Performance Framework

Deliverable ID:	D5.3
Dissemination Level:	PU
Project Acronym:	DACUS
Grant:	893864
Call:	H2020-SESAR-2019-2
Topic:	SESAR-ER4-31-2019 - U-space
Consortium Coordinator:	CRIDA, A.I.E.
Edition Date:	10 November 2021
Edition:	00.02.00
Template Edition:	02.00.03

Founding Members

EUROPEAN UNION EUROCONTROL

SESAR JOINT UNDERTAKING

Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Dominik Janisch	CRIDA contributor	07/04/2021
Pablo Sánchez-Escalonilla	CRIDA contributor	07/04/2021
Gonzalo Torres	CRIDA contributor	07/04/2021
Andrew Hately	EUROCONTROL contributor	07/04/2021
Michael Büddefeld	TU Darmstadt contributor	07/04/2021
Hugo Eduardo	TU Darmstadt contributor	07/04/2021
Ian Crook	ISA Software contributor	07/04/2021
Sandrine Molton	ISA Software contributor	07/04/2021
Aris Anagnostou	EUROCONTROL contributor	07/04/2021

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Dominik Janisch	CRIDA contributor	15/07/2021
Pablo Sánchez-Escalonilla	CRIDA contributor	15/07/2021
Eduardo García	ENAIRE reviewer	19/07/2021

Approved for submission to the SJU

Name/Beneficiary	Position/Title	Date
Pablo Sánchez-Escalonilla / CRIDA	Company PoC	16/07/2021
Maron Kristofersson / AHA	Company PoC	16/07/2021
Nicolás Peña / BRTE	Company PoC	16/07/2021
Andrew Hately / ECTL	Company PoC	16/07/2021
Eduardo García / ENAIRE	Company PoC	16/07/2021
Víctor Gordo / INECO	Company PoC	16/07/2021
Sandrine Molton / ISA	Company PoC	16/07/2021
Anna-Lisa Mautes / Jeppesen	Company PoC	16/07/2021
Yannick Seprey / SSG	Company PoC	16/07/2021
Rohit Kumar / TM	Company PoC	16/07/2021
Michael Büddefeld / TUDA	Company PoC	16/07/2021

Rejected By – Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date

Document History

Edition	Date	Status	Author	Justification
00.00.01	24/03/21	Draft	P. S.-Escalonilla	Template
00.00.02	05/04/21	Draft	P. S.-Escalonilla, G. Torres, D. Janisch	Details on the process Annex A
00.00.03	07/04/21	Draft	All contributors	Integration of contributions to sections 4, 5 and 7 (capacity, flexibility & resilience, security)
00.00.04	12/04/21	Draft	All contributors	Integration of contributions to sections 4, 5 (social impact, mission efficiency, access &equity)
00.00.05	20/04/21	Draft	P. S.-Escalonilla	Contribution to section 6 (capacity)
00.00.06	04/05/21	Draft	All contributors	Integration of contributions to section 6 (social impact, flexibility & resilience)
00.00.07	18/05/21	Draft	All contributors	Integration of contributions to section 6 (mission efficiency and access & equity)
00.00.08	01/06/21	Draft	P. S.-Escalonilla, D. Janisch H. Eduardo M. Büddefeld	Refinement of social and environmental KPAs, resilience and flexibility KPAs
00.00.09	07/06/21	Draft	P. S.-Escalonilla A. Hately, K. Delcourte, A. Anagnostou	Refinement of mission efficiency and access & equity KPAs
00.00.10	18/06/21	Draft	P. S.-Escalonilla A. Anagnostou H. Eduardo	Refinement of access & equity KPAs and social and environmental KPIs Reorganization of sections
00.00.11	05/07/21	Draft	P. S.-Escalonilla	Refinement of comments and inclusions of open points identified in DACUS workshop
00.00.12	15/07/2021	Draft	P. S.-Escalonilla, D. Janisch H. Eduardo	Refinement of sections and conclusions based on internal survey's results.

Document History

Edition	Date	Status	Author	Justification
			M. Büddefeld	
00.01.00	20/07/2021	Final	P. S.-Escalonilla, D. Janisch	Approved version for submission
00.02.00	10/11/2021	Revised	P. S.-Escalonilla	Revised version addressing SJU comments

DACUS

DEMAND AND CAPACITY OPTIMISATION IN U-SPACE

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 893864 under European Union’s Horizon 2020 research and innovation programme.

Abstract

This document details representative indicators that allow the monitoring of drone operations in urban environments. The document covers six areas: capacity – understood as the maximum number of drones that can be safely managed –, environmental & social impact, mission efficiency, equity, flexibility and resilience. DACUS indicators are designed with the objective of supporting the decision-making in a performance-driven DCB process for U-space. The applicability of the indicators within DCB will be tested in the foreseen DACUS experiments.

Table of Contents

List of Tables

List of Figures

1 Executive Summary

DACUS D1.1 [3] describes a detailed concept of operations for Demand and Capacity Balancing (DCB) processes in U-space. DCB in U-space is based on a series of fundamental principles, which sees the operators as the final decision makers, reduces constraints on drone trajectories as much as possible, and prioritizes DCB measures based on their impact on the fulfilment of the drone missions.

The DCB process begins at strategic level (several days before operation) and continuously monitors and updates the traffic situation until and during the flight execution. The need of monitoring the overall traffic and taking effective decisions to balance the demand and the capacity makes it necessary to define indicators that drive the processes from the strategic up to the tactical phase. These indicators should support relevant processes such as the implementation of adequate DCB measures or the selection of those drone operations that should be penalized if necessary, among others.

Although parallelisms with ATM are provided throughout the whole document, we identified early on that particularities of drone operations and U-space make it necessary to redesign not just existing ATM indicators, but even the very definition of the associated performance areas. This document starts by redefining our understanding of Key Performance Areas (KPAs) applicable to U-space. Then, we describe influence factors which impact each of these areas. Finally, these influence factors, together with the identified requirements of the indicators within the DCB processes, are used to assess the representativeness of the proposed indicators.

One difference between ATM and U-space is that areas such as Access & Equity, Resilience or Flexibility are traditionally analysed in ATM through indicators based on historical data, or by means of qualitative assessment. This approach will be insufficient for U-space DCB. The wide diversity of missions and business models makes necessary to understand, before implementing a DCB measure, how inefficiencies will be distributed among the different business models or missions. On the other hand, dynamic changes in the demand and larger number of drone contingencies that can take place in U-space require to measure how resilient or flexible a DCB measure is in comparison with others.

The areas of Access & Equity, Resilience or Flexibility are not used in ATM to take decisions during the DCB processes. DCB decisions are traditionally taken by monitoring capacity-related indicators and, in some cases, mission efficiency indicators. The characteristics of the drone operations or the envisioned environmental conditions in a certain period and area will make it necessary to prioritize more equitable measures, or with higher flexibility or resilience. Then, quantitative indicators are needed to predict the impact on these KPAs.

On the other hand, other differences with ATM emerge due to the change in the notion of hotspot. Such as in ATM, the expected impact of operations on the level of safety is one of the factors to identify a hotspot, but also noise and visual nuisance are identified as limiting factors, especially in urban environments. We therefore designed new indicators to identify social and environmental hotspots. Those indicators rely on factors such as expected noise levels or population densities, which have never been considered in ATM.

Additionally, the trend in ATM of defining other indicators apart from the number of incoming aircraft per hour - such as occupancy or complexity metrics - to limit the number of operations is identified as a fundamental requirement in U-space. The variety of vehicles and the freedom to select the most suitable trajectories in a free route environment make necessary the redefinition of indicators in the

Capacity KPA. These indicators will not quantify the number of drones, but the overall risk of collision derived from the operations. Instead of a static number of drone operations per hour, U-space will manage dynamic numbers that will be determined by the safety margins.

Finally, the document identifies some challenges to calculate some of the indicators. As an example, an easy-to-calculate indicator in ATM such as the Horizontal Flight Efficiency (HFE) could be very challenging in U-space. In ATM, we use the trajectory which is described in the flight plan to compare with the orthodrome (also referred to as “great-circle distance”). In U-space, we will have Operation Plans which are described as a sequence of 4D volumes. Then, several assumptions should be done to estimate the best probable trajectory to compare with the orthodrome.

DACUS will implement some of these indicators in its experiments with the objective of understanding their applicability. The most useful indicators will be included in the final DCB concept of operations that will be delivered at the end of the project.

2 Introduction

DACUS intends to design a U-space DCB ConOps which follows a **performance-based approach** during the execution of the related processes. DACUS proposes to follow a generalization of the Performance Management Process detailed in [1]. Instead of following this approach to select the most relevant ATM solutions according to their impact on relevant Key Performance Areas (KPAs), DACUS will apply it to ensure that the selection of the DCB measures and other DCB decisions are supported by up-to-date data through a consistent performance framework. This will allow a more efficient U-space system through an informed decision-making driven by foreseen results and relying on up-to-date data.

As stated by ICAO [1], past, current and expected performances are quantitatively expressed by means of Key Performance Indicators (KPIs). ICAO defines some **high-level characteristics of the KPIs** to ensure that they are useful in a performance-based approach**:**

- To correctly express the intention of the associated performance objective. Since indicators support objectives, they should be defined having a specific performance objective in mind. This principle is thought when assessing new solutions in ATM. In our case, we will use this principle to ensure that the DCB measures are implemented taking on board some pre-defined objectives with respect to each relevant Key Performance Area;

- Indicators are not often directly measured. They are calculated from supporting metrics according to clearly defined formulas. This idea is also taken on board in our approach as some areas such as Access & Equity cannot be directly measured. Then, we identified the influence factors impacting each area. They were used to extract 'secondary' metrics that should follow similar trends than the theoretical primary indicators.

Within each KPA, DACUS identifies specific areas — **Focus Areas (FAs)** — in which there could be potential intentions to establish performance management. Within Focus Areas, an intention is "activated" by defining one or more performance indicators and then performance objectives.

2.1 Purpose of the document

The purpose of this document is to go deeper in the definition of KPAs and associated KPIs to facilitate the DCB decision-making processes in U-space. This document complements the DACUS ConOps with indicators and metrics to take decisions such as the selection of the best DCB measure to be implemented taking into account its impact on capacity, mission efficiency or social and environmental impact, among others KPAs.

2.2 Scope

The document provides initial definitions of each KPA within U-space, and in DCB in particular. Then, the factors influencing each of the KPAs are also described. These factors are used as an initial reference for the definition of indicators in U-space DCB. Indicators do not intend to measure the whole behaviour of the U-space system, but only those aspects which could be predicted in advance for decision-making. The use of KPIs as part of the DCB process makes it necessary to put the focus on 'leading' indicators, i.e. indicators which are suitable to predict what could happen in a decision point, and not to analyse the system once the drone operations were performed.

Due to the exploratory nature of this document, not all KPAs and KPIs are presented with the same level of maturity. This document intends to provide initial material for further discussions with U-space stakeholders, including Drone Operators.

2.3 Intended readership

This document is oriented towards the following key audiences:

- DACUS consortium working on the experiments: The performance indicators described in this document are to be utilized as a baseline reference for the definition of metrics to be used in DACUS experiments;
- DACUS consortium working on the final DCB Concept of Operations: Indicators which are more mature will be included in the final ConOps to support a performance-driven approach in the DCB decision-making;
- SESAR JU: This document shall be used as an initial reference to readers external to the consortium. It presents a consolidated summary of the proposed indicators to monitor the DCB processes and provides necessary supporting information to be able to justify the selected indicators;
- Other U-space projects addressing performances of the U-space system.

2.4 Background

DACUS D1.1 [3] is use as starting point for the identification of DCB processes in which indicators need to be defined. In addition, an overview of existing literature is provided in Appendix A.

2.5 Structure of the document

This document is structured into six main sections, as well as two 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 concept.

  A short summary of the DCB Concept of Operations in U-space, together with flow diagrams with the main processes in the different phases. They will be the framework for the definition of performance indicators that will guide the processes and support decision-making.

- Section 4: KPAs in the DCB concept.

  Definition of those KPAs that will be highly influential on the decision-making process. These definitions can change with respect to those defined in ATM.

- Section 5: Influence factors associated with each KPA.

  Identification of the influence factors associated with each previously defined KPA. This will allow assessing if the indicators are representative enough of the expected trend of each KPA.

- Section 6: KPIs and DCB decision-making.

  Definition of those requirements that should be covered by the indicators to be able to take decisions in the DCB processes. Based on these requirements, a set of indicators are defined, together with pros and cons of every indicator.

- Section 7: Other KPAs in U-space.

  Other KPAs which are relevant for U-space. These however are not used to support the decision-making in the DACUS DCB Concept of Operations due to the lack of maturity of the area in the definition of 'leading' indicators.

- Section 8: Conclusions and next steps

  This section presents a summary of the main conclusions which were gathered during the elaboration of the performance framework as well as next steps in their development.

- Section 9: References.

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

- Appendix A: Research initiatives and studies addressing performance indicators

  Summary of on-going and previous research initiatives which are relevant to the U-space DCB performance framework. UTM ConOps that make reference to performance expectations are also included.

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	EATMA V12 (ATM Capability)

Term	Definition	Source of the definition
	incompatible airspace activity, weather hazard zones, and terrain-based obstacles).	
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
Ownship	One's own aircraft, as represented in a flight training simulation or traffic collision avoidance system.	WordSense Dictionary

Table 1: Glossary of terms

2.7 List of Acronyms

Acronym	Definition
AOC	Air Operator Certificate
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
AU	Airspace User
CNS	Communication, Navigation and Surveillance
CONOPS	Concept of Operations
DCB	Demand and Capacity Balancing
EPNL	Effective Perceived Noise Level
EU	European Union
FA	Focus Area
HFE	Horizontal Flight Efficiency
ICAO	International Civil Aviation Organization
KPA	Key Performance Area
KPI	Key Performance Indicator

Acronym	Definition
PAV	Personal Air Vehicle
RFL	Reference Flight Level
RTTA	Reasonable Time To Act
SEL	Sound Exposure Level
SESAR	Single European Sky ATM Research
SORA	Specific Operation Risk Assessment
TCAS	Traffic Collision Avoidance System
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
USSP	U-Space Service Provider
UTM	Unmanned Aerial Vehicle Traffic Management
VFE	Vertical Flight Efficiency
VLD	Very Large-Scale Demonstration
VLL	Very Low-Level
VLOS	Visual Line-Of-Sight

Table 2: List of acronyms

3 U-space DCB concept

This chapter provides the framework to understand when performance indicators are needed along the DCB processes in U-space. It goes beyond the information included in the DACUS ConOps [3] by providing diagrams that show how the U-space services interact along the strategic, pre-tactical and tactical phases, including a detailed description of the main and secondary processes which are part of the U-space DCB in all phases.

3.1 Summary

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

The following paragraphs provide an overview of the main DCB flow and the U-space services which participate in it. Those U-space services which have an active role in the identification of contingencies in the tactical phase are not included.

- Operation Plan Preparation service facilitates the preparation and submission of the Operation Plans. It shall allow indicating those parameters which are critical for the fulfilment of the mission. Operation Plans, which are closely linked to the business needs of Drone Operators, include contingency considerations for the declared flights;
- 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 also generate "what-if" probabilistic 4D trajectories taking into consideration contingency volumes or contingency plans which will be included in the Operation Plans;
- Strategic Conflict Resolution Service compares the submitted Operation Plan with the already approved ones and proposes solutions if the risk of a conflict is higher than a certain limit. It must consider mission objectives to propose suitable solutions for the drone operator;
- 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 or the population density.

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

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

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

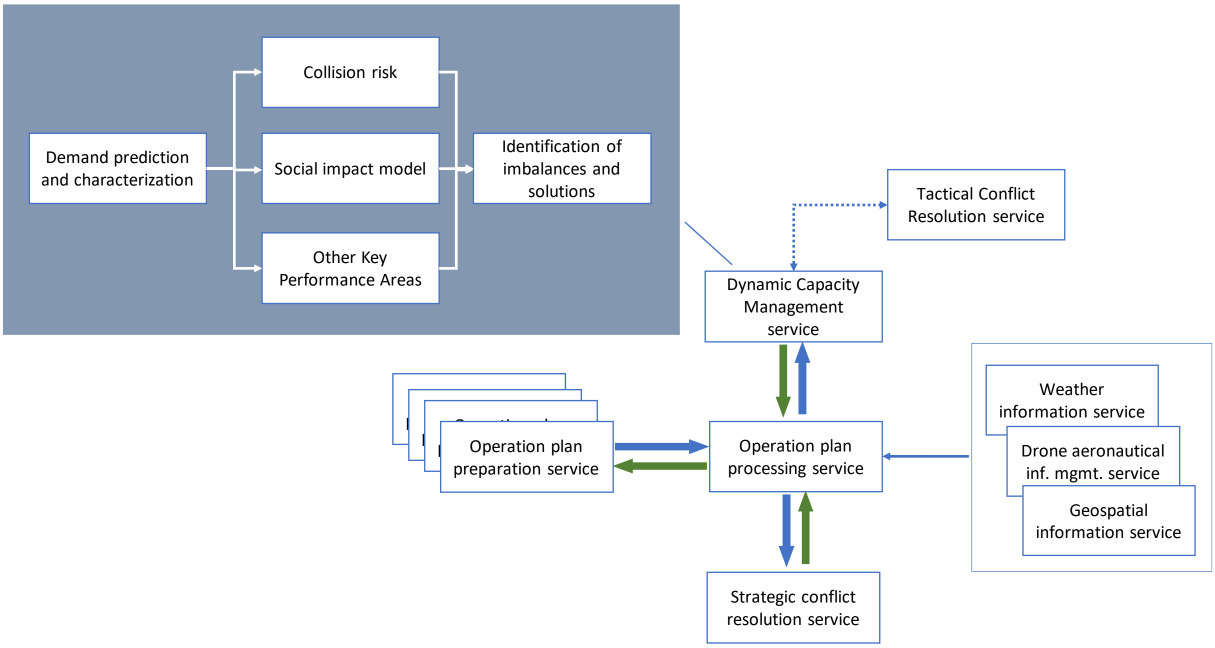


Figure 1: High-level overview of the DCB processes in U-space

Tactical Conflict Resolution Service compares existing Operation Plans in flight, 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 each airspace.

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

3.2 DCB processes and involved U-space services

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

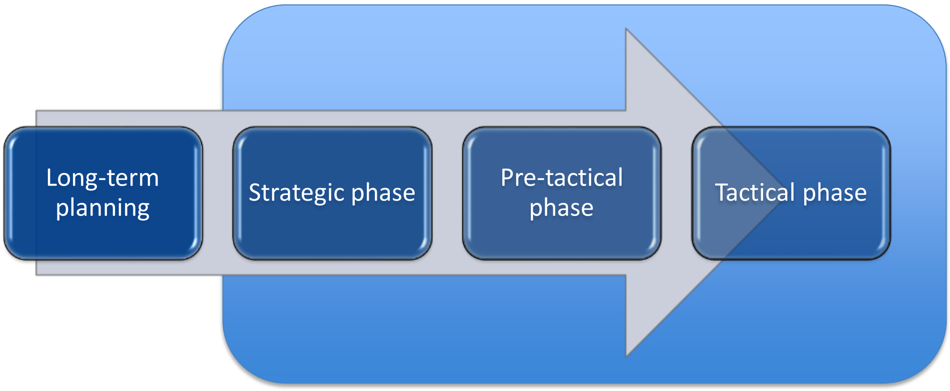


Figure 2: Overview of DCB phases and DACUS scope (in blue)

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

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

3.2.1 Strategic phase

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

- To implement those DCB measures which are not imposing critical constraints to the fulfilment of the mission according to the Drone Operator's expectations;
- To pre-define those DCB measures which do 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 the 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 at short notice, however drones supporting recurrent operations, such as for instance in support of waste management in Smart Cities, could have periodical Operation Plans which are available longer time in advance.

The detailed processes are included in the Figure 3. They will take place before the *"Reasonable Time to Act" (RTTA)*.

3.2.2 Pre-tactical phase

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

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

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

Operation Plans submitted after RTTA[1] are the first candidates to be proposed a plan change if it is necessary. Although there is no advantage to early Operation Plan submission, there is a limit in the interests of giving other operators some stability. At RTTA a flight becomes “protected” and may be considered as being in its Tactical phase. The Figure 4 represents a certain time after the RTTA, so that DCB measures have been already implemented. New submitted Operation Plans will need to comply with the constraints associated with the implemented DCB measures.

