-time inertial data with GNSS and other aiding information (odometer, Doppler velocity log, etc.)
    - An **internal or external GNSS receiver** for Navigation based on position data and velocity.
    - An **internal data logger** if the system data are to be used after operation (e.g., surveying applications)

- **Flight Management Unit (FMU)**: A real time component that reacts to inputs from inertial sensors (IMU/AHRS/INS), GNSS navigation source (if do not use an INS) and others (e.g., air speed, pressure sensors). In addition, it can include communications channels and act upon input from the pilot, through C2 link, or follow a flight plan, uploaded via datalink.

With all this information, FMU will control the ESC, servomotors and other devices (e.g., gimbal) to perform the flight according to the orders received (by pilot or flight plan).

- **GNSS receiver:** As seen, the GNSS receivers can be external or integrated in the INS sensor or in the FMU unit. This receiver is responsible for providing navigation information to the Flight Controller (FC) obtained from Global Navigation Satellite Systems, like GPS, GLONASS or Galileo among others and Augmentations (SBAS, etc.). Section 5.4 provides further details on the analysis of these receptors and their capabilities.

D.1.2 Communication

The command and control (C2) link between the drone and the pilot depends on the communication capability of the drone; the main link is provided by the C2 link. In addition, it is possible to use other technologies for drone communication, like cellular networks.

- **C2 Link**: The 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). By far the most 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** alternates the carrier frequency in a pseudorandom hopping sequence. The transmitter and receiver must be synchronized and use the same hopping algorithm to maintain the connection.
  - **DSSS** occupies a fixed, very large bandwidth, although it decreases the spectral power density to such an extent that the wanted signal is barely above the noise floor and can only be retrieved by using a precisely matching demodulator.

  The two methods, which are sometimes also used in combination, are perfect for the heavily used unlicensed bands, where many user and radio technologies must coexist.

  On 2.4GHz band, the maximum range is **typically 1km**. On 5.8GHz band, this value will be lower (higher frequency). Nevertheless, the range of C2 link will be dependent on a few factors:
  - The output **power** of transmitter (pilot radio control): many run just below the legal maximum to be compliant with international standards (usually **less than 500mW**).
  - The **sensitivity** of the receiver: the signal will travel further the higher the sensitivity of the receiver is; however, it may receive more noise under certain conditions.
  - The quality of the **antennas** at both ends: Antennas with higher gain and optimum placement will make a big difference in C2 link performance.

  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
- Malicious spoofing/link takeover

- **Command and Control over cellular networks**: This solution proposes connecting the drone (Flight Controller) to the mobile network and uses mobile connectivity for command and control.

Table 37: Overview of cellular network parameters.

	3G		4G		5G
Standard	HSPA	HSPA+	LTE	LTE-A	Undefined
Frequency bands (in Spain)	900MHz		800MHz		700MHz
	2100MHz		1800MHz		3500MHz
			2600MHz		26GHz
Channel Multiplex	FDD or TDD	FDD or TDD	FDD or TDD	FDD or TDD	FDD or TDD
Channel BW	5MHz (Single carrier)	10MHz (Dual carrier)	1.4MHz to 20MHz	1.4MHz to 100MHz	Up to 100MHz
MIMO	No	MIMO 2x2	No	MIMO 4x4 (UL) MIMO 8x8 (DL)	mMIMO (massive MIMO)
Theoretical data rates	< 5.76Mbps (UL) < 14.4Mbps (DL)	< 28Mbps (MIMO UL) < 42Mbps (MIMO DL)	< 75Mbps (UL) < 300Mbps (DL)	< 1.5Gbps (UL) < 3Gbps (DL)	< 20Gbps
Expected data rates (max)	< 2Mbps (UL) < 7.2Mbps (DL)	< 5.7Mbps < 21.6Mbps	< 50Mbps (UL) < 100Mbps (DL)	< 500Mbps (UL) < 1Gbps (DL)	> 100Mbps (guaranteed)
Latency	< 150ms	< 100ms	< 50ms		1ms (theoretical)

D.1.3 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 (see section – 5.1), to provide more robust drone navigation solutions.