3.2.3 Tactical phase

The tactical 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 to restore 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.

Figure 5 represents the case in which the Navigation Infrastructure Monitoring service is reporting a degradation of navigation performances. This degradation is impacting drones which are already in the air. The degradation is declared for a long period of time. This implies that additional Operation Plans, which have not been activated, will also be impacted. Contingency plans need to be activated for those drones which are already in the air and cannot fly in the area due to the loss of navigation capabilities.

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

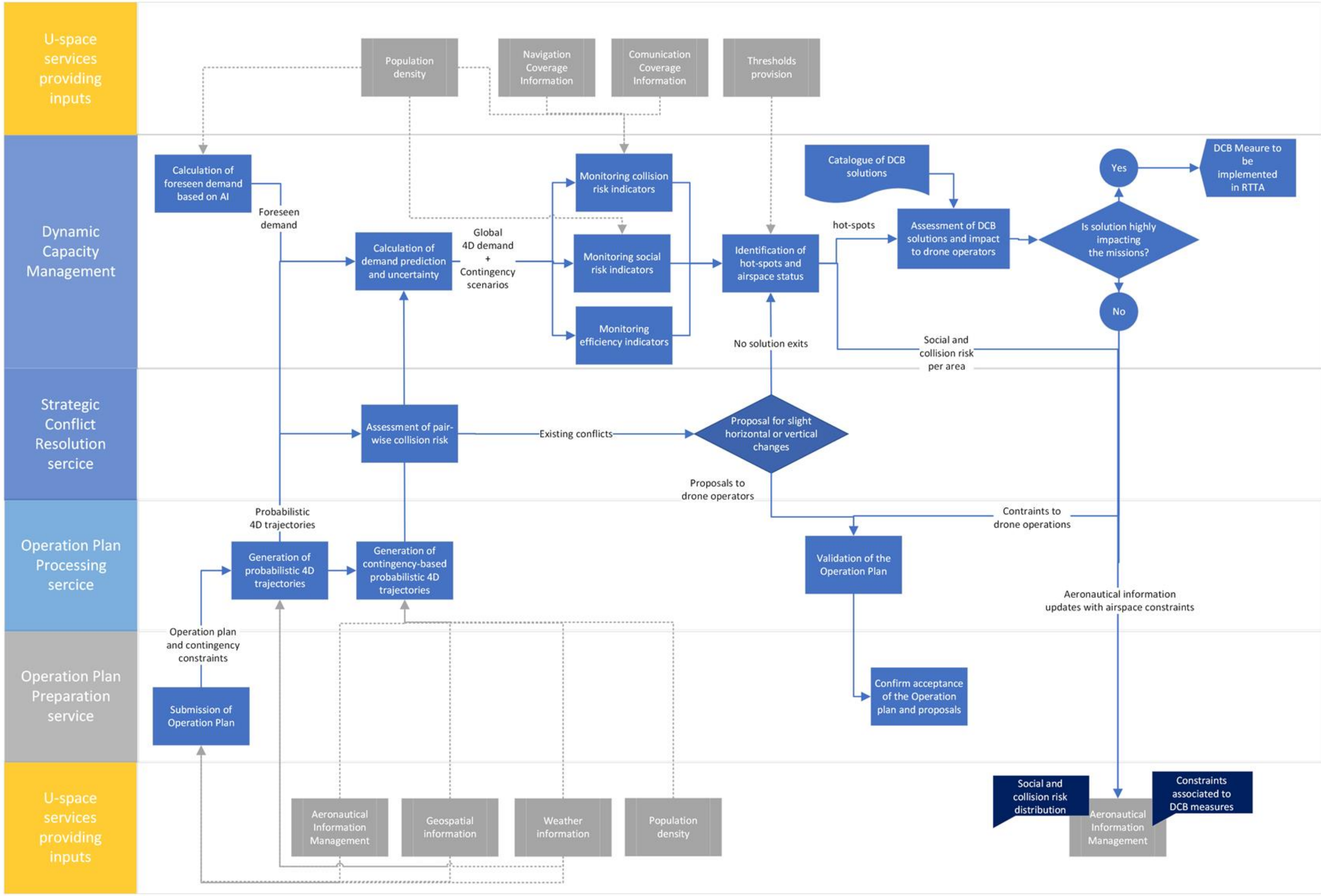


Figure 3: Detailed DCB processes in the strategic phase

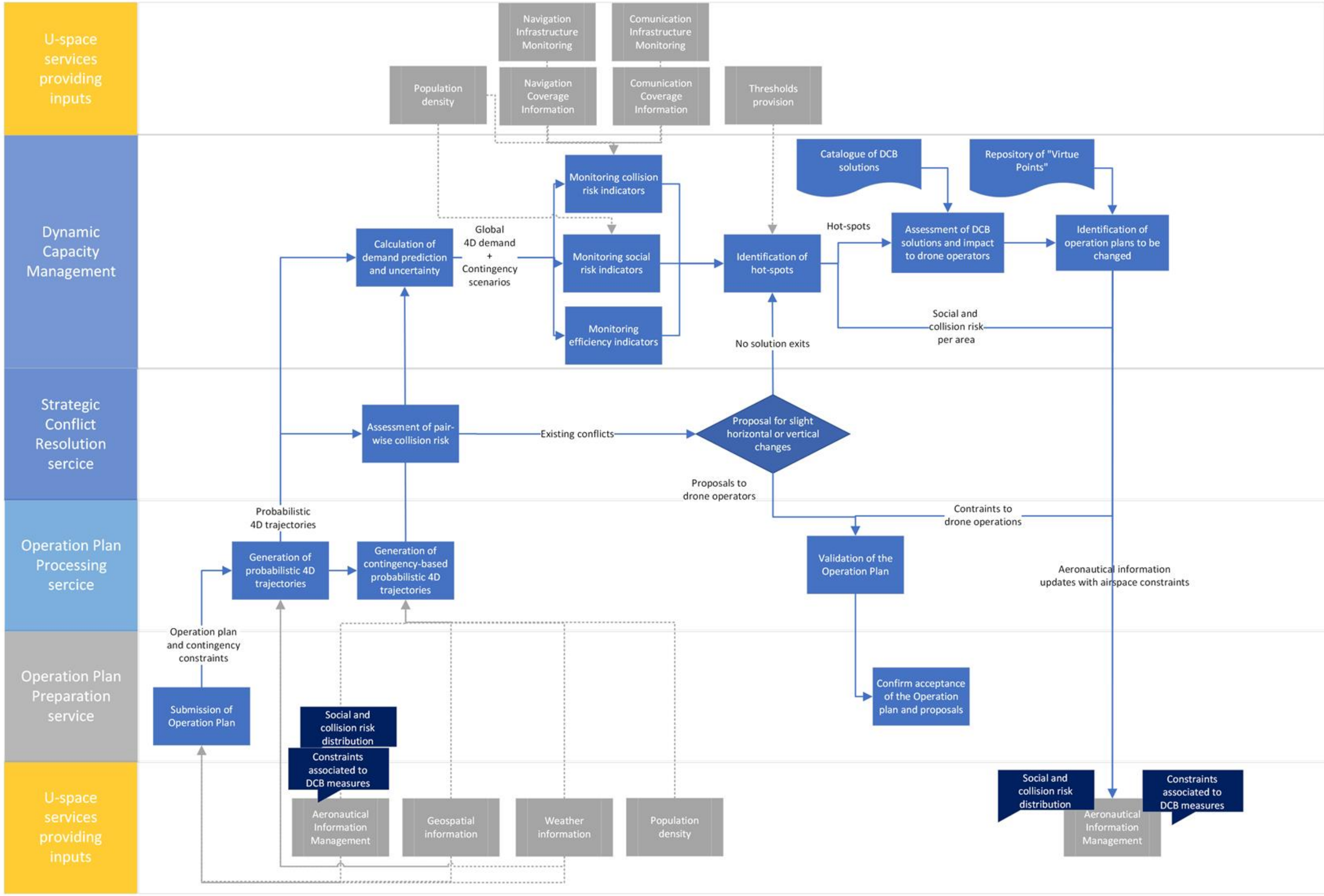


Figure 4: DCB processes in the pre-tactical phase

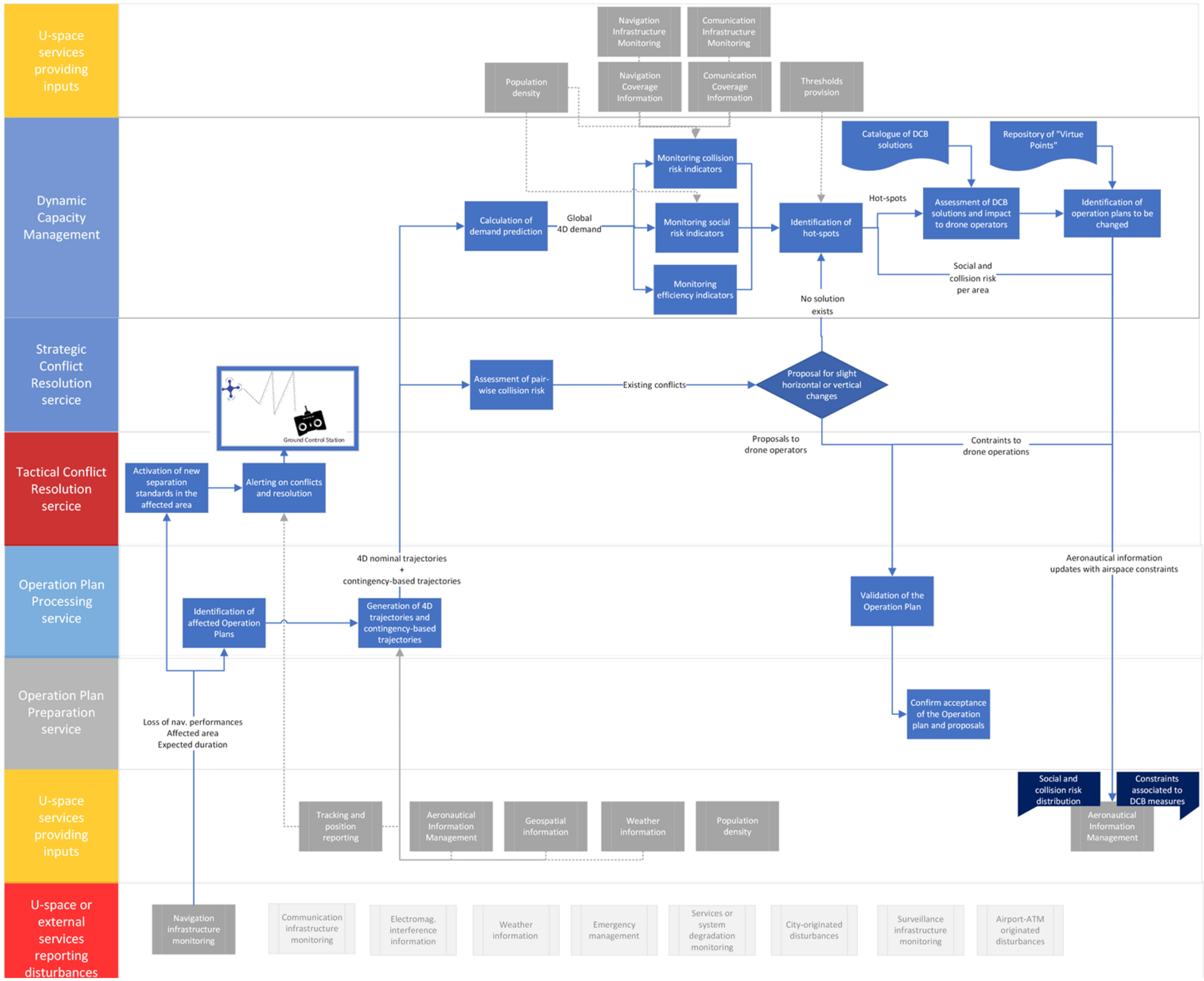


Figure 5: DCB processes in the tactical phase activated by the Navigation Infrastructure Monitoring

4 KPAs in the DCB concept

ICAO "Manual on Global Performance of the Air Navigation System" [1] has defined 11 KPAs: safety, security, environmental impact, cost effectiveness, capacity, flight efficiency, flexibility, predictability, access and equity, participation and collaboration, and finally, interoperability. DACUS has selected those KPAs which are relevant for the decisions to be taken in the DCB process. The following table shows a summary of the selected KPAs and the proposed Focus Areas. This information is expanded in the subsequent sections of this chapter, including:

- Explanations of the definition of each KPA, in case of divergence with existing definitions in ICAO or in SESAR, justifications of the divergences;
- Justification of the selection of each KPA as a relevant component in the performance-based DCB processes.

KPAs in DCB	Scope	Focus Areas
Capacity	Assessment of the maximum number of drone operations that can be accommodated in a given airspace for a certain period whilst maintaining safety-related targets.	Airspace capacity. Terminal capacity.
Environmental and Social Impact	Assessment of the maximum number of drone operations that can be accommodated in a given airspace for a certain period whist maintaining social perception and environmental impact within acceptable margins. The focus is on noise impact, visual impact linked with privacy concerns, and wildlife impact.	Noise impact. Visual impact and privacy. Wildlife impact.
Mission Efficiency	Assessment of the extent to which the number of resources planned for the mission are used, and not more. These include energy used and time taken, both in terms of running hours / working hours and the actual time at which the mission goal is achieved. Significant mission inefficiency could prevent the mission goal being achieved. Before that extreme, the impact will likely be increase cost for each operation.	Cost of operating. Probability of achieving mission goal.
Equity	Assessment of how the inefficiencies of the system are equitably impacting the different airspace users.	Non applicable

KPAs in DCB	Scope	Focus Areas
Flexibility	Assessment of the ability to accommodate dynamic flight parameter modifications which allow users to exploit business opportunities using drones as they occur, given the restrictions of the operating environment.	Non applicable
Resilience	Assessment of the ability to adapt to changes of the environment by anticipating and reacting to sudden, troublesome, or negative disruptions whilst maintaining the overall performance.	Non applicable

Table 3: Summary of KPAs and Focus Areas as part of the DCB process

4.1 Capacity

We envisioned that the expectations of the Drone Operators with regards to capacity will be like the ones of the ATM community included in ICAO "Global Air Traffic Management Operational Concept" [2]. Adapting these expectations to the U-space system, we could consider that the U-space system in a given airspace *is expected to meet airspace user demand at peak times and locations by minimizing restrictions on traffic flow. To respond to future growth, capacity must increase, along with corresponding increases in efficiency, flexibility, and predictability while ensuring that there are no adverse impacts on safety or the environment.*

One aspect to take on board in U-space is that, in contrast to ATM, safety and environment are not the unique areas which could be adversely impacted by the capacity increase. Previous research such as the one performed in IMPETUS [5] showed that the overall efficiency of the missions decreases progressively when the number of drone operations increases. Results showed that it would be counter-productive for the mission efficiency to allow more traffic even with the ability to ensure separation. On the other hand, given that drones will be operating in VLL airspace and in urban areas, limitations on the maximum number of operations can be envisioned from the perspective of the social impact. Citizens will probably claim for limiting the number of operations to reduce the adverse impact of noise or even the visual impact close to their houses. Consequently, mission efficiency and social impact – noise, visual impact – can be seen as a limiting factor in capacity. Then, we need indicators to monitor these areas in U-space DCB, defining associated targets that could limit the maximum number of operations in a certain area. These areas are studied in §4.2 and §4.3.

On the other hand, we should question how airspace user demand is understood in U-space. Looking again at the ATM system, ICAO "Global Air Traffic Management Operational Concept" [2] defines Capacity as *the maximum number of aircraft that can be accommodated in a given time period by the system or one of its components (throughput).* In this context, ICAO found disparity on the methods for determining the number of flights, highlighting that the ability to objectively determine the number of flights able to enter an airspace volume is not a settled matter. Once this number is calculated, it is considered as the main reference – "static" reference – to limit the number of operations into a sector.

This challenge is even bigger in U-space due to the multiple factors which are affecting the maximum number of aircraft that can be accommodated in U-space, as it was identified in DACUS D1.1 Annex B "Detailed analysis of influence factors on capacity and demand" [3]. This wide diversity of factors and their continuous change over time makes it necessary to question whether the maximum number of aircraft can be considered as the main indicator to determine the capacity in U-space, or maybe it should be defined as a "dynamic" value that will change with time depending on multiple factors.

DACUS proposes to define capacity indicators, and methods to calculate them, by taking on board the most relevant influence factors which are impacting the capability of the U-space system to meet the airspace user demand with no adverse impacts on safety[2], environment, mission efficiency and social aspects.

It should be clarified that, similarly to the notion of declared capacity in ATM, DACUS focuses on assessing the capacity that can be offered in a given airspace. However, this notion of declared capacity in U-space will not be so static as it is in ATM due to the high dynamicity of the U-space environment. Then, DACUS defines capacity indicators that can be used in real time to obtain the maximum number of drone operations which is manageable in a given airspace. Measuring to what degree the capacity that will be offered matches the future drone demand is out of the scope of this document.

One aspect to be taken on board in the Capacity KPA is the difficulty to accommodate higher numbers of aircraft due to the constraints of the ground infrastructure. The number of vertiports, or the limitations of their use due to factors such as adverse weather conditions, need to be monitored through specific indicators. Consequently, we proposed to define two Focus Areas within the Capacity KPA: **Airspace Capacity and Terminal Capacity**. This idea of addressing the Terminal Focus Area can be derived from previous literature review such as the performance expectations of UAM ConOps in Australia [14].

Additional focus areas could exist depending on the airspace classification in urban environments. CORUS defined volumes Zu and Za to address the diversity of drone operations and scenarios in urban environments. The introduction of Urban Air Mobility (UAM) and the diversity of operations and scenarios in urban environments could make necessary to introduce additional airspace categorisations. Given that influence factors could be different in each new category, new focus areas would likely be needed in each new airspace category.

4.2 Environmental and Social Impact

Environmental impact is one of the key performance areas that ICAO considers necessary to achieve an interoperable air traffic management system [1]. In this context, it is expected that the air navigation system will contribute to the protection of the environment by considering noise, gaseous emissions, and other environmental issues in the implementation and operation of the system.

[2] In the following sections, we will address capacity from the perspective of maintaining the safety targets. The impact on capacity of the rest of targets will be addressed by other KPAs (Mission Efficiency KPA and Environmental & Social Impact KPA).

The U-space Blueprint has already taken this aspect on board in the key principles for U-space implementation, where the environmental impact should be minimized in the design and application of air traffic management mechanisms [15]. In particular, it is recognized that ensuring environmental protection (e.g., noise & visual pollution) is key for the achievement of the economical expectations of the sector.

On the other hand, CORUS has proposed to measure the social impact of the drones from three different perspectives [16]:

- Safety: benefits versus risks that drones pose to the rest of airspace users and to people on ground;
- Economic impact: accomplishment of economical expectations of the new emerging drone market;
- Social perception: aspects such as citizens' exposure to drone noise, compromise of privacy, visual impact, etc.

The first one is being considered in the DACUS Performance Framework through the Capacity KPA (see §4.1). The second is not addressed by the project as we did not identify that DCB process could contribute to the accomplishment of the economic expectations in the sector. The third one is directly the object of research in this area.

While social acceptance of drone activities may be influenced by numerous factors - privacy, viewshed, pollution, safety or equity -, aircraft noise has dominated recent public discourses and represents a key constraint for drone operations [17]. The DACUS Consortium has conducted a citizen survey to assess the current acceptance of EU residents on commercial drone operations (see Appendix B in [4]). Noise emissions and privacy concerns were ranked, together with security issues, as the main worries perceived by the citizens. Although citizens appear to have a positive attitude towards the operation of drones in general, a significant amount of them reported that they would feel uncomfortable and/or unsafe in the vicinity of drone operations.

With all this background in mind, we define the social and environmental impact as any modification of drone traffic management that influences the social perception and the environment in general. This social perception will be determined by the **noise impact** and the **visual impact linked with privacy concerns**, as these are regarded as very relevant by the society.

Additionally, the **wildlife impact** will be taken on board in order to address the general environment apart from the direct impact on the citizens. In this context, CORUS considered this as a relevant area, proposing best practices to address the potential impact of drones on animal life, and the compliance with recommended practices when flying near wilderness, wildlife, marine sanctuaries, and other environmentally sensitive areas [16].