Thus, leaving INS aside, the navigation capability of the drone depends on the Global Navigation Satellite Systems (GNSS) signals and the GNSS receiver's performance:

- **GNSS signals**: GNSS infrastructure allows users with a compatible device to determine their position, velocity and time by processing signals from navigation satellites providing global coverage. There are **four constellations** available today (two of them in the final phase of full deployment), and all offer free global access to their signals:

- **GPS**: The **US** GPS Standard Positioning Service (SPS) is a positioning and timing service provided by way of ranging signals broadcast at the GPS L1 frequency. The 31 constellation satellites (24 nominally) through a Coarse/Acquisition (C/A) code-ranging signal transmits this frequency, that contains a navigation data message for civil use. Currently a new frequency band (L5) is being added to new satellites (13 of them for the moment)
- **GLONASS**: It is the **Russian** GNSS constellation. Unlike GPS and the other GNSSs, GLONASS uses Frequency Division Multiple Access (FDMA) rather than Code Division Multiple Access (CDMA) for its signals' transmission. Its space segment consists nominally of 24 operational satellites, distributed over three orbital planes.
- **Galileo**: It is the **European** GNSS constellation. Currently its constellation of 30 satellites is not fully deployed but providing initial services. By offering **dual frequencies as standard** (E1 and E5), Galileo is set to deliver better real-time positioning accuracy than others GNSS systems.
- **BeiDou**: It is the **Chinese** version GNSS. The BeiDou Space Segment consists of a constellation of 35 satellites: 5 GEO satellites, 7 IGSO satellites and 21 MEO. To benefit from the signal interoperability of BeiDou with Galileo and GPS China announced the migration of its civil B1 signal to a frequency centred at 1575.42 MHz (like GPS L1 and Galileo E1).

The performance of Global Navigation Satellite Systems (GNSSs) can be improved by regional Satellite-Based Augmentation Systems (SBAS), such as the European Geostationary Navigation Overlay Service (**EGNOS**), which provides an augmentation service to **GPS** (L1 and L5):

- **SBAS**: This service improves the accuracy and reliability of GNSS information by correcting signal measurement errors and by providing information about the status of the constellation's satellites.

Finally, the following table resumes all information about the performance parameters of these GNSS system (and EGNOS augmentation):

Table 38: GNSS signal performances.

Service (one freq. band)	Accuracy	Availability [percentage]	Integrity [probability] (1)	Continuity [probability] (2)
GPS	<9m 95% (H) <15m 95% (V)	>99%	$1e^{-5}$	≥0.9998
GLONASS	≤7.8 m 95%	>98%	$1e^{-4}$	≥0.998
Galileo (3)	≤4 m 95% (dual frequency tests)	≥99.99% in tests	No data	No data
BeiDou	<10m 95% (H) <10m 95% (V)	>95%	No data	≥0.995
SBAS (EGNOS v2)	<3m 95% (H) <4m 95% (V)	>99% of time	$1e^{-7}$	$>1e^{-2}$

1. Probability of exceeding the tolerance per hour. With RAIM: Receiver Autonomous Integrity Monitoring. Except EGNOS v2.
2. Probability of an outage per hour
3. Not fully deployed. Data of Performance report Q1 2020 with estimations based on real measurements with dual frequency.

- **GNSS receivers**: The market leader for usage in drones is **Ublox** because the cost-effectiveness, the power efficiency, the small size of its receivers and their compatibility with Pixhawk FCs. According to its own data, it is estimated that it has around an **80% share** in this market.

Table 39: GNSS receiver performances.

Model	Constellations	Pos. accuracy (1) [3DRMS]	Vel. Accuracy (2) [RMS]	TTFF(3)
Ublox M8P	GPS, GLONASS, GALILEO, BeiDou, SBAS	<6.25m	<0.022m/s	<26s (cold) <1s (hot)
Septentrio AsteRx-i S UAS	GPS, GLONASS, GALILEO, BeiDou, SBAS	<2.52m	<0.05m/s	<45s (cold) <1.2s (hot)
Trimble UAS1	GPS, GLONASS, GALILEO, BeiDou, SBAS	<5m	<0.02m/s	<45s (cold) <2s (hot)
Novatel OEM7600	GPS, GLONASS, GALILEO, BeiDou, SBAS	<3.15m	<0.03m/s	<39s (cold) <0.5s (hot)
ST Electronics Teseo-LIV3F	GPS, GLONASS, GALILEO, BeiDou, SBAS	<4.5m	<0.012m/s	<32s (cold) <1.5s (hot)
Furuno GN87	GPS, GLONASS, GALILEO, SBAS	<6.25m	No data	<33s (cold) <1s (hot)

4. GPS (L1) – Horizontal
5. Maximum value between Vertical and Horizontal
6. Time To First Fix. It could be cold, when device is turn on; or hot, when device realises a re-acquisition.