4.3 Mission Efficiency

The need to monitor mission efficiency indicators to support decision-making during DCB processes in U-space was already identified in previous research. For example, IMPETUS [47] project did an experiment to test the capabilities of the Tactical Conflict Resolution service to manage high number of concurrent drone operations. Although all drone operations could be managed without having unmanageable number of conflicts, the efficiency of each of the affected drone missions decreased when the conflict number increases. IMPETUS observed that it would be counter-productive for the mission efficiency to allow more traffic even with the ability to ensure separation. Then, mission efficiency could be a limiting factor of the maximum number of drones that can be managed in an area.

In general, efficiency of a process in the broadest sense is a relative measure of the quantity of "inputs" consumed (time, fuel, resources) by such process in order to achieve some desired outcome. Increasing efficiency does not mean that all inputs must be minimised. There are generally trade-offs to be considered, e.g. it is not usually the fastest car on the motorway that consumes the least fuel. In general, in any business, the optimisation of a process will trade off one aspect of efficiency against another, but the particular business may have a unique way of comparing the relative importance of the factors. For example, the Norfolk and Western railway (famously photographed by O. Winston Link [45]) continued to operate steam engines into the 1960s, long after other railways in the USA had switched to more energy efficient diesel-powered locomotives. The Norfolk and Western railway owned their own coal mines, the Pocahontas Coal & Coke Company [46], and thus put a different value on coal than competing rail operators who were buying fuel on the open market. For the North Western, the point at which the energy efficiency of diesel would be reflected in cost saved was different. The N&W were also unique in the USA in that they built their own steam engines, which implied a big social cost in changing to diesel.

Such difference in business decision-making means that generalisation of the optimisation of efficiency factors across competing businesses may be impossible. Hence, in our DCB concept we propose to consider that the <u>Operation Plan submitted by the UAS operator represents the optimum for that flight for that operator</u>.

Taking into consideration efficiency as part of the DCB processes could be also a way of determining the most effective DCB solution from the perspective of the Drone Operators. There is a relevant difference between the expectations of the Drone Operators and those of commercial aviation in ATM. In this second case, there could be diverse business models but all of them can be summarised in one single mission objective: to fly from point A to point B at the lowest cost. In U-space, Drone Operators could have different mission objectives, e.g. delivery companies will have the objective of delivering the product to the customer in less than 30 minutes, inspection companies will want to fly as much as they can to complete the inspection. Mission efficiency can be understood in different ways depending on the objectives of each Drone Operator and we need to take these differences on board. Then, we propose two focus areas in this KPA: The **Cost of Operating** and also the **Probability of Achieving Mission Goal**, which is an area very linked to the drone arena.

Within DCB, we must try to judge how efficient the flight is following DCB compared to the original Operation Plan submitted by the UAS operator. In general operations, we would probably compare the flight as flown with the plan, but here our focus is the consideration of how DCB can impact the plans. Then, we need to make a <u>comparison between the filed plan and the regulated plan before the flight takes place.</u>

4.4 Equity

In the ATM-related SESAR approach, Equity KPA is taken into consideration in conjunction with Access. The institutional regard of "Access" in ATM, as stated in the SESAR Performance Framework [33], could be translated as who can obtain access to the ATM system (e.g. obtain an AOC). In U-space, service provision is of a more commercial nature than ATM and thus access might not be an institutional issue. Access to U-space airspace using U-space services may have a financial cost payable by the Drone

Operator to the U-space service provider. Access in U-space might consider the nature of this cost and whether it is the only factor which impacts on the access to U-space airspace, among those who might reasonably expect to have access[3]. The following questions are related to this notion of Access:

- Is the marginal cost-per-flight-hour[4] similar for all users, other factors being equal, or does a high fixed cost penalise operators with fewer flights?
- Are operators who already operate paying similar costs to newcomers, or are there advantages (or disadvantages) for established operators compared to new operators?
- Are operators charged similar costs irrespective of factors such as the place in which they are registered or who owns the business?
- Are operators able to choose between USSPs and switch between them?
- Are USSPs costs transparently published and comparable?
- Are there ownership or other relationships between USSPs and operators that would prevent a service provider offering services to other operators? For example, an operator who generates a large number of flights could also be a USSP.

The questions show that the major driver of Access is the cost of Drone Operators to access the envisioned U-space services which will be provided by different USSPs. We consider that this is not within the scope of the U-space DCB, i.e. decisions in the DCB process cannot be driven by the cost of the U-space services. First, due to the difficulties to calculate these costs in advance, being part of the decision-making processes of DCB. Second, because including this as part of the DCB could imply to have an influence on the envisioned free market to choose between USSPs.

On the other hand, Equity can be addressed from a different perspective. This area in U-space, as in ATM, should examine how negative impacts such as inefficiencies of the system are distributed between the different operators. Equity becomes more relevant in U-space than in ATM because of the diversity of missions and business models in the drone market. The implementation of a DCB measure could impact on some mission types more than others. Then, it is necessary to monitor such imbalances between Drone Operators according to the particularities of their missions. This will allow taking decisions which are more equitable by taking into account the specific characteristics and constraints of the missions operating in an area. Then, Equity should address questions such as if some drone operations are being favoured or penalised by the decisions made in the DCB process.

4.5 Flexibility

Flexibility is a KPA which is very common in the aviation domain and has therefore already been well documented in guiding literature. However, even existing definitions differ from each other depending

[3] Access is expected to be available to organisations which are considered by the regulator to be competent to manage flight safety and adequately financed. Access is theoretically open to “all” but that “all” is more like “all who might reasonably be expected to do so safely and in accordance with the law”.

[4] Flight-hour is a quantity of flight common in manned aviation. U-space might adopt the related but more relevant metric of the flight-minute.

on the area they are aimed at. Two examples are presented below. The first is the ICAO definition of flexibility of the Air Navigation System as a whole, whereas the second is the SESAR definition of flexibility of the ATM system.

- Flexibility addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times thereby permitting them to exploit operational opportunities as they occur [1];
- Flexibility addresses the ability of the ATM System and airports to respond to changes in planned flights and mission. It covers late trajectory modification requests as well as ATFCM measures and departure slot swapping and is applicable to military and civil airspace users covering both scheduled and unscheduled flights [29].

Note the differences in the focus area of both definitions. The first one refers to flexibility that airspace users could have, whereas the second one refers to the flexibility of the ATM system to facilitate associated airspace user requests.

In the case of U-space DCB, the focus is first and foremost on allowing Drone Operators to fulfil their mission requirements in order to exploit business opportunities using drones. As such, the proposed U-space DCB process is inherently user-driven. Flexibility within the U-space domain consists of allowing Drone Operators to modify flight parameters dynamically to accommodate changes in mission requirements. As defined in the DACUS DCB ConOps [3], it is up to U-space DCB processes to balance the provision of such flexibility with the need of maintaining a safe airspace picture for all users. Therefore, the provision of flexibility within U-space must always give way to the "non-modifiable" restrictions set out by the environment in which these vehicles operate in - environment referring to both physical (e.g., buildings, terrain, drone ports) and conceptual (e.g., airspace structure, rules of the air) domains.

The following definition captures this line of reasoning concerning "flexibility" of U-space DCB: Flexibility addresses the ability of U-space DCB to accommodate dynamic flight parameter modifications which allow users to exploit business opportunities as they occur, given the restrictions of the operating environment. Through this KPA, it is possible to monitor how well the U-space DCB process manages to adapt to meet Drone Operators' mission needs.

4.6 Resilience

Resilience as a stand-alone KPA is novel in the aviation domain. Although some elements regarding resilience are covered to a certain extent in other ATM KPAs, the use of resilience as its own KPA has not yet been necessary due to the ATM system's reliance on certification. As per definition, "resilience" is the ability of an ecosystem to return to its original state after being disturbed (*Collins dictionary*). Critical systems in ATM are certified, meaning that they adhere to defined standards and rigorous certification requirements (e.g., built-in redundancy). Therefore, most disruptions in the system are quickly absorbed. Those that are not will likely be captured by Safety, Efficiency or Security KPAs.

The decision to include "resilience" as a KPA for U-space DCB comes from the paradigm shift that U-space is taking away from certification and towards risk management. This allows for much greater flexibility to provide U-space solutions as long as certain risk levels are maintained. This however makes the system much more vulnerable to disruptions, which the "resilience" KPA aims to capture.

Given that the KPA does not yet exist in ATM as a stand-alone area, definitions for resilience from other domains were analysed. Two definitions are presented here, the first is the definition of resilience engineering as a scientific discipline, the second is the definition of resilience in supply chain management (which shares many parallels to the management of DCB processes):

- Resilience Engineering is a discipline that strives to understand how large socio-technical systems cope with the complexity of daily operation. Resilience is concerned with how a system succeeds by adapting its performance to the demands of the environment, not on a failure to do so [30];

- (Supply chain) resilience is the capacity to prepare, plan and construct a network that can anticipate sudden, troublesome or negative disruptions and will adaptively react to interruptions while keeping up command over the network and structure of supply chain [31].

As these definitions highlight, resilience relates to the ability to adapt to unforeseen EXTERNAL disruptions to system processes. This notion is clearly different to flexibility, which relates to the system being able to incorporate INTERNAL changes. This is the reason why we have decided to define two different KPAs which are traditionally managed together in ATM.

Resilience in U-space is related to the ability of the system to monitor its operating environment, anticipate external disruptions and react to them in controlled manner. In this context, “operating environment” refers to disruptions in the physical environment (e.g., infrastructure failures, meteorological disturbances, emergencies) as well as disruptions to the U-space ecosystem (e.g., service performance degradation). Then, other argument in favour of monitoring resilience as part of the DCB is that the number of disruptions in U-space will be much more frequent than in ATM. The high number of drones, the diversity of CNS technologies, the different types of vehicles and emergency procedures are factors which contribute to the fact that drone emergencies or degradation of navigation capabilities, among other disruptions, will be part of the daily operations. Monitoring resilience will allow understanding the impact of such situations.

The following definition captures this line of reasoning concerning “resilience” of U-space DCB: Ability of U-space DCB to adapt to changes of the environment by anticipating and reacting to sudden, troublesome or negative disruptions whilst maintaining the overall performance. This KPA becomes increasingly important to monitor resilience of DCB solutions to disruptions in the tactical phase of operations. Resilience indicators will assist this process by identifying how well the DCB solutions can deal with unexpected changes to the environment. Resilience indicators also serve to understand how much control over the network is kept during tactical disruptions, which can provide insight into any deficiencies that must be accounted for.

Finally, we should highlight that those solutions to improve the overall U-space system resilience such as the redundancy of services, the improvement of ground infrastructure or the definition of USSP certification levels are considered such as “boundary” conditions for the U-space DCB, and are not part of our scope.

5 Influence factors associated with each KPA

This section describes those factors which could influence the previously identified KPAs. The determination of these influence factors will facilitate the selection of primary – and measurable - indicators which are representing how the factors are impacting each KPA, and the identification of quantifiable precursors which will have similar trend than those identified as primary indicators. These precursors could be used when primary indicators cannot be easily quantified.

As an example, one relevant social indicator could be the "visual impact perceived by citizens" in urban environments. This indicator cannot be measured directly, except through citizen feedback by completing interviews and questionnaires, which in the end is a qualitative perception. The identification of factors which are affecting the Social Impact KPA and the theoretical primary indicators such as the "visual impact perceived by citizens", will allow determining precursors, for example, the "mean size of drones in a given airspace" or the "mean flight altitude of drones in a given airspace". In both cases, both precursors are impacting the "visual impact perceived by citizens".

5.1 Capacity

In the previous section, two focus areas in this KPA were identified: Airspace Capacity and Terminal Capacity. Now, a summary of the factors contributing to the different focus areas is detailed. The rationale is focused on airspace capacity, knowing that terminal capacity could be considered as a different piece of airspace in which the target is the same: determine the maximum number of operations ensuring safety.

5.1.1 Airspace Capacity

In the previous section, U-space Capacity was defined as the maximum number of drone operations that can be accommodated in a given airspace for a certain period whilst maintaining safety-related targets. Then, we should take on board how safety is assessed in drone operations. This assessment is mainly done through the Specific Operation Risk Assessment (SORA), which takes into account the ground and air risks of a drone operation. Ground risk considers some characteristics of the drone and how populated the area where the operation takes place is. Air risk considers the risk of collision with manned aviation.

We understand the cumulative risk as the overall risk of causing fatal incidents or injuries to people. This risk will be obtained by considering the risk of direct collision to people on ground and to manned aviation – both taken on board in SORA –, the risk of direct collision to drones with people on board such as taxi drones, and finally, the indirect risk for people on ground or other aircrafts when a collision between two drones takes place.

A wide variety of factors are impacting the cumulative risk. One of the most relevant factors is the performance of the Tactical Conflict Resolution service. In contrast to ATM, the capacity limit will not be determined by the air traffic controller's capability to safely separate aircraft. U-space capacity will be limited by the ability of the Tactical Conflict Resolution to manage the aircraft in flight in order to keep the cumulative risk acceptably low. Other factors, such as the remote control and positioning capabilities of the drone, or the navigation, communication and surveillance data provision, are shown as technical features impacting capacity in Figure 6. Additionally, other aspects related to the characteristics of the traffic and the environment are also identified in the figure. Detailed descriptions of how these factors are impacting the cumulative risk, and then capacity, are included in DACUS D1.1 Annex B [3].

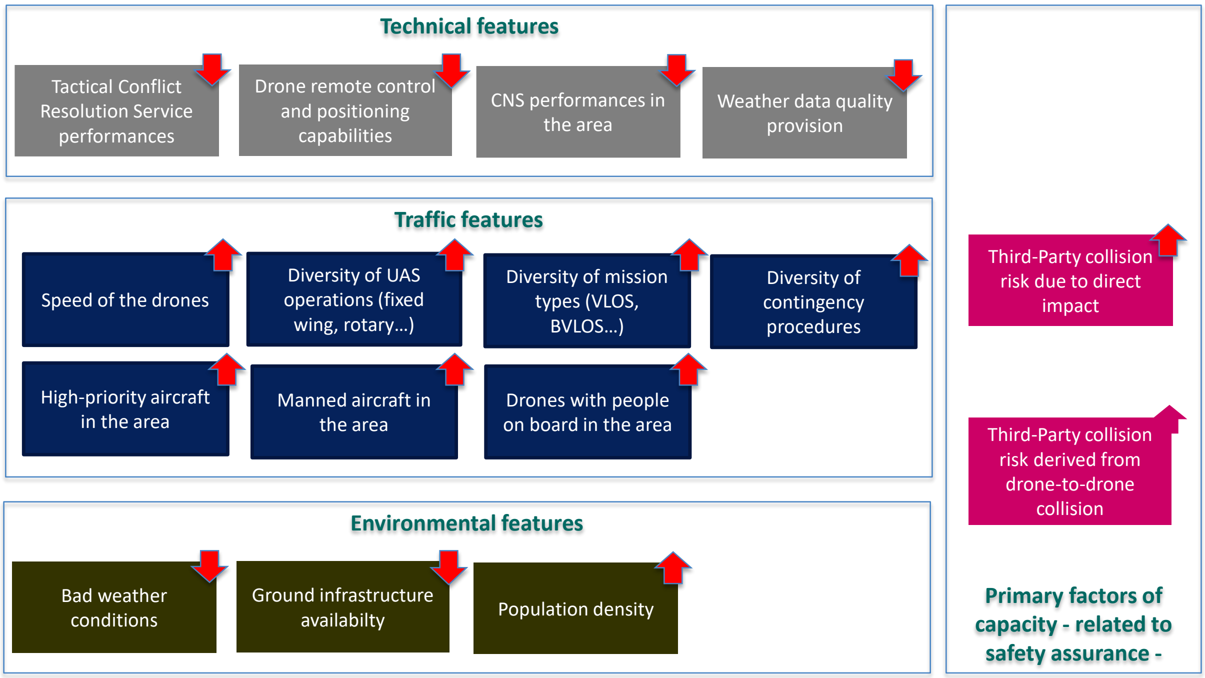


Figure 6: Factors impacting U-space capacity - related to safety assurance -

5.1.2 Terminal Capacity

Most of the drone operations in urban environments will depart or arrive at specific vertiports. We envisioned to have a maximum number of operations per unit of time in each vertiport. We can see that most of the influence factors which are including in Figure 6 will also impact on the number of operations that can be safely managed in a vertiport.

One of the most relevant factors are adverse weather conditions, which in some cases could make it necessary even to close the vertiport, deviating the operations to other landing areas.

5.2 Environmental and Social impact

In the previous section, the key focus areas in this KPA were presented. Now, a summary of the factors contributing to the different focus areas is detailed. For this purpose, a wide literature review was performed (see Annex A section 9.2).

5.2.1 Noise Impact

This focus area treats the impact of noise to citizens or communities. The most obvious indicator of this impact is *annoyance*, which can be described as "all negative feelings such as disturbance, dissatisfaction, displeasure, irritation, and nuisance towards an aircraft operation" [17].

The influence mechanisms through which the aircraft noise influences citizens can be very diverse if all feelings are considered. It has been shown in previous studies that these are not only dependent on physical acoustic mechanisms. As an example, noise levels could be relatively low or under a certain threshold, but if the remaining ambient noise is much lower or the time of the operation is at night, citizens could likely have feelings of disturbance and nuisance. It is therefore important to distinguish between acoustic and non-acoustic factors, as it summarized in Table 4. The latter type of factors leads to what is been referred as "virtual noise". Those which are considered the most significant ones are marked green. As basis for this assessment, the study from Vascik and Hasman [17] has been considered as a reference.

Acoustic Influence Factors	Non-acoustic Influence Factors
a. Sound pressure. b. Event number, duration, spacing, rate and frequency. c. Sound character. d. Spectral composition. e. Flight parameters (height, speed, bearing angle). f. Number of blades per propeller.	I. Ground environment (population density, land use). II. (Personal) noise sensitivity. III. Cultural and living expectations. IV. Adaption and past experience. V. Emotions and personality. VI. Ambient noise. VII. Physical environment. VIII. Time of the day. IX. Weather conditions.

Table 4: Noise Influence Factors

Whereas the relation between noise and some of these factors is clear, others require further explanations:

I. The characterization of the ground environment is one of the main factors that determine the extent of the overall noise impact. The population density and the land use (urban / residential / commercial areas) have been identified in previous DACUS research as the relevant urban environment components [4];

IV. This factor accounts for the temporal timeframe that the listener is exposed to noise. The perception might be positively adapted once the listener has gotten accustomed to the noise, even if the noise levels increase. However, this may take a long period of time to be apparent;

V. Certain sound characteristics can cause fear/anxiety/neuroticism in listeners. This factor can be invariant to a longer or shorter exposure;

VII. The correlation of noise with the air quality/dust can potentiate the noise level. Also the noise insulation of the ground structures around the listener can play a role;

VIII. The most evident differentiation can be made for day and night-time, as the ambient noise considerably changes from day to night. Depending on the air traffic volume at certain timeframes during the day, the noise levels can also vary considerably;

IX. Weather can have different effects on drone noise. Rain makes drones noisier, but also the ambient noise rises. Fog usually has a dampening effect.

5.2.2 Visual Impact and privacy

Another important type of impact is the visual one that, in a similar way as the noise impact, can produce annoyance or negatively influence the community acceptance of drone operations. Therefore, it is conceivable that some influence factors presented previously, such as adaption and past experience, or cultural and living expectations, could play a role in the level of impact.

The DACUS survey and other studies [35][36] have revealed that one of the main concerns of citizens besides noise is privacy infringement by drones. There is still lack of evidence about what could be the concrete influence mechanisms, as with the noise impact. One approach that has been proposed so far is to analyse the aerial congestion (expressed as number of drones flying overhead) over residential and populated areas and to take the effect of technical equipment (cameras) on board that could lead to privacy concerns [18]. Table 5 categorizes the influence factors that are related to the operational management of the missions and those factors related to the technical characteristics of the drone system. Similar to the noise impact, the most significant ones are marked in green.

Operational Influence Factors	Technical Influence Factors
a. Purpose of drone mission. b. Experience or knowledge about drones. c. Number of flights overhead. d. Hovering time overhead. e. Height. f. Ground environment (population density, land use)	I. Size of the drone. II. Configuration and specification of cameras.

Table 5: Visual Influence Factors

The influence of some of these factors on the visual impact are further explained:

a. Assuming that the citizens can learn about the purpose of the mission, they could feel more or less bothered by the operation. For instance, citizens could react more positively if the mission has a search and rescue character. Without having a mechanism in place to inform the citizens about the purpose of the mission it is hard to evaluate their perception;

II. The general use of cameras can grow privacy concerns on the citizens. Added with less knowledge of the purpose of the cameras in the context of the mission, this factor can negatively influence the visual impact.

5.2.3 Wildlife Impact

On the one hand, previously studied use cases have shown that drones can be successfully used to efficiently monitor wildlife without disturbance [36][37][38][39][40][41]. On the other hand, there is evidence which shows that drones can pose a threat to wildlife if the drones perform certain approaches [19].

Similarly, as with the visual impact, the influence factors captured from the literature review have been classified in relation to the operational management and the technical characteristics of the drones. Those factors which are more relevant are identified in green.

Operational Influence Factors	Technical Influence Factors
a. Distance b. Number of flights c. Duration d. Approach speed e. Approach angle	I. Drone noise II. Drone colour

Table 6: Wildlife Influence Factors

5.3 Mission Efficiency

We identified four relevant factors which are affecting one or both of the previously identified Focus Areas – the Cost of operating and the Probability of achieving mission goal. These are flight efficiency, battery life, elapsed time and arriving on time. Table 7 maps these factors with these two Focus Areas. Battery life is impacting both Focus Areas as we will see in section 5.3.2.

Factors of mission efficiency for UAVs	Focus Area	
	Cost of Operating	Probability of achieving mission goal
Flight Efficiency	✓	
Battery life	✓	✓
Elapsed time	✓	
Arriving on time		✓

Table 7 Mission Efficiency Focus Areas

The following sections analyse each of these factors in detail.

5.3.1 Flight efficiency

A big part of the overall efficiency of a mission has to do with the flight segment and how efficiently a trajectory is flown. In manned aviation two measures of flight efficiency are generally used, Horizontal Flight Efficiency and Vertical Flight Efficiency.

Horizontal Flight Efficiency (HFE) [25] compares the 2D distance flown with the optimum. This method usually refers not to the requested plan but to the great circle path joining the start and end of the flights. HFE is widely used, including by ICAO [26].

Vertical Flight Efficiency (VFE) [27] compares the cruise level of the flight with that typically achieved by flights flying a similar route. This measure relies on a pool of statistical data from which this reference can be drawn.

Both measures show how much the flight varies from the shortest path in ATM. There are a number of assumptions in these metrics that are not necessarily valid for UAS and U-space, nevertheless the basic idea may be applicable. For HFE, the most significant assumption is that the 2D distance flown is a useful indicator of other factors that interest the aircraft operator or society as a whole, for example the cost of operating the flight or the amount of CO_2 generated by the flight. For European airliner flights, typically averaging around 1 hour 30 minutes duration, a significant fraction of the distance covered will be at the cruising altitude, hence this 2D measure is useful. Further, as States consider introducing free routing, HFE is a measurable improvement.

For VFE, the same model of a standard flight can be applied, and the requested cruising altitude is generally the most fuel efficient for the aircraft given the load, cost factor, expected wind and so on. Hence VFE is again a proxy for matters of interest to the aircraft operator and society - how closely the flight got to the minimum cost / minimum CO_2 emission.

With these clarifications in mind, flight efficiency for UAS flight can be considered as <u>to what extent is the horizontal or vertical flight made longer than originally planned</u>.

Focusing on this aspect of mission efficiency throughout the DCB process, one secondary factor that can cause DCB to have a noticeable effect on flight efficiency is the airspace structure. U-space does not anticipate a route network in the sense of that used by manned aviation. However there are likely to be commonly used routes and bunching due to the need to avoid ground risk – which may be protected by airspace restriction – and the expected tendency of flight plans to seek optimal paths – those involving paths with less climbing will also tend to group flights –. This may result in a limited range of desirable routes. The fictional example in Figure 7 shows three blue routes bypassing four restricted zones in Hamburg. DCB rerouting action may intend to be subtle but may trigger a switch from one blue route to another. Hence the non-isotropic nature of the airspace may emphasise the impact of DCB on efficiency metrics.

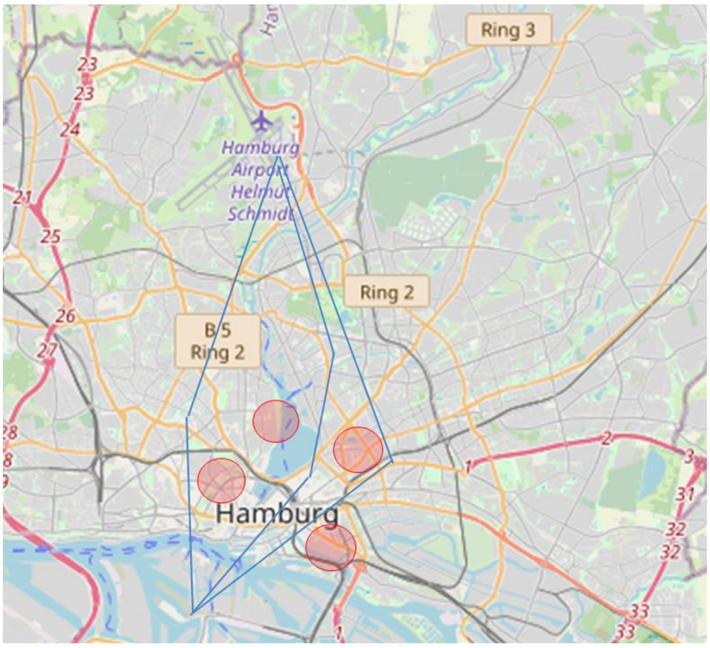


Figure 7 Diversity of routes due to restrictions

A related effect is when a rerouting due to DCB requires a flight to fly over an obstacle. This implies to change the requested flight level increasing the inefficiencies.

5.3.2 Battery life

The majority of UAS, especially small UAS, are expected to be battery-powered for the foreseeable future. Currently, the energy stored per unit weight of batteries is much lower than for liquid fuel for internal combustion engines, which at the time of writing are commonly used. It is safe to assume that for most drone flights in the short and medium term, battery energy capacity will be a limiting factor and hence Operation Plans will be optimised to make the best use of battery. Further, there is a link between how deeply a battery is discharged and the ability of the battery to hold charge afterwards – that is the overall lifetime of the battery. Hence it seems likely that Drone Operators will be interested on quantifying any impact of DCB (or anything else) that will increase the discharge of the battery during a mission, hence reducing range on the current flight and impacting the battery overall lifetime, implying a replacement cost. Hence a good indicator for mission efficiency will be one that is a proxy for energy consumption.

A more extreme effect of DCB may be that the regulated plan is beyond the limit of the endurance of the aircraft. The result may be the cancellation of the plan after DCB. A metric for this might be a count of the number of such cancellations.

In conclusion, the term "battery life" has two meanings, related to the two identified Focus Areas. While both are linked, from now on, the discussion will focus on extent to which the battery is discharged by the mission, thus the energy consumed by the flight.

Proxies for energy consumption are flight efficiency as well as increases in air speed relative to the original plan. As drag is proportional to the square of airspeed, it can be generally assumed that DCB measures that increase the air speed will increase the rate of discharge of the battery. A metric for this speed effect on battery charge is not so easy to develop as the effect we want to look at is something like the integral over the duration of the flight of the square of the instantaneous air speed. Calculating anything like this will require a very detailed trajectory which may not be available before DCB and may require a lot of assumptions to generate after DCB.

5.3.3 Elapsed time

Elapsed mission time or time spent airborne is an interesting efficiency element of a mission as it may represent some other costs associated with flying – such as the number of flights that can be made between maintenance or the costs of piloting the aircraft. Further it may indicate something about the noise (nuisance) of the flight. Then, it may also be interesting for DCB processes that typically resolve excess demand either by rerouting or speed control.

There is an antagonism between the elapsed time metric and the impact of speed on battery charge. A DCB solution that lengthens the path and then "solves" the problem of longer elapsed time by requiring higher airspeed is taking the trade-off between business constraints away from the operator.

Elapsed time flying can increase if path length increases (flight efficiency decreases in our terms), if speed is decreased deliberately as a DCB measure or if rerouting causes the flight to face increased head wind hence groundspeed is reduced as a side effect of DCB. Hovering and holding (flying in circles) is considered as "a deliberate speed decrease," though rather extreme.

5.3.4 Arriving on time

Another mission efficiency measure is the achievement of a mission goal, for example delivery of a package at the planned time. This might be measured by considering the effect of DCB on the arrival time[5]. In the considerations that follow, “arriving on time” is considered to be distinct from “elapsed time”, even though there is an obvious link.

Similar to battery life, some DCB measures could make it difficult to arrive on-time up to a point in which the business goal is unachievable, e.g. a drone will deliver food later than expected by the customer. The metric for this can also be the number of flights cancelled after DCB.

Any effect which increases elapsed time can impact the flight arriving on time. The other related factor is delayed departure, a common method of DCB in manned aviation.

5.3.5 Summary of Influence factors

A more general consideration of influence factors follows in Figure 8. The focus in most of these is the likelihood of clustering. Terrain (relief) and obstacles of any kind are likely to reduce the number of paths (willingly) used by the operators while at the same time increasing the probability of conflict.

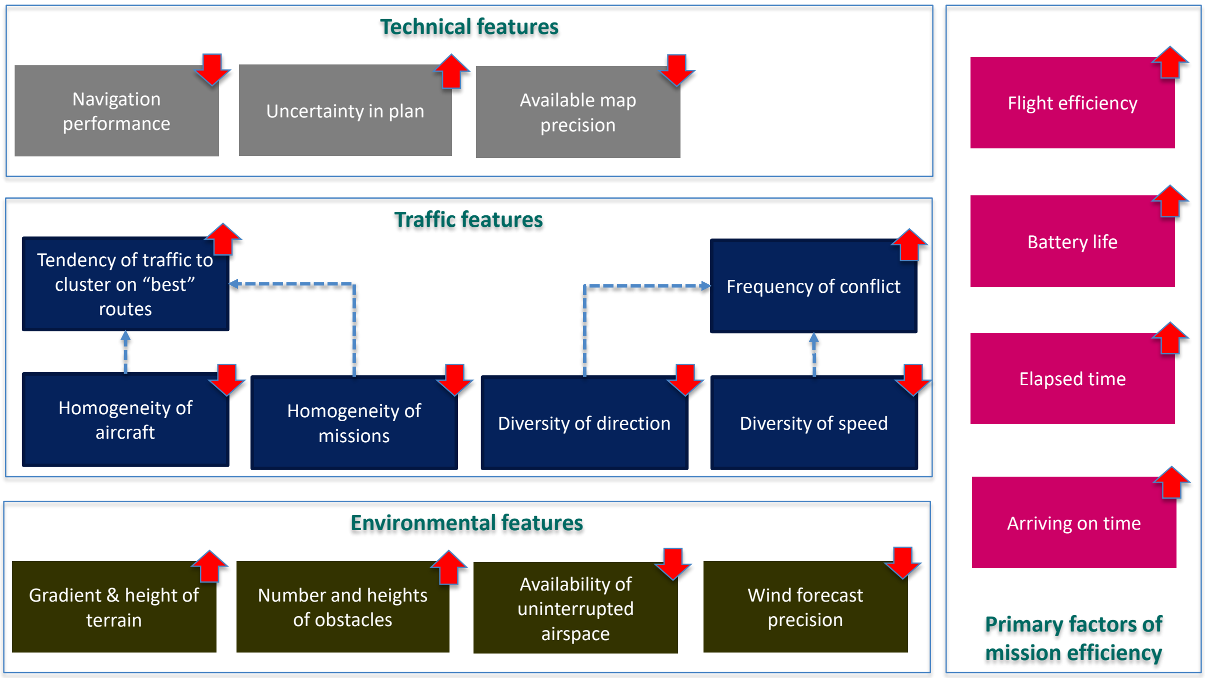


Figure 8 Efficiency influence factors

In this KPA, we propose to directly measure the primary influence factors impacting mission efficiency. Then, it will not be necessary to define precursors indicators to capture the trends of the primary indicators.

[5] The term “punctuality” is not used as in manned aviation where it has often been used to refer to departing on time.

5.4 Equity

SJU PJ19 Performance Framework [33] explains that a lack of Equity can arise if, for example, a particular airspace user or group of airspace users is subject to additional cost or additional delay. This notion of ensuring that there are no imbalances amongst airspace users can be extrapolated to U-space. However, monitoring the distribution of delays is not necessarily a relevant indicator in U-space. The reason is that there will be a wide diversity of DCB measures in U-space which are constraining some of the Drone Operators and not others, and they are not related to impose delays. As an example, a DCB measure could consist of imposing flight levels according to the direction. Drone missions such as package delivery will not be highly impacted but others such as aerial photography will. In conclusion, the differences in the impact to the mission operating costs, and even in the possibility of executing the mission successfully, are key influence factors related to Equity in U-space.

As we have seen in §5.3, there are a lot of factors impacting operating costs and probability of achieving the mission goal. We propose to consider the same factors and analyse the differences among Drone Operators with regards to flight efficiency, battery life consumption, elapsed time and deviations with respect to the expected arrival time.

On the other hand, there is another aspect that should be taken on board both in the Equity and in the Flexibility KPA. DCB processes should promote behaviours that facilitate to plan the day of operations in advance.

One behaviour to be promoted is the submission of the drone operation plans well in advance, and do not request unjustified last-minute changes should be benefited. This is already identified in the DACUS ConOps [3] and in the CORUS ConOps [16]. Both projects sought to establish processes that were fair. DACUS considers that the majority of the DCB measures – in particular, those which imply changes in the submitted drone operation plans – 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. However, those operation plans which are submitted after the RTTA could be penalized.

Another behaviour which could be promoted is the access to the systems performing demand predictions of the drone operators. As today in ATM, drone operators will themselves have predictions that are likely to be more accurate than those of the USSP or CIS providing the DCB services. The provision of this information will improve the demand predictions and then, those operators should be benefited.

DACUS ConOps [3] defines "Virtue Points" which would be awarded to operators whose flights were selected to be delayed or rerouted, or to those operators whose behaviour is benefiting the overall efficiency of the DCB processes. These points would in future be used to raise the priority of a flight. Consequently, both Equity and Flexibility indicators should take on board that this does not mean inequities when distributing the inefficiencies of the system. The way to take on board these effects into the indicators such as the introduction of corrections factors is subject to further debate.

5.5 Flexibility

Flexibility KPA was defined as the ability to accommodate dynamic flight parameter modifications which allow users to exploit business opportunities of using drones as they occur, given the restrictions of the operating environment. For instance, if a local surveying mission reserves an airspace for their operation but will need to amplify the length of time of the operation on short notice because of an unplanned occurrence, they should be provided the flexibility to do so, if the conditions allow. Another example would be the late filing of a package delivery operation beyond the established RTTA. Providing for flexibility means that this operation will still be accommodated, albeit under the restrictions which apply for filing the mission plan beyond RTTA.

In order to better understand the impact of DCB on the provision of flexibility within an airspace, it is best to understand the conditions under which maximum flexibility to users can be provided. In an ideal world, maximum flexibility can be provided to drone operations when infinite airspace capacity is available for an infinite amount of time and no restrictions to operations are applied (full free-routing). Given that this is impossible to achieve in a practical sense, assuring a maximum amount of potential flexibility revolves around providing two fundamental elements:

1. An adequate capacity buffer to absorb dynamic changes to the traffic situation; and
2. Imposing as few spatial and temporal restrictions as possible to drone missions.

It is the combination of available capacity and the number of restrictions that defines how much flexibility the DCB solutions can provide. As it will be explained in the following sections, we are assuming that capacity buffers are addressed by the Capacity KPA. Then, we will focus on understanding if two DCB solutions providing the same capacity buffers can provide different levels of flexibility to the Drone Operators.

5.5.1 Capacity buffers

Providing a large capacity buffer will allow U-space DCB to accept unplanned missions and changes to existing ones on short-notice. The combination of several factors will determine how large the available capacity buffer will be. These factors can be static or dynamic. Static factors, such as those of the operating environment (spatial restrictions, operational restrictions, CNS performances, route structures, rules of the air, etc.), would be considered boundary conditions which determine a fixed limit to the capacity buffer. Dynamic factors are those which have the potential to change the available capacity buffer over time. Therefore, influence factors on flexibility are those dynamic factors which limit the amount of available capacity buffer at a given time. Then, these influence factors are those factors identified in Figure 6 which can dynamically vary with the time.

The relation between static and dynamic factors is outlined graphically in Figure 9. As long as the declared airspace capacity is larger than the combined impact of static factors, a capacity buffer is present, and as such, flexibility can be provided. Therefore, there is always a means to provide flexibility as long as no demand and capacity imbalance is present. As soon as demand exceeds the declared airspace capacity however, no flexibility can be provided given the lack of available capacity, and a DCB measure is applied. DCB measures will assure that, through a specific manner, capacity will exceed demand in the overloaded situation. The amount of available capacity buffer that the DCB solution manages to provide influences the amount of flexibility that can be given to drone operations.

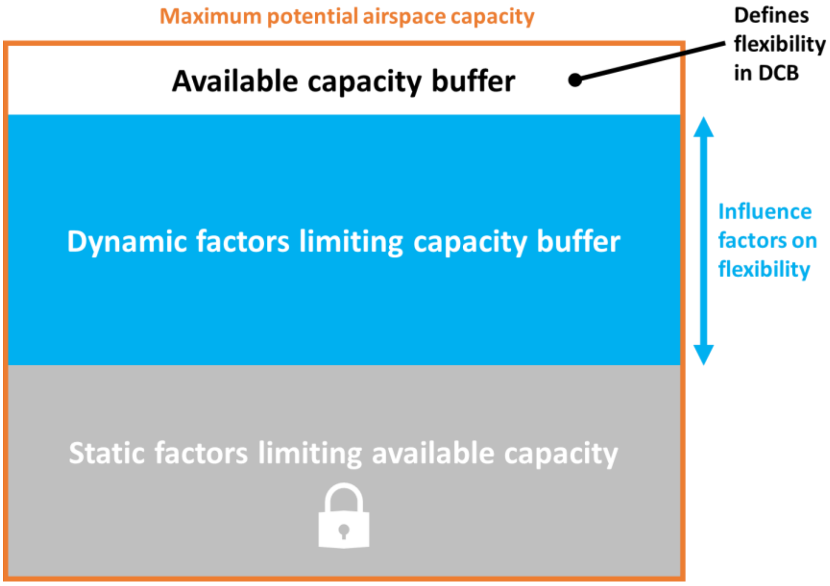


Figure 9: Representation of the impact of dynamic and static restrictions on the capacity buffer.

We have seen that there is a close relation between the flexibility that can be provided to Drone Operators and the capacity buffer resulting from the implementation of a DCB solution. The more capacity is provided over the expected demand, the more flexibility exists.

Whereas this aspect of flexibility will be addressed by the Capacity KPA, we should wonder if two DCB solutions providing the same capacity can provide different levels of flexibility to the Drone Operators. This is analysed in the following sub-section.

5.5.2 Restrictions on drone missions

It is clear that the size of the capacity buffer defines to which extent flexibility can be provided to Drone Operators. However, even the largest capacity buffer cannot provide flexibility if the operating restrictions to achieve it are so strict that no changes can be made. Any restriction on operations away from full free-route airspace decreases flexibility of users.

Similar to capacity, restrictions on drone missions can be static or dynamic. Static restrictions are those which define the rules on how operations must take place in a given area. These include, among others, airspace classifications, flight rules, restrictions due to noise, as well as proximity to reserved and prohibited areas. Again, we will focus on dynamic factors which determine restrictions to drone missions.

DCB measures which affect demand by nature impose restrictions on operations. Therefore, the type of DCB solution influences the amount of flexibility which can be provided to all missions, or in some cases only to a specific type of mission. Some examples are shown in the following bullets:

- The implementation of any DCB solution which will increase **restrictions in the airspace** will decrease flexibility. For instance, the organization of airspace from “free-route” to a “layers” concept will restrict flexibility of all users. However, point-to-point missions will be less affected by this change than those which require a fixed flight profile or operating volume. On the other hand, an organization of the airspace into a “tubes” concept will limit point-to-point missions but potentially provide more room for localized missions, and subsequently more flexibility. In summary, the organization of airspace as a DCB measure will reduce overall flexibility, but potentially affect some missions more than others;

- DCB measures with longer **duration will uphold restrictions** on drone operations for a longer time. Therefore, shorter DCB measures should be preferred to limit the decrease in flexibility.