Some GNSS receivers allow **RTK solutions**. Real Time Kinematic (RTK) is a differential GNSS method able to provide real time positioning corrections near a base/reference station. The service can be offered by public authorities (e.g. IGN), private providers (e.g. Trimble, Novatel) and in-situ own base stations (e.g. connected to the drone GCS). The coverage of this service will depend on the coverage of the technology through which corrections are sent. That is, it will depend on whether the corrections are transmitted:

- From **satellites**: very good coverage.
- Through the **cellular network**: good coverage in urban and semi urban environments but could not be enough in rural zones.
- By a **base station**: coverage limited to the range of the station link (usually 1-2km)

RTK is a highly accurate technology, reaching cm accuracies. The following table indicates the GNSS receiver performance using RTK solutions.

Table 40: GNSS receiver performances with RTK.

Model	RTK	Offered via	Pos. accuracy [3DRMS]	Initialization time (1)
Ublox M8P	Yes	RTK rover and base	>0.0625m (H) No data (V)	< 60s

Model	RTK	Offered via	Pos. accuracy [3DRMS]	Initialization time (1)
Septentrio AsteRx-i S UAS	Yes	RTK rover and base	>0.0126m (H) >0.0210 (V)	< 7s
Trimble UAS1	Yes	Trimble RTK services and OmniSTAR. (Payment)	>0.008m (H) >0.015m (V)	< 8s
Novatel OEM7600	Yes	TerraStar Global Services and RTK ASSIST. (Payment)	>0.0525m (H) >0.1050m (V)	< 18m
ST Electronics Teseo-LIV3F	No	N/A	N/A	N/A
Furuno GN87	No	N/A	N/A	N/A

1. Depends on the required accuracy.

Finally, it should be noted that the **GNSS receiver must be compatible with the Flight Controller** (FC). For example, the Pixhawk FCs are compatible with Ublox receivers (M8P and FP9 among others) and some Trimble receivers.

D.1.4 Surveillance

It is very important that both the pilot and the UTM system always know the location of the drone. This is critical in environments where there is high drone traffic demand and, especially, close to ATM airspace. Surveillance can be classified in two main groups:

- **Cooperative**: They **depend on the capabilities of the drone**, since they require an on-board device to assist in their location or the use of any of the drone's systems. The most used techniques are:
  - **Datalink**: This system uses a radio-frequency transmission to transmit and receive information to and from the drone. These transmissions include location, remaining flight time, distance and location to target, distance to the pilot, location of the pilot, payload information, airspeed, altitude, and many other parameters. This link can be included in Command and Control (C2) link (2.4GHz or 5.8GHz bands), or it can be used an independent link in the **433 KHz** frequency (Europe).
  - Like C2 link, 433 KHz datalink operates with powers less than or equal to **500mW**, that allows operation ranges of a **few kilometres** (depending on the sensitivity of the devices). In general, non-commercial drones use this link because it provides a greater range than C2 link, because of its lower frequency. However, commercial drones usually simplify the communications on the Command and Control link.

    Datalink is a technology for **local surveillance**. It is the most extended tech for drone surveillance.
  - **Telemetry detection**: These systems are passively listening to the unlicensed frequency bands used for C2 links, searching for drone communication links (mainly 2.4GHz and 5.8GHz). **Knowledge of the commercial drone communication protocols** allows collecting information such as the type of drone, position, flight status, routes and other information,

in real time. In addition, some of these systems can take the drone control through communication supplanting.

Telemetry detection is a technology for **local surveillance**. It is used for survey critical infrastructures (e.g. an airport).

- **Surveillance over cellular network**: As in the case of communications, cellular networks can be used for drones' surveillance. If the drone can integrate a small modem, it will allow **sending all the information of the Flight Controller (and other sensors) via cellular network (5G/4G/3G)**. With this technology, BVLOS operations and UTM surveillance could be implemented easily and safely in VLL space. In addition, the pilot will have a more robust and long-range link to monitor its operations.

  Surveillance over cellular network is a technology for local and **wide area surveillance (in VLL space)**. Today it is beginning to be implemented experimentally.

- **ADS-B**: Automatic Dependent Surveillance – Broadcast (ADS-B) is a system by which an aerial vehicle can share position, velocity, and other information by Mode-S 1090MHz link. **ADS-B periodically transmits its state vector**, which includes horizontal and vertical position, and velocity. The system is broken down into two separate components: "ADS-B Out" and "ADS-B In". The transponder mode is the "ADS-B Out" portion which broadcasts all state vector information. The receiving part of the system is "ADS-B In" which receives communication from other aerial vehicles, and it can be integrated in an aerial vehicle for situational awareness.

  ADS-B is a technology for **wide area surveillance**. Currently it is not very common in drones yet.

- **Non-cooperative**: They do **not depend on drone's capabilities**. These technologies are used for local surveillance at critical infrastructures (e.g. an airport).