5.6 Resilience

Resilience KPA was defined as the ability to adapt to changes of the environment by anticipating and reacting to sudden, troublesome, or negative disruptions whilst maintaining the overall performance. Then, the core of resilience as a KPA is the ability of U-space DCB solutions to deal with external disruptions. At this point, we should analyse the factors causing that a DCB solution is more resilient to certain disruptions than others. We assume that a DCB solution can be highly resilient to a specific disturbance, but it could be strongly impacted by another. The different types of disruptions in U-space and their impact were analysed in the DACUS ConOps pp.76-78 [3].

As an example, we consider a disruption caused by a drone emergency. As stated in [3], the Operation Plan processing service will recalculate a new 4D trajectory based on the contingency plan which is part of the approved Operation Plan. If no DCB solution is in place, drone operations in the surrounding will avoid the assigned area for emergency protection. As drones are flying in free-route, trajectories can be adapted without altering the overall network.

If a DCB solution is active when the emergency is declared, two factors will provoke higher impact on the network; on one hand, the emergency trajectory might be inconsistent with the airspace or flow organization in place; on the other hand, affected drone operations might be requested to get out of the emergency area without respecting that organization.

We will compare two different DCB solutions to determine which of them is more resilient to a drone emergency and the reasons that underlie. Figure 10 shows an emergency with several drones which are requested to exit the impacted area (in red colour). Due to the high demand, a DCB solution was implemented to organize the traffic flow per layers. Drones will exit the area by using the faster trajectory without moving to a different layer. Then, the unexpected event is not expanded out of that area, and the disturbance can be absorbed.

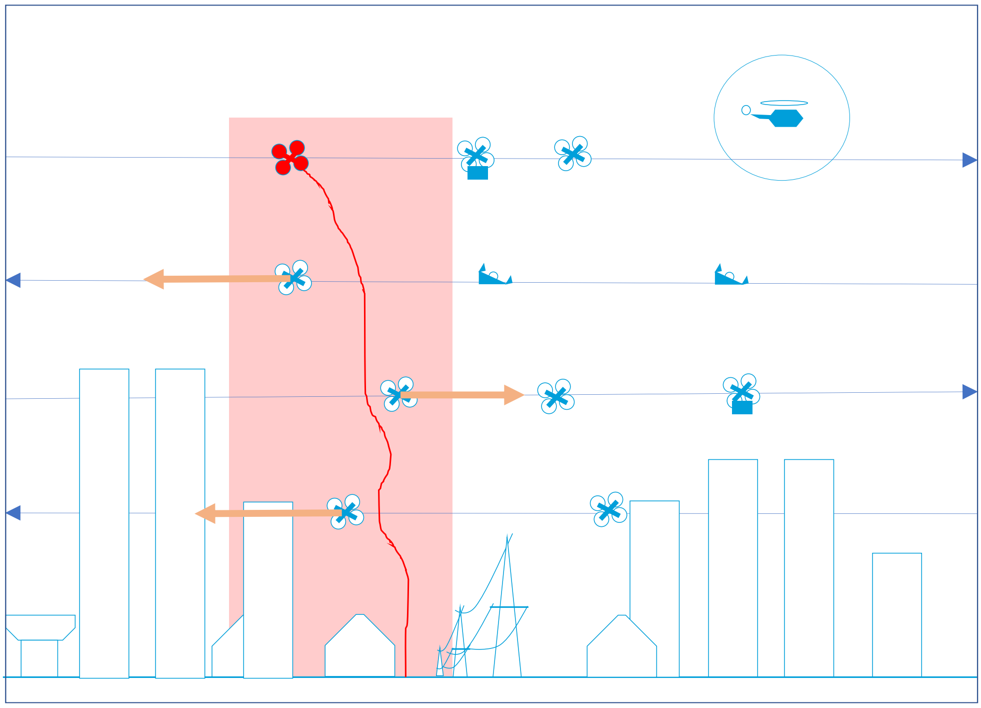


Figure 10 Drone emergency with organization of flows per layer is in place

Figure 11 shows the same emergency with a different DCB solution in place. In this case, a highly structured organization based on tubes was implemented. Intuitively, the affected drones will have less options to exit the area as soon as possible, and at the same time, respecting the existing organization in tubes. Consequently, they could impact to other drones which are out of the affected area.

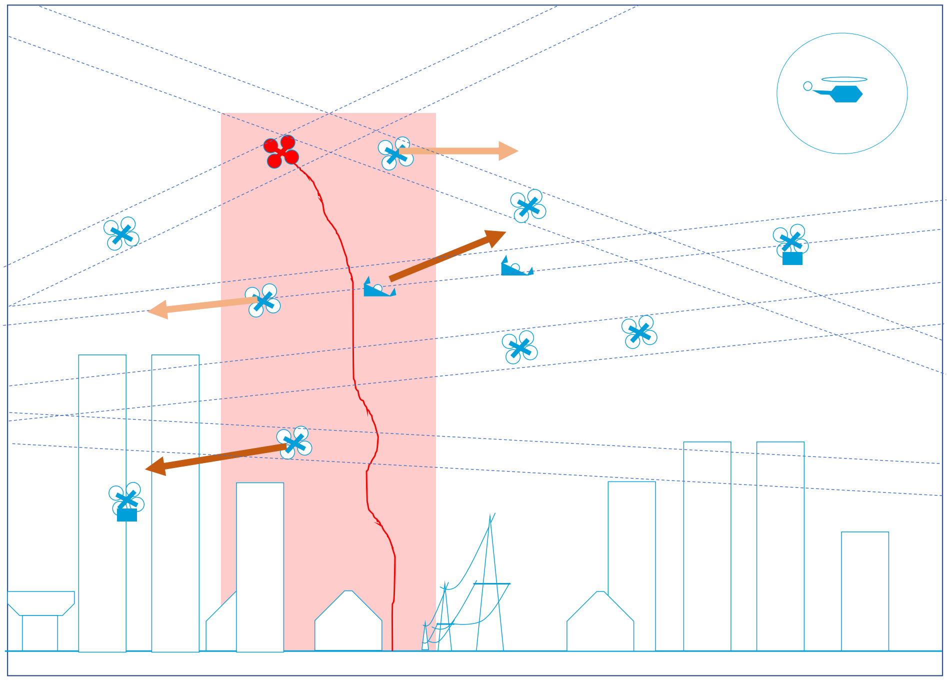


Figure 11 Drone emergency with organization of flows by tubes is in place

As stated in [3], the disruptions in U-space can be classified as follows: navigation disturbances, communication disturbances, electromagnetic disturbances, meteorological disruptions, drone emergencies, service performance degradation or service emergencies, city-originated disturbances, airport-originated and ATM-originated disturbances. In general, all of them cause an increase of the collision risk in the area. To keep the collision risk below the threshold, several alternatives are identified depending on the origin of the disturbance:

- All drones in the affected area need to get out as soon as possible, e.g. disturbance caused by a drone emergency;
- Drones do not need to exit, but it is necessary to increase the separation between them by taking into consideration how the perturbation is impacting the separation standards. As examples, Table 9 shows that the increase of the latency or unexpected changes in the wind conditions increase the separation standards.

Consequently, all disturbances make it necessary to reorganize the traffic in the affected area as soon as possible because the collision risk values in that area are probably above acceptable thresholds. Then, the disturbance is quicky absorbed and the network is able to recover without high impact.

On the other hand, the reorganization of the traffic in the affected area could impact other drone operations in the surrounding, especially in those cases in which affected drones are not respecting the existing traffic organization scheme. In this case, although the disturbance in the affected area could be quicky absorbed, the effects are extended to a wider area.

Diverse factors are impacting the capability of the system to reorganize the traffic. We have seen in the example that a DCB solution which is imposing higher restrictions to the drone operations in the area seems to be more impacted by a disruption in the tactical phase. Then, **existing restrictions to drone operations is identified as an influence factor on the resilience**. The question is how to quantify this notion of “DCB measure which imposes higher restrictions to the drone operations”.

Another factor which is affecting the capability to reorganize the traffic is **the duration of the potential disturbances**. If the duration is long, it is necessary to adapt other Operation Plans which are not yet in the affected area or even they are still on ground, but they will be affected by the disturbance in the short to medium-term.

On the other hand, following these arguments, the characteristics of the traffic in the area affected by the disruption will also have an influence on how easily the disruption can be absorbed. One of these factors is the **typology of the drones** (quadcopters, fix wing drones, etc.) operating in the airspace. As an example, fixed wing drones will have less options of getting out of the affected area when a disruption is taking place.

Finally, an additional factor could be the **type of contingency plans or emergency protocols** of the drones operating in the area. Some of drones should return to home in case of a loss of datalink, others will land automatically in a dedicated landing area or they will deploy an emergency parachute. This implies that the extension of the area affected the emergency of each drone will be different. Consequently, the number of drones impacted will be higher.

Something to be further discussed is whether some of these factors (such as the typology of drones) are external factors to DCB and whether they should be considered as “boundary" conditions of the process. In any case, monitoring these factors will allow understanding if the system can be more penalized in case of a disturbance, and consequently, DCB solutions which provide higher resilience should be prioritized. In other words, we should be able to measure if the resilience of the nominal scenario – no DCB measures are implemented – is high or not. If resilience is low, DCB measures with higher resilience could be recommended.

The following figure shows an overview of all factors identified, including those which are considered static, because they are very related to the airspace in which the DCB process takes place.

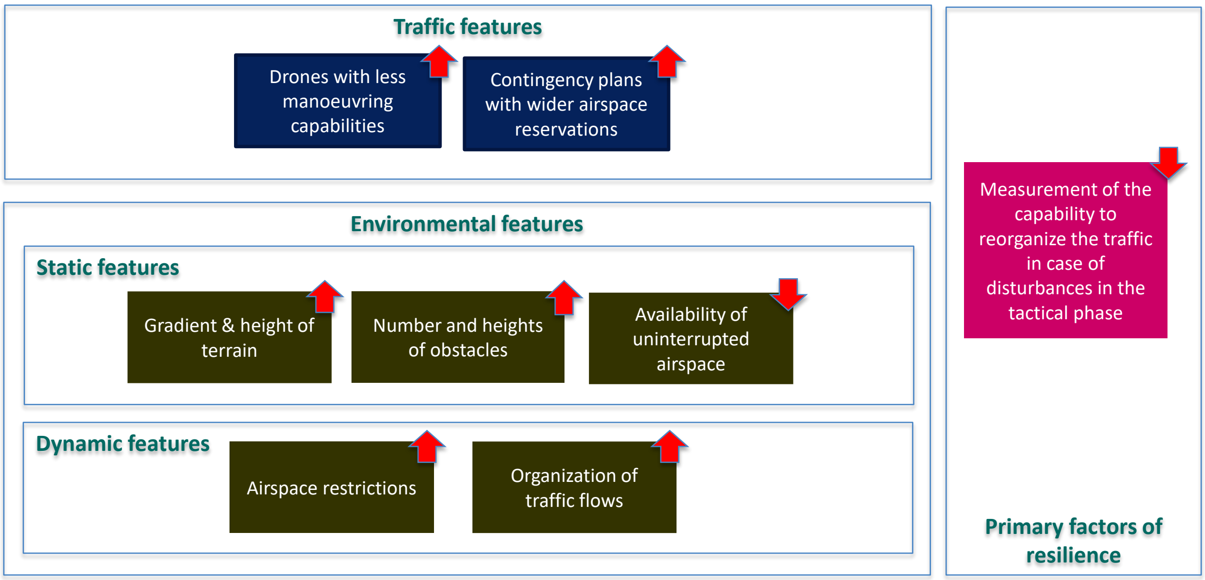


Figure 12 Resilience influence factors

6 KPIs and DCB decision-making

This section details the requirements of the indicators to design a performance-based decision-making processes for U-space DCB. Indicators will allow taking informed decisions along the different processes which are in place, driven by foreseen results and relying on up-to-date data. In general, each indicator should be characterized by:

- Its "understanding", which represents if it is easy to understand the indicator, what it means;
- Its "Representativeness", which means if it is representative enough of the behaviour of the key factors which are influencing the KPA;
- Its "Applicability", as part of the DCB processes with are identified in Chapter 3.

In the next chapters, justifications and challenges associated with the calculation of each indicator are included. The level of detail is not the same in all KPAs because of the different maturity of each KPA within DCB, e.g. capacity is a mature area as it is commonly used in ATM as part of the DCB.

6.1 Capacity

6.1.1 DCB processes and capacity

First, we should question if it is necessary to monitor capacity in the U-space DCB processes. In other words, if U-space had no difficulties to meet the envisioned airspace user demand, it would not be necessary to monitor capacity indicators. There are a lot of investigations [5] [6] [7] showing that these difficulties will exist. As an example, AIRBUS concluded in the study "Metrics to characterize dense airspace traffic" that "*traffic will be 'dense' at levels below what we expect to see in urban areas*". Then, we are assuming that maximum number of operations should be limited due to safety concerns, i.e., in order to keep the cumulative risk acceptably low.

The need to monitor the maximum number of operations as a function of the cumulative risk is extended to the different phases of the DCB processes. Then, we need to define indicators which could be used in the **strategic, pre-tactical and the tactical phases** identified in the DACUS DCB concept. In addition, several high-level requirements of the capacity indicators were identified in [3]. They are summarized in the following bullets:

1. Applicability in the strategic, pre-tactical and tactical phases;
2. Capacity indicators based on the cumulative risk shall consider third-party ground and air risk;
3. They shall 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 to provide the highest level of service to its users;
4. Mean values of the indicators in a certain period shall be calculated to identify trends and not instantaneous values that can drastically change from one instant to the next. Due to the dynamic nature of drone operations and the expected dynamicity when implementing DCB measures, this period shall be reduced in comparison with the 20-minute time slot in ATM;

5. They shall support the establishment of a consolidated global traffic picture in the RTTA. Therefore, the values of these indicators shall not substantially change with minor updates of the Operation Plans;

6. They shall quantify the impact of the uncertainty of the operation plans as a fundamental part of the overall DCB process;

7. They shall quantify the different priorities of the foreseen missions in each pre-defined airspace volume and time, including existing manned operations, as a limiting factor of the maximum number of operations;

8. Capacity indicators shall allow comparing their actual or predicted values with certain safety thresholds for each pre-defined airspace volume and time, supporting the identification of areas above the thresholds, i.e., hot-spots;

9. Capacity indicators shall be easily understandable to allow authorities deciding on the level of safety that shall be maintained in each pre-defined airspace volume and time;

10. Capacity indicators shall allow comparing the effectiveness of several DCB measures to minimize hot-spots;

11. They shall be able to quantify specifically the risk of collision with manned aviation and with UAM operations with people on board. This requirement is aligned with the performance expectations which are defined in some of the existing UAM ConOps [14].

The following figure is a part of Figure 3, Figure 4 and Figure 5 that identifies the DCB processes which should monitor capacity metrics to support their decision-making. The methodology to calculate the indicators or even the indicators to be used in each planning phase could be different due to the potential impact of the uncertainty of the demand on their calculation. In particular, in the strategic phase, it is relevant to use capacity-related indicators that do not substantially change with minor updates of the operation plans. Otherwise, decisions based on these indicators could reduce their effectiveness, e.g. a DCB measure cannot be implemented because the global view of the indicator could drastically change.

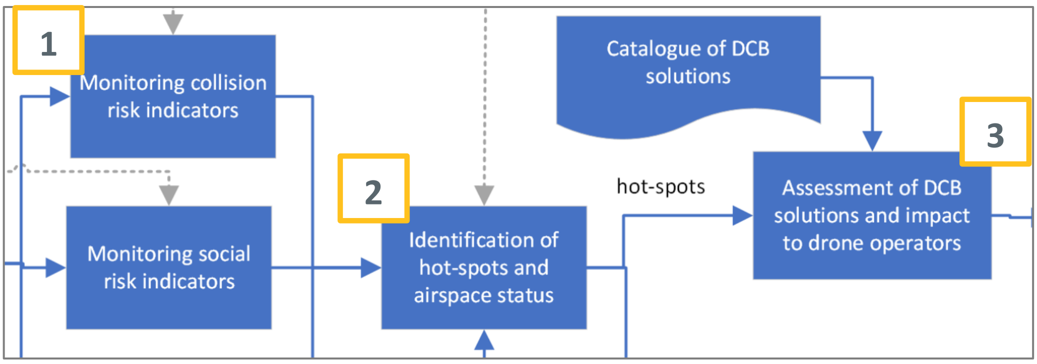


Figure 13: DCB processes which needs capacity indicators in all planning phases.

6.1.2 Definition of indicators

The following table shows an overview of the proposed indicators which are described in the detail in the following sections. Although some of these indicators are based on instantaneous values, we assume that mean values in a certain period shall be calculated. This period needs to be determined in the DACUS experiments, but we foresee a shorter time period than the 20-minute time-slot which is typically used in ATM.

Ind.	Focus Area	Name	Description	Units
A.CAP1	Airspace capacity	Cumulative risk against link-third parties.	Overall risk of causing fatal incidents or injuries to people in an area.	Risks per flight hour in an area.
A.CAP2	Airspace capacity	Average Lowest closing time.	Amount of time that aircraft will have to react and manoeuvre to avoid other aircrafts.	Seconds in each time instant in an area.
A.CAP3	Airspace capacity	Number of Close Aircraft.	Number of aircraft that are at risk of collision (one of them could have time to do an avoidance manoeuvre).	% of aircraft over the total number of aircraft in an area per time instant.
A.CAP4	Airspace capacity	Flight time manoeuvring.	Average for all aircraft in an area of the time doing avoidance manoeuvres.	% of time doing avoidance manoeuvres over the total time in an area per time slot.
A.CAP5	Airspace capacity	Number of severe intrusions	Number of aircraft that are at risk of collision without the possibility of doing an avoidance manoeuvre.	% over the total aircraft in the area per time instant
V.CAP1	Airspace capacity	Maximum number of drone operations	Maximum number of drone operations which can be accommodated in all vertiports in a given area per time unit	Number of operations per time slot.
V.CAP2	Terminal capacity	Vertiport distribution.	Standard deviation of the number of vertiports per square meter in each area of the city.	% of deviation.
V.CAP3	Terminal capacity	Delays per drone operation.	Delays on ground and airborne holding in the vertiports of an area.	Minutes of delay per operation.

Table 8: Summary of the capacity indicators

6.1.2.1 Focus Area: Airspace

The notion of “dense traffic” is quantified through diverse indicators that were proposed in previous bibliography - Appendix A, Section 9.1.

A.CAP1. Cumulative risk against link-third parties.

It is defined as the overall risk of causing fatal incidents or injuries to people in an area. This indicator is integrating the ground risk - considering the risk of direct collision to people on ground and the indirect risk for people on ground when a collision between two drones takes place - and the air risk-considering the risk of direct collision to manned aviation, the risk of direct collision to drones with people on board such as taxi drones, and finally, the indirect risk for other manned aircraft when a collision between two drones takes place.

A.CAP2. Average Lowest closing time.

This is computed by looking at all the aircraft in the airspace, measuring their closing time (distance from the ownship to another aircraft, divided by the speed at which the other aircraft is moving toward the ownship), and selecting the lowest for each single aircraft. This measure approximates the amount of time that the ownship has to react and manoeuvre to the situation when it must manoeuvre to avoid another aircraft.

The indicator will consider the average for all aircraft in a certain airspace is calculated. Probabilistic 4D trajectories will allow calculation statistical deviations of the mean values.

A.CAP3. Number of Close Aircraft.

This is determined by computing the lowest closing time for all aircraft in the airspace and counting the number that have a closing time less than the seconds assigned to each aircraft to perform an avoidance manoeuvre according to its capabilities (this will be named as the “minimum closing time”).

This metric makes necessary to define the time which is needed by each aircraft to perform an avoidance manoeuvre. As an example, 15 seconds is approximately the time for avoidance manoeuvre in manned aircraft with TCAS. However, the thresholds for UAVs are not yet determined, and likely vary widely: a remotely-piloted fixed-wing UAV being operated using VLOS rules at the extreme of visual line-of-sight distance seems likely to have reaction times much slower than those assumed by TCAS, while an autonomous UAV with high performance on-board detection capabilities is likely to react much faster.

In conclusion, this indicator can be implemented provided that **a categorization of the minimum closing time is determined**. An initial categorization can be extracted by the previous work done in IMPETUS project. These factors were successfully implemented in IMPETUS for the design of the Tactical Conflict Resolution service. The table allows identifying those influence factors on capacity that were successfully taken on board in part studies.