  - **Drone RADAR**: This technology works analogously to the PSRs (Primary Surveillance Radar) used in ATM surveillance: targets' horizontal position is determined by the reception of the echoes generated in the target due to pulses transmitted through a narrow beam.

  - Frequencies of drone RADARs are higher than civil PSRs ones, typically in the X and Ku (from 8GHz to 20 GHz) bands. This is due to the drones' size, much lower than aircrafts' size, which requires a **shorter wavelength for detection**. The measure of a target's ability to reflect radar energy, or Radar Cross Section (RCS), is related to this concept, being necessary to adapt RADARs to detect small RCS.

  - **Direction Finding and RF sensors**: Unlike drone RADAR, Direction Finding (DF) is a passive technique based on Radio Frequency received signals analysis that enable determination of direction or location of signals from the drones and/or pilots. RF sensors only detect the signals transmitted between the drone and the Ground Control Station (GCS).

Three techniques allow determining the **Angle of Arrival (AoA)** of the interest signal (for drone tracking: C2 link transmissions) and estimating the emission source: TDOA (Time Difference of Arrival), phase interferometry and amplitude comparison.

To calculate the drone position, it is necessary to obtain two or more AoA of different DF sensors, and apply triangulation and power measurement methods.

- **EO/IR and acoustic sensors**: These sensors are not usually a surveillance system by themselves. Commonly, they are part of another surveillance system (drone RADAR or Direction Finding sensor) to increases its performances and/or capabilities.

  EO/IR (ElectroOptical/InfraRed) cameras can be integrated into surveillance systems to provide situational awareness, visual/thermal classification and visual/thermal recording. Video (EO) and thermal (IR) analysis allow distinguishing drones from aeroplanes, birds and other moving objects. This is very complementary to Direction Finding surveillance systems or drone RADARs without Doppler analysis.

  Acoustic sensors can listen for the high-pitched frequencies emitted by drones, their motors and propellers. Analysing the specific noises from the drones, an acoustic sensor can give short-range classification of a drone. This makes these sensors very useful in areas with low visibility, as it is very difficult to mask the noise of the drone motors.

D.2 GCS capabilities

This section will describe the capabilities of a generic GCS. The main elements are shown in the following figure:

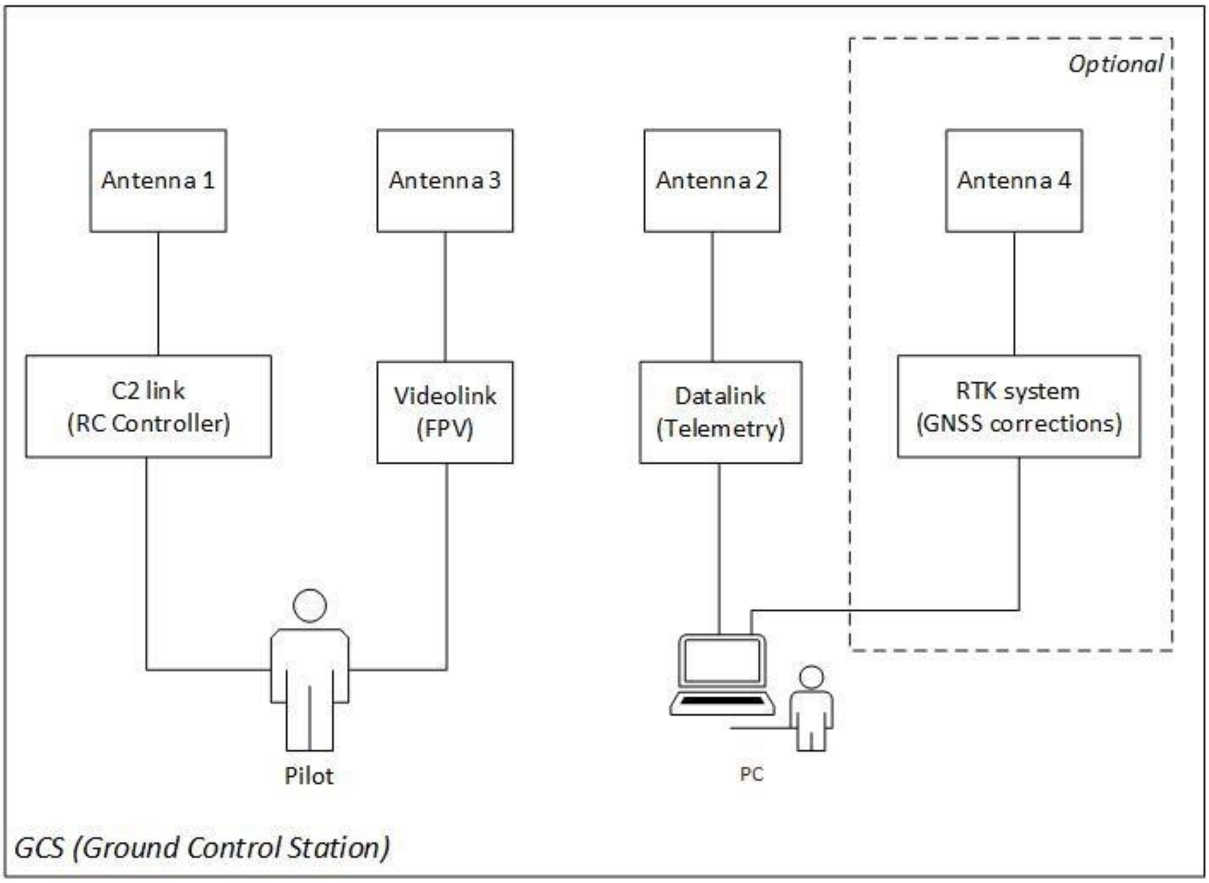


Figure 36: Main elements of a ground control station (GCS).

- **RC Controller-C2 Link**: A RC controller-C2 link system is made up of two elements, the transmitter you hold in your hands and the receiver inside the drone. The transmitter is integrated on RC controller, which controls the movement of the drone through its sticks' movement:

  RC Controller C2 transmitter will read the stick inputs and send them through RF signals (**usually 2.4GHz**) to the receiver in near real time. Once the receiver gets the information, it passes it on to drone's Flight Controller (FC) that makes the drone move accordingly.

- **Video link**: The FPV drone camera sends video data through a video link. This link operates on unlicensed bands, generally **in 5.8GHz** due to the higher bandwidth to transmit video with good resolution. In the GCS, the pilot can view the video with a FPV monitor or FPV glasses, thus increasing the situational awareness.
- **Datalink**: It provides the GCS the information about the drone's position and its status. This link can be used on the **433 KHz** band or directly from the C2 link (2.4GHz). To display position and status data, a PC with compatible HMI software connected to the datalink receiver are required. Mission Planner is the non-commercial software more frequently used for this propose. The following image shows its HMI:

Figure 37: HMI of a mission planning software.

In addition, with this software it is possible: to load Flight Plans, to change drone settings and to configure additional options, like RTK system (see section 5.3). For this option, the RTK base stations must be connected to the GCS's PC.

Appendix E DCB processes in ATM

E.1 Capacity enhancement in air traffic management

In air traffic management, predominantly two types of capacity resources exist: **airport capacity** and **airspace capacity**. The size of either capacity is determined by the baseline (declared capacity) in combination with dynamic factors.

E.1.1 Definition of the declared capacity

Declared capacities are determined through a rigorous capacity assessment process. This process can be summarized loosely in the following manner:

Table 41: Definitions of declared capacity of airports and airspace.

Airport Nominal Capacity	Airspace Nominal Capacity

• Each runway configuration receives its own capacity determination.
• The capacity is determined by the **runway occupancy time**.
• The runway occupancy time is influenced by:
    ○ The number of high-speed taxiways
    ○ Intersecting runways
    ○ Adequacy of runway to specific aircraft types
    ○ Complexity of surface operation
• Nominal capacity should be used as reference for long-term strategic planning
	• Nominal airspace capacity is initially dependent on:
	    ○ Type of surveillance used
	    ○ Type of communication used
	    ○ Equipage of aircraft
	    ○ Airspace design
	    ○ Type of operation
	• The capacity definition is performed in one of two ways. The first built around the **average time of an aircraft in a sector**, which is multiplied by the **average time a controller dedicates to each aircraft** to determine the final capacity value.
	• A more sophisticated method utilizes **historical operational data** divided into various operational categories. The ratio of each category alongside the average workload per type defines the sector capacity.

E.1.2 Improvement of the declared capacity

Several means and concepts to increase the declared capacity exist, and are summarized in the table below:

Table 42: Initiatives to improve the declared airspace capacity.