Probabilistic 4D trajectories in the Operation Plan will allow calculation statistical deviations of the mean values.

	Fixed wing				**Rotary**			
Drone operation	Autonomous	Automated	Semi-automated	Human controlled	Autonomous	Automated	Semi-automated	Human controlled
Standard separation	5	5	5	8	3	3	3	5

	Fixed wing				Rotary			
Drone operation	Autonomous	Automated	Semi-automated	Human controlled	Autonomous	Automated	Semi-automated	Human controlled
Drone speed: $10km^{-1}$	3	3	3	5	3	3	3	5
$30km^{-1}$	5	5	5	8	5	5	5	8
Endurance	5	5	5	8				
Mission VLOS	N/A	N/A	5	8	N/A	N/A	3	5
BVLOS	5	5	N/A	N/A	3	3	N/A	N/A
Location Rural	5	5	5	8	3	3	3	5
Semi Urban	5	5	5	8	3	3	3	5
Urban	3	3	3	5	2	2	2	3
Mission Priority:								
Emergency service flight	10	10	10	10	10	10	10	10
Commercial flight	5	5	5	8	3	3	3	5
Recreational flight	N/A	N/A	5	8	N/A	N/A	3	5
Drone electronic conspicuity:								
Plan only								
ADS-B	10	10	10	12	10	10	10	12
LTE	5	5	5	8	3	3	3	5
combination	5	5	5	8	3	3	3	5
	3	3	3	5	2	2	2	3
Drone command:								
LTE	5	5	5	8	3	3	3	5
GCS	5	5	5	8	3	3	3	5
Human control	N/A	N/A	N/A	8	N/A	N/A	N/A	8
LTE Coverage								
Poor	8	8	8	10	5	5	5	8
Good	3	3	3	5	2	2	2	3
Latency (poor)	8	8	8	10	5	5	5	8
Weather data quality:								
National	8	8	8	10	5	5	5	8
Regional	5	5	5	8	3	3	3	5

	Fixed wing				Rotary			
Drone operation	Autonomous	Automated	Semi-automated	Human controlled	Autonomous	Automated	Semi-automated	Human controlled
Hyper local	3	3	3	5	2	2	2	3
Actual weather; wind speed								
Low	5	5	5	8	3	3	3	5
Medium	8	8	8	10	5	5	5	8
high	10	10	10	N/A	8	8	8	N/A

Table 9: Dynamic Separation Criteria in IMPETUS project [5]

A.CAP4. Flight time manoeuvring.

This is determined by calculating the percentage of the time within each pre-defined airspace volume in which each drone has a minimum closing time lower than the minimum time threshold to perform avoidance manoeuvres according to the categorisation of the drone. Then, the mean value for all drone operations which are at each airspace volume is calculated.

This may be calculated by considering the average for all aircraft per time slot. The suitable time slot could be determined assessing how the indicator varies with the time. DACUS ConOps [3] assumed that this time slot will be reduced with respect to the 20-minute time slot in ATM.

A.CAP5. Number of severe intrusions.

This is determined by identifying the number of close aircraft in a portion of airspace in each instant of time and distinguishing between those which are identified as severe intrusions. The challenge of this indicator is to be able to **categorise the severity of the intrusions**. We propose to identify those pairs of drones in which both aircraft have a closing time lower than their minimum closing time, i.e. none of them has the possibility of avoiding the collision.

The following table shows the identification of those influence factors which are taken on board by each indicator and the justification. The colour code – red, yellow and green – shows up to which point the factor behaviour is captured by each indicator. For those factors which cannot be considered by any indicator, their impact on the maximum manageable aircraft in the area could be captured by increasing or reducing the thresholds of the indicators.

	A.CAP1 Cumulative risk against people	A.CAP2 Average lowest closing time	A.CAP3 Number of close aircraft	A.CAP4 Flight time manoeuvring	A.CAP5 Number of severe intrusions
Tactical Conflict Resolution perf.	This influence factor can be taken on board in a collision risk model.	No changes in the indicator.	The seconds-minimum closing time - to determine the number of close aircraft can vary depending on this influence factor[6].	This indicator is derived from CAP3. Then, TCR performances are taken on board.	Assuming that a severe intrusion will occur in both aircraft at risk have lower closing time than the minimum, TCR performances of both aircraft are considered.
Drone remote control and positioning capabilities	This influence factor can be taken on board in a collision risk model.	No changes in the indicator.	The seconds – minimum closing time - to determine the number of close aircraft can vary depending on this influence factor.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.
CNS performances	This influence factor can be taken on board in a collision risk model.	No changes in the indicator.	The seconds – minimum closing time - to determine the number of close aircraft can vary depending on this influence factor.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.
Weather data quality provision	Difficulties to take on board in the collision risk model.	No changes in the indicator.	Weather data quality can be a factor impacting the minimum closing time as it is shown in Table 10.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.
Speed of the drones	This influence factor will be one of the most relevant factors in a collision risk model.	The indicator varies with the speed of the drones.	The indicator varies with the speed of the drones.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.

[6] This can be understood as the key factor that determines the standard separation according to Table 9.

	A.CAP1 Cumulative risk against people	A.CAP2 Average lowest closing time	A.CAP3 Number of close aircraft	A.CAP4 Flight time manoeuvring	A.CAP5 Number of severe intrusions
Diversity of UAS operations (fixed wing, rotary)	This influence factor can be taken on board in a collision risk model.	No direct changes in the indicator. As velocity considers the drone type, this influence factor can be considered as partially addressed.	The seconds – minimum closing time - to determine the number of close aircraft can vary depending on this influence factor.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.
Diversity of mission types (VLOS, BVLOS)	This influence factor can be taken on board in a collision risk model.	No changes in the indicator.	The seconds – minimum closing time - to determine the number of close aircraft can vary depending on this influence factor.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.
Diversity of contingency procedures	Difficulties to take on board in the collision risk model.	No changes in the indicator.	Difficulties to determine time separation standards based on foreseen contingency procedures. Anyway, this is not local as some standard methods exist (parachute…)	This indicator is derived from CAP3. Then, the factor is taken on board in the same way.	This indicator is derived from CAP3. Then, the factor is taken on board in the same way.
High-priority aircraft in the area[7]	This influence factor can be taken on board in a collision risk model provided that pre-defined categorization of priorities is agreed.	No changes in the indicator.	Need to define time separation standards for a pre-defined categorization of priorities.	This indicator is derived from CAP3. Then, the factor is taken on board in the same way.	This indicator is derived from CAP3. Then, the factor is taken on board in the same way.

[7] Another option to capture this influence factor is by defining the threshold of the indicator, which will vary depending on the number of high-priority flights.

	A.CAP1 Cumulative risk against people	A.CAP2 Average lowest closing time	A.CAP3 Number of close aircraft	A.CAP4 Flight time manoeuvring	A.CAP5 Number of severe intrusions
Manned aircraft in the area	This influence factor can be taken on board in a collision risk model.	No changes in the indicator.	A larger minimum closing time could be defined in case of manned aircraft. If it is included in the indicator description, no need to reduce the threshold depending on the number of manned aircraft in the area.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.
Drones with people on board in the area	This influence factor can be taken on board in a collision risk model.	No changes in the indicator.	Minimum closing time will be the same than for manned aircraft.	This indicator is derived from CAP3. Then, the factor is taken on board.	This indicator is derived from CAP3. Then, the factor is taken on board.
Bad weather conditions[8]	Difficulties to take on board in the collision risk model.	No changes in the indicator.	Difficulties to determine time separation standards based on weather conditions as this is closely linked to the local environment.	This indicator is derived from CAP3. Then, the factor is not taken on board.	This indicator is derived from CAP3. Then, the factor is not taken on board.
Ground infrastructure availability	Difficulties to take on board in the collision risk model.	No changes in the indicator.	Difficulties to determine time separation standards based on ground infrastructure availability as this is closely linked to the local environment.	This indicator is derived from CAP3. Then, the factor is not taken on board.	This indicator is derived from CAP3. Then, the factor is not taken on board.

[8] Instead of characterising this factor in the indicators, specific thresholds can be used to reduce the number of operations in case of bad weather conditions.

	A.CAP1 Cumulative risk against people	A.CAP2 Average lowest closing time	A.CAP3 Number of close aircraft	A.CAP4 Flight time manoeuvring	A.CAP5 Number of severe intrusions
Population density[9]	This influence factor can be taken on board in a collision risk model.	No changes in the indicator.	The seconds – minimum closing time - to determine the number of close aircraft can vary depending on the ground category. Minimum closing time could vary along the trajectory. Difficulties to standardize.	This indicator is derived from CAP3. Then, the factor can be captured in the same way.	This indicator is derived from CAP3. Then, the factor can be captured in the same way.

Table 10: Capacity indicators versus influence factors

The pros and cons of each indicator are identified in the following table. Given that the indicators should be used to determine the maximum number of drones that can be managed in certain period for a given airspace, the feasibility of using the indicators for this purpose is one of the key requirements to be covered. The rest of high-level requirements identified in §6.1.1 are used as a reference to identify the pros and cons of each indicator. Those requirements that could not be fully covered by each indicator are marked in red, and those which are fully covered by the indicator are marked in green.

	Req.	Pros	Cons
A.CAP1 **Collision risk**	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	**Acceptable threshold is predefined.** Intuitive indicator that could support the definition of thresholds by authorities. Emphasis on collisions with manned aviation.	**One single trajectory could change the overall picture. Then it could be less useful if the strategic phase where the overall picture is less stable.** Difficulties to decompose in cells of the grid. Need to assess how to capture the uncertainty of drone operations.
A.CAP2 **Average Lowest Closing time**	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	Easy to decompose in cells of the grid by calculating the average of all aircraft in each cell. Even the mean value in a time slot could be easily obtained.	No predefined threshold. Difficulties to define the thresholds by authorities. Need to assess how to capture the uncertainty of drone operations.

[9] With respect to population density, a categorization could be done taking into account a theoretical ground category according to the expected population. As an example, rural, semi-urban, urban type “A”, urban “type “B”, etc.

	Req.	Pros	Cons
A.CAP3 **Close aircraft**	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	Easy to decompose in cells of the grid. Tactical conflict resolution performances are captured by determining the necessary time to perform an avoidance manoeuvre. Priorities and manned aviation requirements could be captured by imposing more separation.	No predefined threshold although it could be easier to understand by authorities. Need to characterize the minimum time to perform an avoidance manoeuvre according to the key influence factors. Need to assess how to capture the uncertainty of drone operations.
A.CAP4 **Flight time man.**	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	Easy to decompose in cells of the grid. Intuitive for Drone Operators. Allowing to determine thresholds according to their inputs. So, we have a consolidated traffic picture to take decisions.	Previous bibliography [6] exists with respect to the maximum (10%). Rationale should be properly justified. Need to assess how to capture the uncertainty of drone operations.
A.CAP5 **Severe intrusions**	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	This indicator is more related to safety concerns and risk of collision, and maybe it could be more useful than CAP1 in the strategic phase. Easy to decompose in cells of the grid. Risk of collision with manned aviation could be emphasized.	Intuitive for regulatory entities and authorities to stablish the thresholds. Need to assess how to capture the uncertainty of drone operations.

Table 11: Capacity indicators versus high-level requirements in the DCB process

6.1.2.2 Focus Area: Terminal area

We propose to use standard indicators as those defined in ATM. Some of these indicators were successfully used in [12] such as the maximum number of drone operations that can be accommodated in the hub per time unit, or the minutes of delay in the hub per time unit.

V.CAP1. Maximum number of drone operations

This indicator quantifies the maximum number of drone operations which can be accommodated in all vertiports in a given area per time unit. This time unit shall be consistent with the selected time slot to be used in the airspace-related focus area. This will allow comparing the number of drones which can operate in an area without passing the collision risk threshold, and the number which can be departing and arriving in the area taking into consideration the ground constraints.

HUBCAP2. Vertiports distribution

This indicator quantifies up to which point the distribution of vertiports in a given portion of airspace is homogenously distributed. It allows to capture imbalances in the distribution of capacity which is offered [13].

HUBCAP3. Delays per drone operation

This indicator quantifies the minutes of delay on ground before departure as well as the airborne holding in the set of vertiports which are in a given area. It allows to assess the availability of vertiports as the limiting factor of the maximum number of manageable operations.

This indicator complements the previous ones, and it is aligned with the performance expectations stated in UAM ConOps [14].

6.2 Environmental and social impact

6.2.1 DCB processes and environmental and social impact

As it has been mentioned in §4.2, social and environmental indicators are well-embedded in the monitoring functions of the envisioned DCB process. This to consider the citizen/community concerns in having significant increases of drone operations in diverse urban environments. The importance of addressing these concerns and their impact on the growth of operations has been widely discussed in previous studies (see for example the Airbus report on Managing UAS Noise Footprint [34]). Given that the monitoring process can be applied as soon as new traffic picture is available, it is mandatory to define indicators for all phases of the DCB process. This will ensure that, as soon as the traffic demand and the environmental picture change, the Dynamic Capacity Management service will be able to identify/update hot-spots of interest and react accordingly. Figure 14 shows the processes where social indicators shall come into play during the strategic phase, but this looks the same in the remaining two phases (see Figure 4 and Figure 5).

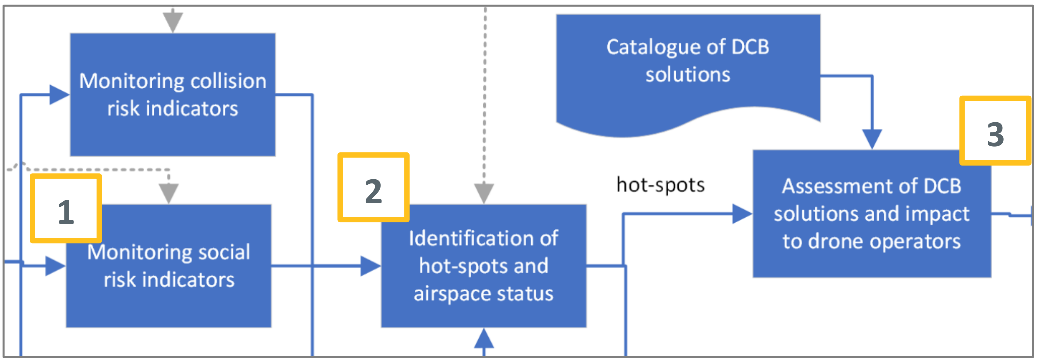


Figure 14: DCB processes which needs environmental and social indicators in all planning phases.

In order to clarify our objectives, we present a number of high-level requirements:

1. Indicators shall allow the comparison of two trajectories based on their environmental, social and wildlife impact;
2. Indicators shall allow to compare two different traffic scenarios in a limited area for a specific time;
3. Indicators shall rely on the number of people exposed to well-established noise exposure levels[10] (L_{den} values) and thereby allow for population-related limits in the future to support a

[10] Noise indicators can be based on noise emission (e.g. the certificated noise level or the noise quota count of an aircraft), but also on noise exposure (e.g. the size of a certain noise contour zone, or the number of people exposed to a certain noise level) [37].

fair capacity estimation and impact assessment of DCB measures, so that the least amount of people are affected;

4. Indicators shall capture subjective influence factors, such as:

    a. Different perception of noise depending on the time of the day e.g., lower tolerance levels at night;

    b. Higher or lower sensitivity based on the primary human usage of the area e.g., industrial, residential or commercial areas;

    c. General acceptance level of drone operations;

    d. Objection of drone operation based on the purpose of the mission e.g., search-and-rescue missions are likely to be less negatively perceived than media flights, though both drones are equipped equally;

5. Indicators shall be designed to allow the progressive refinement or inclusion of additional subjective influence factors. Then, future studies e.g., on the sensitivity of areas, will be taken into account easily. This way, not the whole formulations formulation of the indicator will need to be adapted. Instead, only weights of factors will be modified inside the formulas.

6.2.2 Definition of indicators

The proposal of environmental and social indicators to measure the impact of traffic is done in a two-step approach (objective and subjective) for three different mechanisms (blue colour in Figure 16).

First, the noise exposure (obj. indicator) on the human population and the related annoyance (subj. indicator) based on local sensitivity mechanisms (pink). The local sensitivity mechanisms represent in general the pathways through which the influence factors (of subjective character) influence the constraint [17].

Second, the visual impact on the human population, also called visual pollution, and the related annoyance perceived.

Third, the visual and noise exposure on wildlife and, again, the expectable annoyance. So far, we do not discriminate between visual and noise annoyance to wildlife, since there are no studies yet that differentiate between the origin of both effects. Though, the wildlife most behaviourally affected by the drone disturbances were species that predominantly use airspace and terrestrial habitats [21].

For all indicators we differ between an individual, trajectory-based approach (orange) and an area-based approach (green). Whereas the individual examination of a single flight could be used for evaluation of specific routes, the area-based approach looks on a set of trajectories over a period. For instance, this could be useful when comparing different DCB measures and their effects.

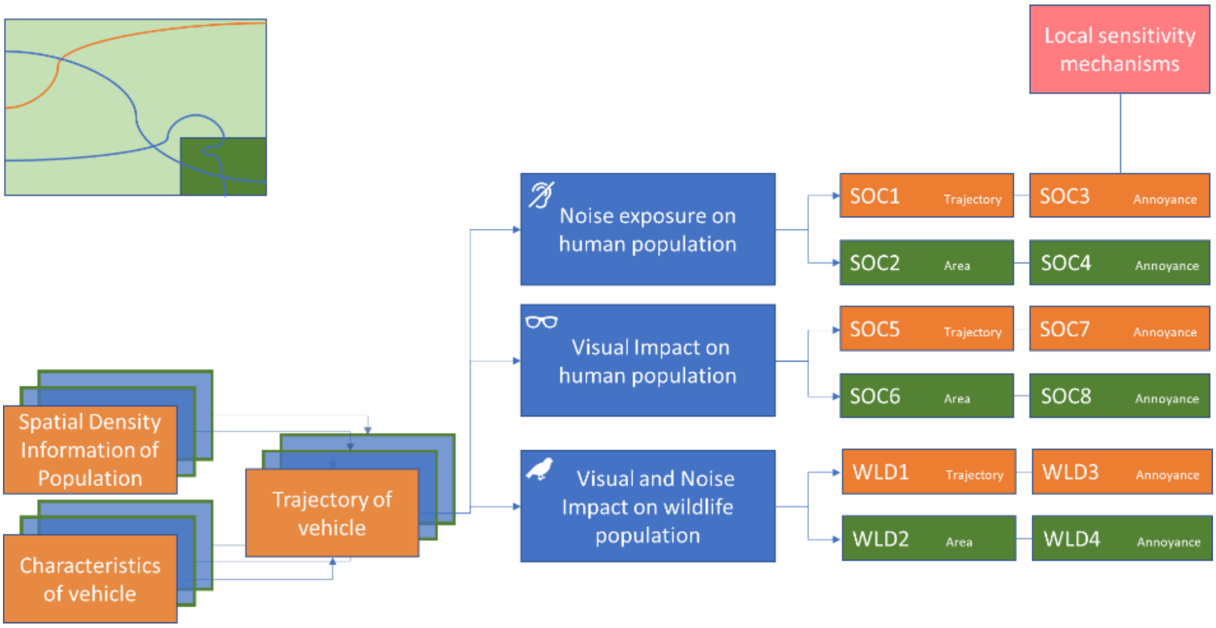


Figure 15 Approach for deriving social and environmental indicators.

All three mechanisms (blue) are based on the same basic inputs: a (set of) trajectory(ies), the local population density (human/wildlife) and the characteristics of the vehicle(s) overflying. These three inputs are then used to either calculate a cumulative exposure created by a single flight or an area-wide effect calculated over a specific period. In case of the noise impact, the outcome of this is an exposure metric that cumulates the total number of exposed people in a contour (area of effect) with a given noise emission L_{den}[11] [e.g. person.dB] or the same metric areawide for a given time [e.g. person.dB / hour]. For the visual and the wildlife impact, a similar approach will be followed.

On the other hand, annoyance is traditionally measured in % of the affected population and can be further discriminated into *annoyed* [%A] and *heavily annoyed [%HA]*. Due to the comparative nature of our indicators, we recommend the usage of total numbers here, as well. For annoyance modes, as explained in the previous section, an indefinite amount of influence factors could be added to refine the indicators with studies that could come in the future.