Initiatives to improve Declared Airspace Capacity		
Route-network Design	**Sector Design**	**ATC Staff**

Initiatives to improve Declared Airspace Capacity		
• **Design of the en-route and terminal manoeuvring area (TMA) routes network** to fit several factors such as traffic complexity, operational procedures, performance-based navigation (PBN) operations, ATC sectors' design and joint management of traffic volume with adjacent ATC units. • **Delegation of national airspace and sectors** to other ATC units. Specifically useful for countries with oddly-shaped borders. • **Definition of Free-route Airspace**, so that airspace users can plan the most efficient route for their needs. • **Implementing Point Merge Systems at airports** to optimize runway intercepts and descents by utilising a common merge point and several predefined legs, each equidistant from the merge point. The legs are used for path stretching or shortening to smooth peak load (simultaneous arrivals) upstream of the individual legs.	• **Adaption of en-route sectors to common traffic structures** by varying their numerosity, their shapes and vertical separation. • **Implementation of Dynamic Airspace Sectorization** to make sector arrangements adaptable to actual traffic complexity. This is performed by splitting sectors vertically depending on the traffic load throughout the day. This technique also uses dynamic virtual volumes to modify the sector shape (and hence capacity) in accordance with traffic flows, moving weather or other dynamic factors "on-the-fly".	• **Consider human factors issues** related to the re-definition of airspace design and operational procedures. • **Define controllers' operational roles and interactions**, such as assigning a dedicated role for arrival coordinations or multisector coordination roles for clusters of sectors.
ATC Procedures	**Military Operations**	**Automation Systems**
• **Runway optimization** of mixed mode runway operations, prioritizing departures or arrivals	• **Close coordination between military and the ANSP** to assure that most of the military training activities remain within the	• **Targeted use of air traffic management automation systems** to reduce controller workload and improve sector capacity.

Initiatives to improve Declared Airspace Capacity		
depending on demand during a given peak. • **Minimum authorized spacing** between aircraft on final approach to assure that capacity is not wasted. • **Time-based separation on final approach** dynamically adjusts the separation between arrivals and reduces approach separation during strong headwind conditions. • **Speed control and the definition of standard speeds** improves efficiency and removes unpredictability for pilots and controllers. • **Assignment of arrival runways to specific flights** depending on their parking stand or airline preferences. • **Aircraft-specific standard instrument departures,** assigning aircraft to type-specific and diverging tracks as soon as possible after departure.	limits of temporary segregated areas. • **Utilization of the Flexible Use of Airspace concept** allows preparation of a daily airspace use plan at pre-tactical level. Capacity of an airspace is increased when military areas are used for civil purposes.	• **Synchronization of ATM and ATFCM** to avoid multiple delay assignments to a flight. • ATM automation systems should be **fully integrated into the airport CDM process.** • **Support of a comprehensive exchange of information** among internal and external components of the automation systems.

Table 43: Initiatives to improve the declared airport capacity.

Initiatives to improve Declared Airport Capacity		
Runway/Taxiway Design	**Parking Stands**	**Air traffic controller factors**
• **Optimization of capacity influencing factors**, including number and layout of runways, separation requirements imposed by the ATM system, mix of movements using the runway and type and location of runway exits. • **Building a new runway** is the most impacting way to improve airport capacity. • **Initiatives to reduce runway occupancy time**, such as rapid exit taxiways, rapid access taxiways, multiple line-up aprons and bypass taxiways (avoiding runway crossings). • **Low-visibility systems**, such as improved instrument landing systems, runway/taxiway lighting and high-fidelity weather reporting systems.	• **Minimize 'cul-de-sac' effect** so as not to inhibit movement of other aircraft when vacating the stand. • **Remote holding areas** to allow freedom of movement on surface areas, runways and taxiways and freeing up stands. • **Holding bays** can hold aircraft to allow others to bypass on last minute changes on the departure sequence.	• **Enforce proper training and facilitate buy-in** of controllers to new operating procedures is crucial. • **Provide a clear definition of controllers' operational roles and interactions.** • **Wake turbulence grouping of arrivals and departures** with the same wake category. This is particularly effective for runways exclusively dedicated to take-off/landings
ATC Airport Procedures	**Airport Automation Systems**	
• **Pilot reaction time monitoring** to track the time it takes for pilots to react to certain orders. • **Early clearances** of the line-up and take-off clearances prompt pilots to complete all necessary checks and move away from the runway and taxiway without stopping. • **Conditional clearances** expedite traffic by allowing	• **Situational awareness enhancement** by equipping all ground vehicles with transponders. • **Comprehensive surveillance** in conjunction with a surface conflict detection tool improves capacity by allowing controllers to focus on	

Initiatives to improve Declared Airport Capacity		
pilots to proceed immediately after the restricting condition has been satisfied. • **Adherence to the departure slot time**, by avoiding early or late starts helps maintain predictability. Controllers should never issue start-up clearance unless they are certain that the aircraft can make the departure slot time. • **Setting up intermediate holding points** along the taxi path which allows controllers to set up an efficient departure sequence. • **Multiple line-up procedures** ensure that aircraft will be fully lined-up and ready to depart as soon as the take-off clearance is given. • **Limit aircraft with limited performance characteristics** during peak hours. • **Enhance taxiway efficiency** to provide a one-way traffic flow.	tasks related to ground movement efficiency. • **Arrival and departure manager systems** to support balancing among available runways and dynamic prioritization. • **Route Planning and Monitoring** systems can provide automated solutions to manage complex layouts and large traffic volumes. • **Communication and information transmission** can be supported by automated systems, such as the implementation of controller-pilot data link communications to reduce verbal communication and lighting guidance systems to optimize traffic movement in low visibility conditions. • **Turnaround process optimization** by planning and monitoring ramp activities, human resources, vehicles and message exchange with operators.	

E.2 Demand and Capacity balancing solutions in ATFCM

When demand exceeds capacity at a given airport or airspace, stakeholders will work together to solve the imbalance. From an ATFCM point of view, two types of solutions can be offered: **Capacity optimization** and **ATFCM measures**. In U-space, it will be necessary to limit the capacity of the airspace, but it is not so clear if drone airports will be a limiting factor of the number of operations.

E.2.1 Capacity Optimization

Capacity Optimization is a process applied by air traffic management to find means to amplify the available capacity to meet the imbalance. This process usually does not involve or impact airspace users. The following solutions for optimizing capacity are typically applied:

Table 44: Capacity optimization solutions.

Capacity Optimization solutions		
Sectorization	**Flexible Use of Airspace**	**Arrival and Departure Capacity Balancing**
Affected **sectors may be split into two** or more smaller sectors. **Changing the configuration of several sectors** to spread the demand is another valid method.	**Coordination with authorities** (typically the military) that own **danger, restricted and/or prohibited airspace**, so that parts of that airspace can be freed-up in peak hours.	Airports with several runways may establish rules for using specific runways only for departures and arrivals, as well as a "shared use runway" in the case of high departure or arrival load.
Staff Optimization		
Controllers in charge of managing a capacity constrained set of airspace can be assisted by additional ATC staff to facilitate coordination, clearance creation and delivery.		

E.2.2 ATFCM Measures

These measures directly impact the flow of air traffic and thus have an impact on airspace users. ATFCM measures are typically only applied when Capacity Optimization measures have been exhausted. Several types of ATFCM measures exist and are described below:

Table 45: Measures for Air Traffic Flow and Capacity Management.

ATFCM Measures		
Minutes-in-Trail (MINIT) and Miles-in-Trail (MIT)	**Minimum Departure Intervals (MDIs)**	**Rerouting**
A **defined number of minutes or miles between successive aircraft at a boundary point** of an airspace or airport. This is a relatively "light" measure and should be superseded by other measures if implemented over an extended period.	Minimum Departure Intervals are essentially **Minutes/Miles-in-Trail measures applied to the departure flow of an airport**. They usually support short-term imbalances when sectors become excessively busy or suffer reduced capacity.	Vertical and Horizontal Reroutes are **measures that remove flights from a constrained airspace or airport**. Organized in "scenarios", they can be mandatory or advisory: • Mandatory reroutes divert flows around constrained areas. • Alternative/advisory reroutes are made available to airspace users as optional. However, should airspace users avoid such measures then mandatory ATFCM measures are usually required.
Rerouting Scenarios Catalogue	**Level Capping Scenarios**	**Fix Balancing**
Recurring route scenarios are usually collaboratively developed into pre-defined routes and published as a Rerouting Scenarios Catalogue.	**Restrictions on flight levels** that limit climb or descent into congested areas.	**Aircraft are assigned different arrival/departure fixes than originally planned** to distribute demand and avoid excessive holdings and delays. This usually comes into play when thunderstorms make the standard departure/arrival routes unusable.
Ground Delay Programs (GDP)	**Ground Stop (GSt)**	
Ground Delay Programs issue delayed departure times that correspond to the aircrafts'	Ground Stops are implemented when **severe unpredicted constraints apply** to an	

ATFCM Measures		
entries into a constrained airspace or airport. The idea is to transfer the delay time from the airborne phase of flight to the ground phase and provide a manageable flow of air traffic to reduce airborne measures, such as holdings, or excessive tactical ATC actions.	airspace or airport (i.e., an aircraft accident or significant Communication, Navigation and Surveillance system failure). Aircraft will be held on-ground indefinitely until the situation improves. After that, Ground Delay Programs are typically applied to manage flow recovery.	