For a better understanding of this scheme, we have adapted an example from a report [37] to the European Commission (2005) on noise metrics for airports:

We assume that 200 people in the L_{den} 70-74 dB contour are exposed to noise levels exceeding the cut-off value of 55 dB. The average exceedance is 72.50 - 55 = 17.5 dB, accounting for 200 x 17.5 = 3,500 person-decibels (person.dB). These can be added to say 1,000 exposed people in the L_{den} 65 - 69 contour accounting for 12,500 person.dB, to get a total exposure of 16,000 person.dB in these two contour zones for a specific drone flight. Now translating this into annoyance levels, each contour can be multiplied with a factor that depends on the specific sensitivity of the area, for instance a residential

[11] L_{den}: average noise levels during daytime, evening, and night-time, applying a 5 dB penalty to noise in the evening and a 10 dB penalty to noise in the night [38].

area has 73% annoyed people for the contour of 72.5 dB and 48% annoyed people for the contour of 67.5 dB. This leads to a total of 146 + 480 = 626 person.annoyed. The percentage values are hypothetical but taken from a societal study discussing the annoyance of aircraft [38], and as discovered in a recent EASA study, the annoyance caused by the noise of drones and PAVs is nearly in the same range as are typical for aircraft (see following table).

Lden	Aircraft		Road traffic		Rail traffic	
	%A	%HA	%A	%HA	%A	%HA
45	11	1	6	1	3	0
50	19	5	11	4	5	1
55	28	10	18	6	10	2
60	38	17	26	10	15	5
65	48	26	35	16	23	9
70	60	37	47	25	34	14
75	73	49	61	37	47	23

Table 12: % A and % HA per noise exposure for aircraft, road traffic, and rail traffic (source: [38])

The contour which was mentioned now a few times is defined as the 2D effect of the drone on the overflown area. As shown in the next figure a static drone at 50 meters altitude that causes an 80 dB noise exposure on the ground, has a decreasing noise effect as the distance to the drone increases. In this example it takes nearly 1000 m until the 55 dB cut of-value is reached. All other areas would need to be considered when calculating the indicators for the whole population. When the drone is not static but flying forward in a steady altitude, of course this leads to a contour on the ground inside a corridor in which differently populated or sensitive areas are affected.

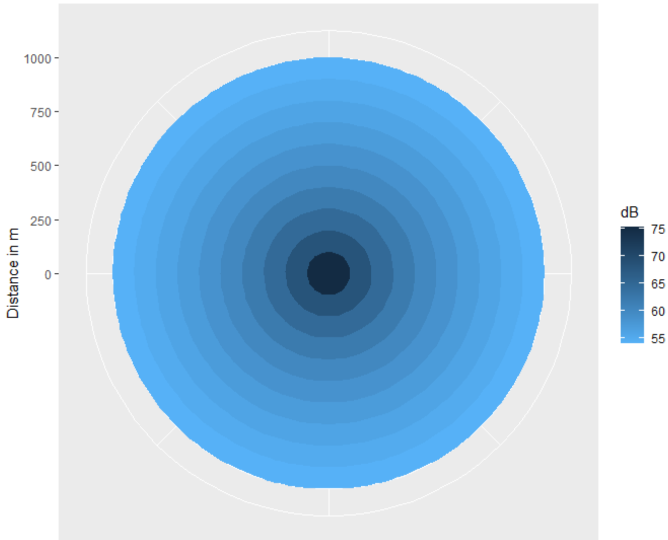


Figure 16 Decreasing Noise distribution of a drone in 50 meters altitude with 80 dB in the centre.

The following tables show an overview of the proposed metrics and the formulas needed for the calculation.

Indicator	Focus Area	Perspective	Observation	Units	Description
SOC1	Noise	Exposure	Trajectory-based	person.dB	Total amount of persons exposed within noise contours of a single flight.
SOC2	Noise	Exposure	Area-based	person.dB/h	Total amount of persons exposed within an area in a period t.
SOC3	Noise	Annoyance	Trajectory-based	person.annoyed	Total amount of annoyed persons within noise contours of a single flight.
SOC4	Noise	Annoyance	Area-based	person.annoyed/h	Total amount of annoyed persons within an area in a period t.
SOC5	Visual Pollution	Exposure	Trajectory-based	person.vp	Total amount of persons in presence of a single flight.
SOC6	Visual Pollution	Exposure	Area-based	person.vp/h	Total amount of persons in presence of UAVs within an area in a period t.
SOC7	Visual Pollution	Annoyance	Trajectory-based	person.annoyed	Total amount of annoyed persons by presence of a single flight.
SOC8	Visual Pollution	Annoyance	Area-based	person.annoyed/h	Total amount of annoyed persons by presence of UAVs within an area in a period t.
WLD1	Noise & Visual	Exposure	Trajectory-based	wld.vp.dB	Total amount of wildlife exposed within noise and appearance contours.
WLD2	Noise & Visual	Exposure	Area-based	wld.vp.dB/h	Total amount of wildlife exposed within an area in a period t.
WLD3	Noise & Visual	Annoyance	Trajectory-based	wld.affected	Total amount of affected wildlife within noise and appearance contours.
WLD4	Noise & Visual	Annoyance	Area-based	wld.affected/h	Total amount of affected wildlife within an area in a period t.

Table 13: Summary of the environmental and social indicators.

Ind.	Metric	Formula
SOC1	person.dB	$person.dB = \sum L_{DEN}(trajectory, UAV\ noise\ specs) * \frac{Population\ density}{Noise\ contour}$
SOC2	person.dB/h	$\frac{person.dB}{area(t)} = \bigcap_{area} \sum_{t}^{0} L_{DEN}(trajectories(area,t), UAV\ noise\ specs) * \frac{Population\ density}{Noise\ contour}$

Ind.	Metric	Formula
SOC3	person.annoyed	$person.annoyed = \sum \frac{Population\ density}{Noise\ contour} * \%A(L_{DEN})$
SOC4	person.annoyed/h	$\frac{person.annoyed}{area(t)} = \bigcap_{area} \sum_{t}^{0} \frac{Population\ density}{Noise\ contour} * \%A(L_{DEN})$
SOC5	person.vp	$person.vp = \sum Visual\ pollution\ (trajectory, UAV\ appearance) * \frac{Population\ density}{Appearance\ contour}$
SOC6	person.vp/h	$\frac{person.vp}{area(t)} = \bigcap_{area} \sum_{t}^{0} Visual\ pollution\ (trajectories(area,t), UAV\ Appearance) * \frac{Population\ density}{Appearance\ contour}$
SOC7	person.annoyed	$person.annoyed = \sum \frac{Population\ density}{Appearance\ contour} * \%A(Privacy)$
SOC8	person.annoyed/h	$\frac{person.annoyed}{area(t)} = \bigcap_{area} \sum_{t}^{0} \frac{Population\ density}{Appearance\ contour} * \%A(Privacy)$
WLD1	wld.vp.dB	$wld.vp.dB = \sum (\lVert L_{DEN}(trajectory, UAV\ noise\ specs) \rVert + \lVert Visual\ pollution\ (trajectory, UAV\ appearance) \rVert) * \frac{Wildlife\ density}{Impact\ contour}$
WLD2	wld.vp.dB/h	$\frac{wld.vp.dB}{area(t)} = \bigcap_{area} \sum_{t}^{0} (\lVert L_{DEN}(trajectories(area,t), UAV\ noise\ specs) \rVert + \lVert Visual\ pollution\ (trajectories(area,t), UAV\ appearance) \rVert) * \frac{Wildlife\ density}{Impact\ contour}$
WLD3	wld.affected	$wld.affected = \sum \frac{Wildlife\ density}{Impact\ contour} * \%A(nature)$
WLD4	wld.affected/h	$\frac{wld.affected}{area(t)} = \bigcap_{area} \sum_{t}^{0} \frac{Wildlife\ density}{Impact\ contour} * \%A(nature)$

Table 14: Formulas of the environmental and social indicators.

The following sections provide further details on the proposed indicators.

6.2.2.1 Focus Area: Noise Impact

SOC1. Noise exposure on human population for a given trajectory.

This is the cumulated number of exposed people in a contour with a given Noise Exposure Lden, represented in person.dB.

The noise exposure is influenced by the acoustic mechanisms (see §5.2.1 for complete list) that the human population is able to perceive from the vehicle. Some of the mechanisms are determined in turn by the specific technologies and characteristics of the vehicle (e.g. sound character of the blades, number of blades per propeller). Typical noise metrics such as Effective Perceived Noise Level (EPNL: relative loudness of an individual aircraft operation based on frequency spectra and duration of the sound, measured in dB) [34], and Sound Exposure Level (SEL: sound dose generated by a single aircraft at a particular point, measured in dB) [37] can be used to estimate the noise exposure. What is important for this indicator is to capture the cumulative exposure over ground areas, as the drone trajectory can overfly extensive urban areas and on different airspace levels. We propose the use of the Noise Exposure (Lden: average noise levels during daytime, evening, and night-time, applying a 5 dB penalty to noise in the evening and a 10 dB penalty to noise in the night) [38] as metric for including the weighting of noise emissions depending on the time of the day.

$$\text{Lden}^{12} = 10 \lg \left[(12/24).10^{\frac{LD}{10}} + (4/24).10^{\frac{LE+5}{10}}(8/24).10^{\frac{LN+10}{10}}\right]$$

SOC2. Noise exposure on human population for a traffic scenario.

This is the number of exposed people in a contour with a given Noise Exposure Lden for a given time, represented in person.dB/hour.

This indicator uses the same principles and metrics as the previous one (SOC1) but aims to determine the noise impact of a traffic scenario over a particular area or zone.

SOC3. Annoyance level originated from a single trajectory.

This is the cumulated number of annoyed people in a contour, represented in person.annoyed.

This indicator basically translates the noise exposure into a score level of the human population feeling annoyed by the effects of a single drone trajectory. As it has been pointed out in related studies and surveys, not only acoustic mechanisms can play a role in the annoyance characterization, but also non-acoustic mechanisms, such as sensitivity and situational factors (see §5.2.1). Therefore, the information from the aforementioned subjective mechanisms is aggregated in order to estimate the annoyance level. We propose to multiply the noise exposure in a contour (see indicator SOC1) with the specific sensitivity in the area which is represented as the percentage of people annoyed [%A], and the percentage of people highly annoyed [%HA]. The annoyance percentage values can be obtained from surveys or estimations such as the one presented in **¡Error! No se encuentra el origen de la referencia.**.

SOC4. Annoyance Level for a traffic scenario in an area.

This is the number of annoyed people in a contour for a given time, represented in person.annoyed/hour. Similarly, as indicator SOC3, this indicator focusses on performing an impact assessment for a traffic scenario over a particular area.

The following table shows the identification of those influence factors which are taken on board by each indicator and the justification. Only the significant factors (as identified in §5.2) have been here considered. The colour code – red, yellow and green – shows up to which point the factor behaviour is captured by each indicator.

[12] LD, LE, and LN are the A-weighted long-term L as defined in ISO 1996-2 (1987) for the day (7-19h), evening (19-23h), and night (23-7h) determined over the year [38].

	SOC1 Noise exposure for a given trajectory	SOC2 Noise exposure for a traffic scenario in an area	SOC3 Annoyance level originated from a single trajectory	SOC4 Annoyance Level for a traffic scenario in an area
Sound Pressure	This influence factor determines the noise exposure Lden parameter.	This influence factor determines the noise exposure Lden parameter.	This influence factor is taken onboard.	This influence factor is taken onboard.
Number of events	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.
Sound Character[13]	No changes in the indicator.	No changes in the indicator.	This factor could be included in the estimation of the annoyance, but is not considered currently.	This factor could be included in the estimation of the annoyance, but is not considered currently.
Spectral Composition	No changes in the indicator.	No changes in the indicator.	This factor could be included in the estimation of the annoyance, but is not considered currently.	This factor could be included in the estimation of the annoyance, but is not considered currently.
Flight Parameters	The height as influence factor is taken onboard (determines the resulting noise exposure on the ground).	The height as influence factor is taken onboard (determines the resulting noise exposure on the ground).	The height as influence factor is taken onboard.	The height as influence factor is taken onboard.
Ground Environment	The population density as influence factor is taken onboard.	The population density as influence factor is taken onboard.	The population density and the land use as influence factor are taken onboard.	The population density and the land use as influence factor are taken onboard.
(Personal) Noise Sensitivity	No changes in the indicator.	No changes in the indicator.	The general noise sensitivity as influence factor is taken onboard.	The general noise sensitivity as influence factor is taken onboard.

[13] The character of the sound can be impulsive (such as helicopter blade slap), sharp (few low-frequency tones), rough, or exhibits strong tonality such as purse tones or a buzzsaw effect **¡Error! No se encuentra el origen de la referencia.**.

	SOC1 Noise exposure for a given trajectory	SOC2 Noise exposure for a traffic scenario in an area	SOC3 Annoyance level originated from a single trajectory	SOC4 Annoyance Level for a traffic scenario in an area
Ambient noise	This factor could be included to refine the resulting noise exposure, but is not considered currently.	This factor could be included to refine the resulting noise exposure, but is not considered currently.	This factor could be included to refine the resulting annoyance, but is not considered currently.	This factor could be included to refine the resulting annoyance, but is not considered currently.
Time of day	The noise exposure Lden is weighted for 3-day times.	The noise exposure Lden is weighted for 3-day times.	This influence factor is taken onboard	This influence factor is taken onboard

Table 15: Noise Impact Focus Area indicators versus influence factors

6.2.2.2 Focus Area: Visual Impact

From a systematic point of view, the visual impact is determined in the same manner as the noise impact, only that influencing factors are different. These have been previously introduced in §5.2.

SOC5. Visual exposure on human population for a given trajectory

This is the cumulated number of people in presence of Visual Pollution for a single flight, represented in person.vp).

This is determined by the visual mechanisms that the human population is able to perceive from the vehicle, such as experience or knowledge about drones, number of flights overhead, altitude or size of the drone (see §5.2.2 for complete list). As opposed to the acoustic metrics, which are well known and established, visual metrics are yet to be defined and are more difficult to be standardized and measured. We propose to use the metric Visual Pollution which is influenced directly from the trajectory profile (altitude) and the UAV appearance (size of the drone). The drone size squared can be approximated as surface of the drone. The effective size seen by population decrease as the altitude squared. What is important in this indicator is to capture the cumulative visual impact over populated areas, as the drone trajectory can overfly extensive urban areas and on different airspace levels.

SOC6. Visual exposure on human population for a traffic scenario.

This is the number of people in presence of Visual Pollution in a contour for a given time, represented in person.vp/hour.

This indicator uses the same principles and metric as the previous one (SOC5) but aims to determine the visual impact of a traffic scenario over a particular area or zone.

SOC7. Privacy infringement level originated from a single trajectory.

This is the cumulated number of annoyed people due to visual exposure for a single flight, represented in person.annoyed.

We propose to multiply the visual exposure in a contour (see indicator SOC5) with the specific sensitivity in the area which is represented as the percentage of people annoyed [%A], or the percentage of persons highly annoyed [%HA]. It is likely that different configuration of drones e.g., camera yes/no, and the purpose of the drone e.g., search and rescue vs. real estate photography will play a relevant role in the people perception, but this requires further analysis.

Similarly to the existing annoyance relationship used for noise impact (see **¡Error! No se encuentra el origen de la referencia.**), we propose to estimate the annoyance through privacy infringement levels related to the use of cameras and to the ground environment typology (residential, industrial, commercial area).

As starting point for defining the annoyance values, the results of the DACUS survey on citizens have been utilized [4]. In this survey, ~50% of the respondents were highly annoyed when drones were flying above their homes and the majority of the citizens found appropriate to use drones in public areas, such as commercial ones.

In the following table, we assume that people are able to discriminate between drones with and without camera (usage). In real world scenarios it is much more likely, that people will always expect a drone to have an operating camera.

Type of area	Use of cameras	%A	%HA
Commercial	No	20	10
Commercial	Yes	30	20
Industrial	No	50	30
Industrial	Yes	60	40
Residential	No	70	50
Residential	Yes	80	60

Table 16: %A and %HA at various privacy infringement levels.

SOC8. Privacy infringement level for a traffic scenario in an area.

This is the number of annoyed people in a contour for a given time, represented in person.annoyed/hour). Similarly, as indicator SOC7, this indicator focusses on performing an impact assessment for a traffic scenario over a particular area.

The following table shows the identification of those influence factors which are taken on board by each indicator and the justification. The colour code – red, yellow and green – shows up to which point the factor behaviour is captured by each indicator.

	SOC5 Visual exposure originated by a trajectory	SOC6 Visual exposure for a traffic scenario in an area	SOC7 Privacy infringement level originated by a trajectory	SOC8 Privacy infringement level for a traffic scenario in an area
Number of flights overhead	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.
Hovering time overhead	This factor could be included in the estimation of the exposure, but is not considered currently.	This factor could be included in the estimation of the exposure, but is not considered currently.	This factor could be included in the estimation of the privacy, but is not considered currently.	This factor could be included in the estimation of the annoyance, but is not considered currently.
Height	This influence factor is taken onboard.	This influence factor is taken onboard.	This factor could be included in the estimation of the privacy, but is not considered currently.	This factor could be included in the estimation of the annoyance, but is not considered currently.
Ground Environment	The population density as influence factor is taken onboard.	The population density as influence factor is taken onboard.	The population density and the land use as influence factor are taken onboard.	The population density and the land use as influence factor are taken onboard.
Size of the drone	This influence factor is taken onboard.	This influence factor is taken onboard.	No changes in the indicator.	No changes in the indicator.
Configuration and specification of cameras	No changes in the indicator.	No changes in the indicator.	The use of cameras as influence factor is taken onboard.	The use of cameras as influence factor is taken onboard.

Table 17: Visual Impact Focus Area indicators versus influence factors

6.2.2.3 Focus Area: Wildlife Impact

As stated in the previous chapters, there are several publications [20][21] that show evidence that drone traffic is affecting wildlife in a variety of ways, if not used specifically for monitoring purposes. Until now, the only tool to prevent nature from a negative impact is the establishment of dedicated no-drone zones e.g., in sanctuaries. But since wildlife is not limited to these confined areas, DCB measures could take on board the impact on wildlife.

We propose the usage of specific indicators, WLD1-4, which evaluate this impact based on the expectable density of animals and the characteristics of the aerial vehicles that overfly the particular areas. This approach will require the collaboration of other disciplines such as biologists, and it will require a continuous monitoring of the values due to the dynamic nature of wildlife numbers and their sensitivity.

This is comparable to the approach chosen for social impact, but other than there, it is not possible yet to discriminate between *noise* and *visual* effects. Although it is likely that approach speed, angle and colour are perceived differently by the diverse type of animals, we understand that this needs further elaboration and experience to be included in the future. This can be captured from various studies

[22][23][24] which also show that different types of animals show different responses and sensitivity to drone traffic. As a result, it should be possible to determine different levels of annoyance.

The following paragraphs define a set of indicators which allow to monitor the impact of drone traffic on wildlife based on exposure and annoyance.

WLD1. Exposure on wildlife for a given trajectory,

This is considering the impact on overflown wildlife based on the altitude / distance of an individual drone and its characteristics. This allows to calculate the visual pollution as well as the noise effect, which can be cumulated in normed form. This normalization could be based on scales of historical exposure observations.

Noise Level in dB	Normed Score Noise	Visual Pollution Level based on AGL or vegetation height	Normed Score VP
45 db	0	500 ft	0
50 dB	2	400 ft	2
55 dB	4	300 ft	4
60 dB	6	200 ft	6
65 dB	8	100 ft	8
70 dB	10	0 ft	10

Table 18: Normalization of noise and visual pollution to be summarized in a single factor.

WLD2. Exposure on wildlife for a traffic scenario.

This is considering the impact in a specific area that is caused by a set of flights passing through and their distance and duration.

WLD3. Annoyance level for single trajectory.

This determines the individual annoyance level that is created by drone flight based on the specific sensitivity of the overflown wildlife.

WLD4. Annoyance level for a traffic scenario.

This determines the annoyance level created by a set of flights in an observed area based on the specific sensitivity in that area.

The following table shows how the influence factors of wildlife impact are addressed by the proposed indicators.