E.3 Roles and Collaborative Decision-Making processes

In air traffic management, so-called, Collaborative Decision-Making (CDM) processes are used to support ATFCM for en-route airspace as well as airports by **sharing all relevant information between stakeholders in all flight phases**. In this context, ATFCM will monitor airspace and airport demand, capacity and constraints. Once imbalances are detected, CDM processes come into play to help ATFCM find solutions to balance demand and capacity. Through the assistance of CDM authorities hope to take appropriate decisions that take all stakeholders' requirements into consideration. A good CDM environment requires agreed procedures and the provision of information from all stakeholders in a transparent manner. The following table provides an overview of how individual stakeholders participate in CDM:

Table 46: Roles of stakeholders within the Collaborative Decision-Making process.

Stakeholder	Participation
Airspace Users	Increased flying times, holdings or surface congestion also increase airborne and delays. Airspace users must assist air navigation service providers (ANSPs) in **identifying the reasons for the delays and develop mitigation strategies**.
Airport Authorities	Airport operators need to participate just as airspace users to have a say in how ATFCM measures are implemented.
Air Traffic Control	The success, or failure, of ATFCM procedures can be **directly measured through their impact on air traffic control** (the tactical arm of an ANSP). Specifically, indications of a failed ATFCM manifest in lack of predictability, incomplete situational awareness of all stakeholders, unmanageable traffic peaks, excessive measures on airborne traffic and generally high workload, stress and fatigue of air traffic controllers.
Network manager	The Network Manager Operations Centre (NMOC) coordinates ATFCM at pan-European level, by **proposing modifications to capacity or adjustments to demand to local experts at national and/or regional level** known as Flow Management Positions (FMP). The FMPs partner with the NMOC to provide an effective ATFCM service to air traffic control and

Stakeholder	Participation
	airspace operators. They ensure the local implementation of measures and procedures within the area of their responsibility. This area of responsibility is typically linked to an area control centre (ACC) where air traffic services are provided.

Different actors will participate in the DCB processes in U-space. The role of each actor from the perspective of how they can contribute to the processes to balance demand and capacity will change with respect to the ATM.

E.4 DCB developments in SESAR

The way that ATFCM is performed is continuously scrutinized and subject to improvements. SESAR is tasked with identifying shortcomings and with the development and testing of potential improvements Several key developments of SESAR operational concepts relevant to the development of DCB are presented in the table below.

Table 47: Examples of key developments in SESAR regarding the improvement of DCB concepts.

SESAR concepts on DCB		
Demand predictions	**Workload predictions**	**Network Performance**
• The development of a **Forecast Business Trajectory** to enhance the prediction of Flight Intentions. These trajectories are adjusted by statistical information on buffer and time variability and including most likely Airspace User responses to the traffic situation and ATFCM scenarios. • Using **forecasted Airspace Configuration and Capacity data** to detect demand vs. capacity imbalances. These lead to further adjustments of the trajectory and forecast solutions to solve these imbalances resulting in a Network Impact Forecast.	• **Traffic density management** aiming at managing that there are not too many flights in a traffic volume. • **Traffic complexity management** aiming at managing that there is not too much complexity induced by flights in a traffic volume. Complexity management shall act in the 3h-20min time horizon. Complexity should be calculated as soon as quality data is available. • **Traffic interaction management** aiming at managing that there are not too many interactions of a certain type (adapted to the local specificities of	• Visible and shareable **Network Performance Indicators** reflecting the stakeholder's individual performance criteria (ANSP, APT, AU, NM) that other actors can unambiguously interpret and accommodate. • **Defined thresholds for network state** (nominal, critical, crisis) management and trade-offs during nominal state guiding the solution decision-making, respecting acceptable limits to declare different network states.

SESAR concepts on DCB		
	the TV/ flows under analysis)	
Synchronisation	**Target Time Management**	**Constraint Reconciliation**
• Management of simultaneous concurrent corrective **short-term measure strategies** resulting in compatible modifications, on SBT and RBT. • **Intra DCB measures** related to density, complexity, traffic organization. • The inclusion of DCB into the Arrival management process (e.g., **Extended Arrival Management**) and Airport processes (e.g., **User Driven Prioritization Processes**).	• **TTO/TTA** (Target Time Over/Target Time at the Arrival) for measures-initiated business trajectory elaboration phase. • **tTTO/tTTA** (tactical Target Time Over/tactical Target Time at the Arrival) for measures initiated in the business trajectory revision phase.	• Ensure the collection of the locally planned **DCB Target-Time solutions** to determine the global consistency and to detect which flight trajectories will be affected by multiple constraints interferences. • Provide a **Network Consolidated Constraint (NCC)** to the local-DCB actors which allow them to be informed about the Network situation by a network consolidated target-time reply based on their target-time proposal request. • **Offering re-assessment** based on other existing constraints that would make the candidate constraint unnecessary/ not efficient