	WLD1 Exposure on wildlife for a given trajectory	WLD2 Exposure on wildlife for traffic scenario	WLD3 Annoyance level for single trajectory	WLD4 Annoyance level for traffic scenario in an area
Distance	The height as influence factor is taken onboard.	The height as influence factor is taken onboard.	The height as influence factor is taken onboard.	The height as influence factor is taken onboard.
Number of flights	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.
Duration	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.	No changes in the indicator.	This influence factor is taken onboard as the indicator is calculated per hour.
Ground environment	The wildlife density as influence factor is taken onboard.	The wildlife density as influence factor is taken onboard.	The wildlife density as influence factor is taken onboard.	The wildlife density as influence factor is taken onboard.
Drone noise	This influence factor is taken onboard.	This influence factor is taken onboard.	This influence factor determines annoyance	This influence factor determines annoyance

Table 19: Wildlife Impact Focus Area indicators versus influence factors

Regarding to the requirements we set in the beginning of the chapter the results are summarized in the following table:

#	Requirement	Fulfilled	Note
1	Indicators shall allow the comparison of two trajectories based on their social and wildlife impact.	Y	Applicable to all trajectory-based indicators.
2	Indicators shall allow to compare two different traffic scenarios in a limited area for a specific time.	Y	Applicable to all area-based indicators.
3	Indicators shall estimate the number of people exposed to specific L_{den} values.	Y	This is done by the definition of person.db, a metric that combines the dose with the absolute number of affected persons.
4	Indicators shall capture subjective influence factors.	Y	Acquired for noise impact by taking into account L_{DEN}, which adjusts noise levels based on day and night-time, and the usage of %A to calculate the amount of actually annoyed people. Analogous, we constructed the metrics for visual pollution and wildlife, where further research and experimental studies

#	Requirement	Fulfilled	Note
			should be encouraged to allow for a more substantial assessment.
5	Indicators shall be designed to allow the progressive refinement or inclusion of additional subjective influence factors. Then, future studies e.g., on the sensitivity of areas, will be taken into account easily.	Y	As previous studies showed, the mechanisms that influence the subjective perception of social impacts can be extremely detailed. In this study we decided to limit the level of complexity by using the analogy found in the dose-response relationship for classic aviation, %A or %HA and L_{DEN}. Though current studies show that the annoyance level of drones and PAV are comparable to aircraft, it is likely that future studies and developments based on the effect of getting used to a sound could further improve the metrics. Same applies for the visual pollution and the related privacy infringement where we have been able to propose a set of mechanisms, that could be used as a guidance. This applies to the affected wildlife as well. Nevertheless, the existence of the sensitivity mechanisms in our indicators serves as a placeholder for these future studies and could be easily refitted, as requested by the requirement.

Table 20: Environmental and social impact indicators versus high-level DCB requirements.

6.3 Mission Efficiency

Ideas for metrics are refined here considering the influence factors identified in §5.3 and an examination of how each might be measured.

6.3.1 DCB processes and mission efficiency

DCB has a primary purpose of matching the demand and the capacity. Our aim is to produce metrics that allow the impact of DCB on mission efficiency to be assessed.

The strategic, pre-tactical and tactical phases of the DCB process all feature the same two operations where this consideration would be made: 1) The assessment of DCB solutions and impact to Drone Operators and 2) The confirmation of acceptance of the Operation Plan and proposals.

In all three phases the first evaluation is of a set of traffic related to a hotspot and the second evaluation is by the Drone Operator. Measures which strongly influence mission efficiency may lead to the Drone Operator cancelling the mission after DCB measures have been applied, possibly because the flight arrives too late, possibly because the flight cannot fly the plan safely due to insufficient range or because the cost of the operation becomes unacceptable. Such cancellations may be measurable in the real world and should be an indicator.

In addition, mission efficiency indicators may support the decision-making in the decision point to implement or not a DCB measure in the strategic phase as it can be seen in process "3" in the figure. Due to the high uncertainty of the demand in this phase, DCB measures will only be implemented provided that they are not highly impacting the fulfilment of mission objectives. Acceptable thresholds of mission efficiency indicators will determine if the measure can be implemented or not.

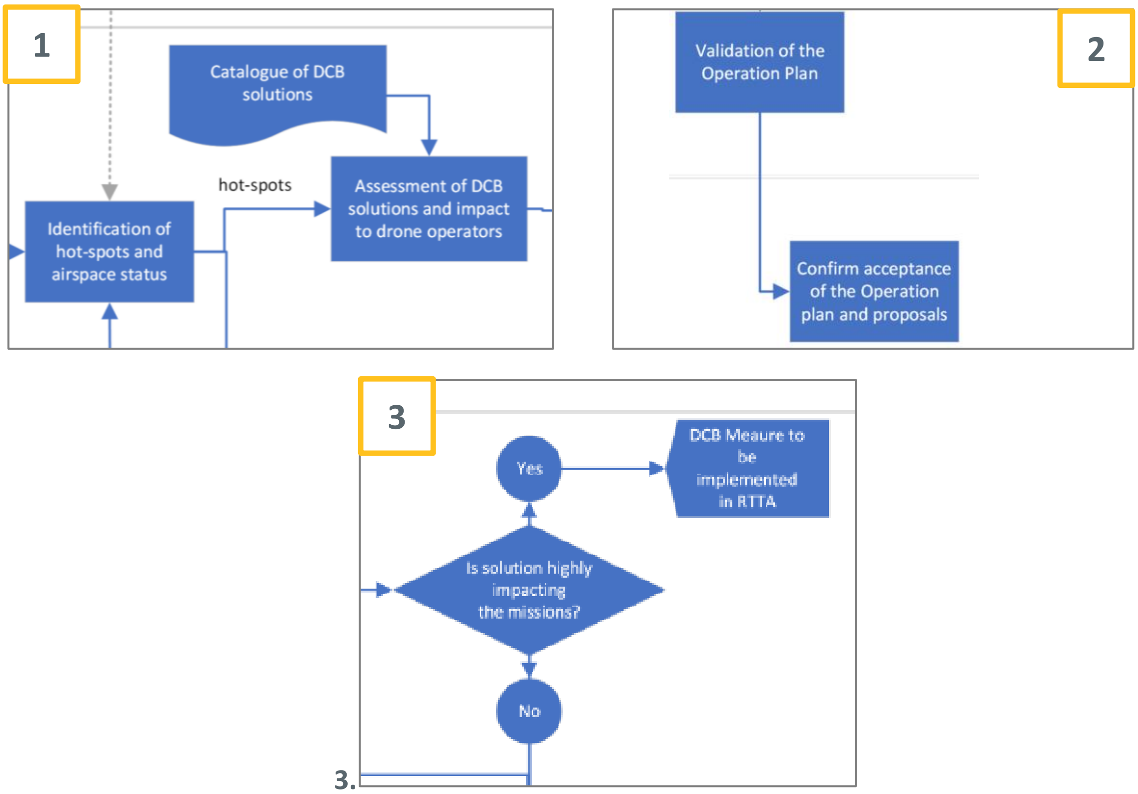


Figure 17.- DCB processes where mission efficiency indicators are needed.

6.3.2 Definition of indicators

The following table shows an overview of the proposed indicators which are directly based on the primary influence factors on mission efficiency identified in §5.3. Some indicators assigned to the "Cost of operating" Focus Area are also impacting to the "Probability of achieving mission goals". This is due to the close relation between those metrics and the battery life. Then, increasing the values of those indicators beyond certain limits will imply reducing the probability of achieving the mission goal, i.e., the other Focus Area.

Indicator	Focus Area	Name	Description	Units
EFF1	Cost of operating	Horizontal Drone Operation Efficiency	Difference between the number of metres flown horizontally in the submitted Operation Plan and the metres that will be flown when a DCB measure is implemented.	% of difference with respect to the Operation Plan submitted by the Drone Operator.
EFF2	Cost of operating	Vertical Drone Operation Efficiency	Difference between the total number of metres climbed in the submitted Operation Plan and the total number of metres that will be	% of difference with respect to the Operation Plan submitted by the Drone Operator.

Indicator	Focus Area	Name	Description	Units
			climbed when a DCB measure is implemented.	
EFF3	Cost of operating	Elapsed time airborne.	Difference between duration of the flight in the submitted Operation Plan and the duration when a DCB measure is implemented.	% of difference with respect to the Operation Plan submitted by the Drone Operator.
EFF4	Probability of achieving mission goal	Arrival time.	Difference between the arrival time in the submitted Operation Plan and the arrival time when a DCB measure is implemented.	% of difference with respect to the Operation Plan submitted by the Drone Operator.
EFF5	Probability of achieving mission goal	Cancelled flights.	Number of flights that will not be able to complete their missions – and then they will be cancelled – when a DCB measure is implemented.	% cancelled flights over the total in the area where the DCB measure is implemented.
EFF6	Cost of operating	Airspeed impact.	Integral of square of airspeed in the submitted Operation Plan and the value when a DCB measure is implemented.	% of difference with respect to the Operation Plan submitted by the Drone Operator.

Table 21: Summary of the mission efficiency indicators

Applying these indicators faces two, linked, difficulties:

- Not all drone flights are linear;
- We expect the descriptions of trajectory to be flown in a drone operation to consist of a series of one or more 4D volumes.

A drone being used for filming or inspection may follow what appears to be a random path starting and ending at the same point. Our efficiency metrics are not going to be very informative for such operations – the most efficient route that starts and ends at the same point is not to fly at all. If the efficiency metric applies to only some flights, then there should be some guidelines as to when our metric can be applied.

The 4D volumes used to describe the operation should have a size in each of x, y, z and t, generally corresponding[14] to longitude, latitude, height and duration. Uncertainties should be expressed in the 4D volume and it is likely that these volumes will overlap. An operation that should be disregarded will only have one volume, or will start and end with volumes that significantly overlap in terms of x, y ,z.

[14] Other approaches might be used, for example the use of distances rather than latitude and longitude, for example the UK's "National Grid".

For operations that consist of a progression in time and space, a method is needed to extract the flown path from the trajectory comprised of a list of 4D volumes. A line of best fit might be calculated as the basis for efficiency comparison – not necessarily the centre line but the most likely path of a vehicle through these volumes if flown in a "reasonable" way:

- At the lowest speed (at any point) resulting in a path explores the series volumes;
- With the minimum acceleration or change of direction;
- With the minimum change of height;
- With approximately as much time spent towards any side of each volume as its opposite side.

The approach can be implemented with regression techniques, the details may depend on the data available. Hence, we should be able to calculate EFF1, EFF2, EFF3 and EFF4.

The line of best fit approach as described above will produce the shortest line fitting the 4D volume trajectory, by definition. It does this by reducing the speed and rate at which the flight turns to the minimum values that still fit the trajectory. This minimisation is likely to impact all four metrics.

The metrics will be invalidated if different minima are used between the Reference scenario (the plans submitted) and the Solution scenario (the plans after DCB) being compared. Hence the same minima must be used for both, those being the larger value found for either. When comparing multiple solution scenarios, common values must be used, again the largest (fastest) of any found in the fitting process. Figure 18 shows the scheme.

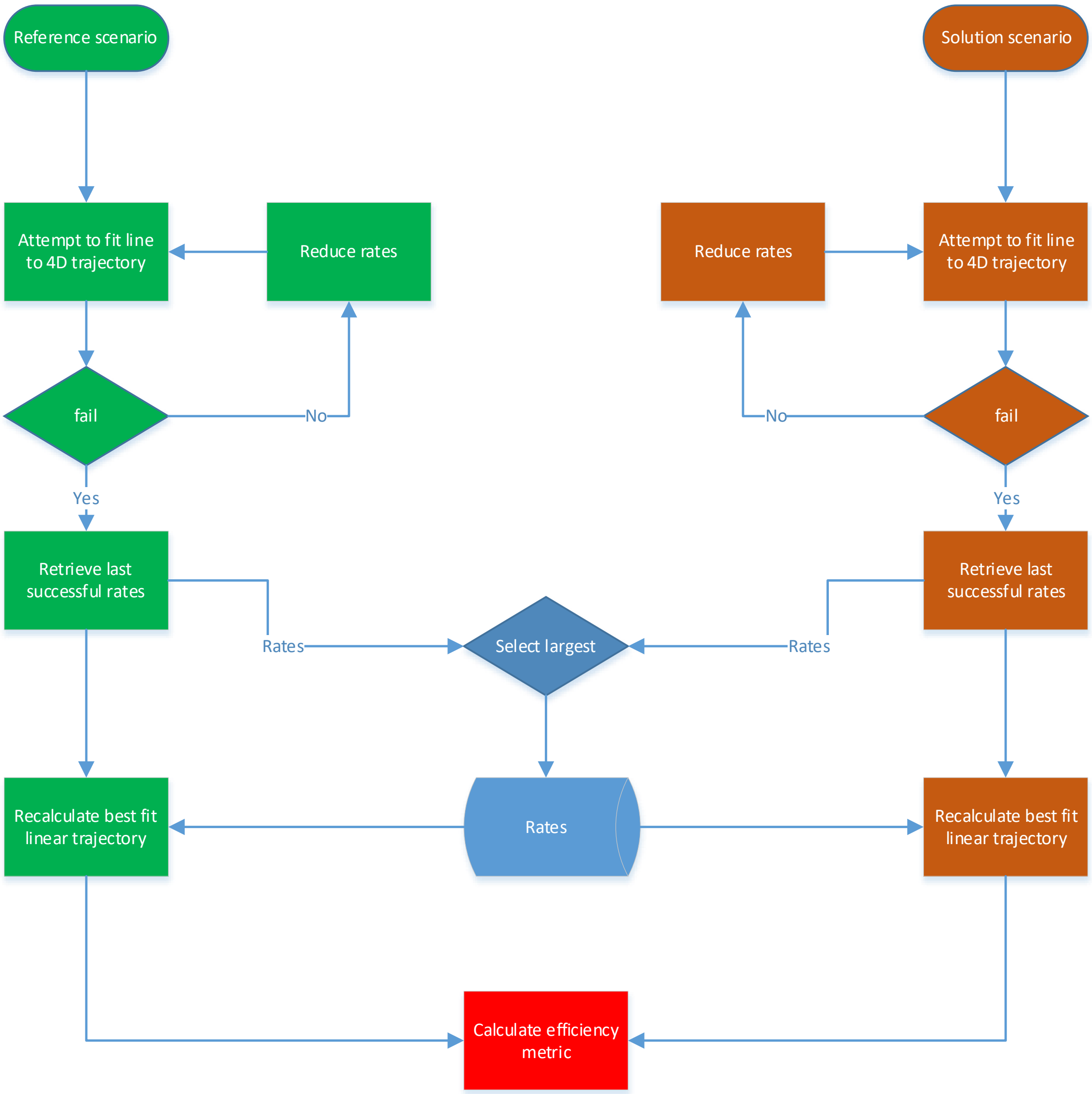


Figure 18 Interaction between line of best fit and efficiency.

In addition, as noted in §5.3.2, there is a link between battery life and airspeed. Airspeed is likely to be inferred from the plans provided. Any calculation of drag on this basis is likely to be error prone.

Other proposed metric is the "Number of flights cancelled after DCB". This metric is more interesting but likely to be unusable for the determination of the best DCB measures prior to the execution.

In summary, four measures for the KPA are proposed, in each the effect of DCB is detected by comparing the plan filed by the operator with the plan that emerges from the DCB process. Two further metrics are noted but not considered easy to obtain.

6.4 Equity

6.4.1 DCB processes and Equity

As analysed in §5.4, Equity will address the differences in the impact of the DCB decisions to the mission operating costs of the different Drone Operators, and even to the possibility of executing the mission successfully. Equity indicators should convey how fairly or equitably inefficiencies are distributed among Drone Operators.

In the strategic phase of the DCB process in Figure 3, the need of using Equity indicators is identified in one process: 1) Assessment of DCB solutions and impact to Drone Operators.

In the pre-tactical and tactical phases - Figure 4 and Figure 5 -, the same apply as in strategic phase, with the addition of 2) Repository of "Virtue Points". DCB should ensure that the assignment of "Virtue Points" to the Drone Operators considers fairness as the main driver. As an example, drone deliveries cannot be penalized with less "Virtue Points" because they are not able to plan so early as those Drone Operators which are doing inspections. The particularities of the mission types need to be captured through Equity indicators, ensuring the fairness of the system.

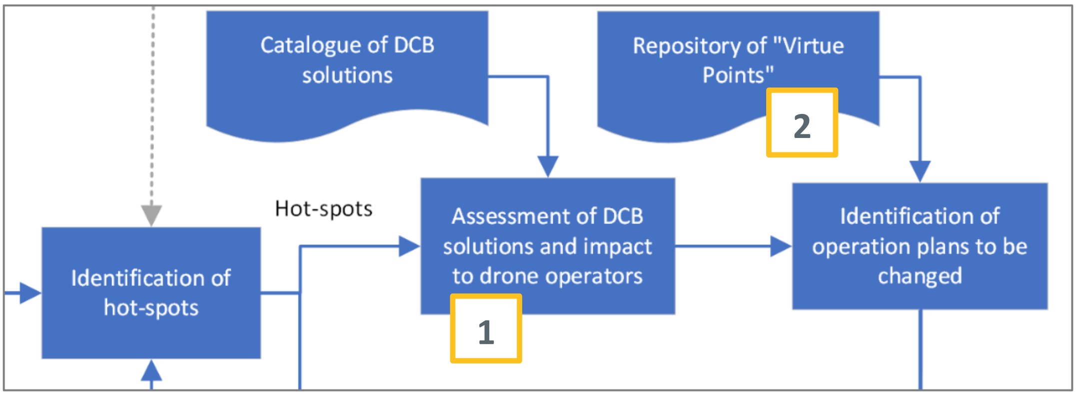


Figure 19: DCB processes which needs equity indicators in the pre-tactical phase.

6.4.2 Definition of indicators

In the context of SJU PJ19 Performance Framework [33], six performance indicators are suggested for Equity:

1. Net Difference in Au's Delay or Cost Compared with other AUs: Change in Delay (or Cost) of the AU concerned / Total Delay (or Cost) of All the AUs;

2. Relative Advantage Gained by one AU over the Others weighted by impacted flights: Change in Delay (or Cost) of AU1 divided by Number of Movements of AU1 / Change in Delay (or Cost) of AU2 divided by Number of Movements of AU2;

3. Total ATM Delay per AU relative to Baseline ATM delay per AU: Total delay (per airspace user) in the Solution Scenario / Total delay (per airspace user) in the Reference Scenario;

4. Number of Flights Advantaged and/or Disadvantaged: Number of Flights impacted (+ or -) by the change;

5. AU Delay per Flight Compared to Baseline: Delay per Flight of AU concerned in the Solution Scenario / Delay per Flight of AU concerned in the Reference Scenario;

6. AU cost per Flight Compared to Baseline: Cost per Flight of AU concerned in the Solution Scenario / Cost per Flight of AU concerned in the Reference Scenario.

From these six metrics, three (3,5 and 6) depend on comparison with a baseline – in our case, the baseline could be the situation without implementing any DCB measure, four (1,2,3 and 5) are focus on delays as the major impact on airspace users, and one (4) proposes to identify the flights which are affected by a change, e.g. a DCB measure, and those which are not. This is not easy to identify in U-space as a DCB measure could be affecting to the whole set of drones in the area, although with different impact.

We propose to expand these ideas by considering the most relevant factors that are penalizing the mission efficiency of each Drone Operator. To quantify the distribution of inefficiencies, we can leverage the mission efficiency indicators EFF1 to EFF5 defined in the previous section – we did not consider EFF6 due to the difficulties to capture how speed constraints are impacting differently to different Drone Operators. A normalised metric for the distribution of inefficiency could be the ratio between the geometric and arithmetic mean of the efficiency indicators across all operators. This approach can be seen in the paper “Fairness in Decentralized Strategic Deconfliction in UTM” [28], where fairness is quantified by comparing the distribution of costs across operators using this normalized fairness metric. Then, these indicators can show the differences in fairness among all Drone Operators in an area.

Indicators based on the ratio between the geometric and arithmetic means show that there are differences in fairness among drone operations in a certain area. Nevertheless, they are not suitable for the identification of those Drone Operators which are more penalized in comparison with the others. In this regard, AURORA [48], research project funded by SESAR, proposed indicators to measure how fairly the inefficiencies in the ATM system are distributed among the Airspace Users. Those indicators served to quantify the differences in the inefficiencies experienced by the Airspace Users in a given area. AURORA proposed two indicators applicable to ATM:

1. Differences between Airspace Users (AUs) in terms of percentage of flights reaching the optimum en-route flight level from the perspective of the users;

2. Differences between AUs in terms of costs of the actual flow trajectory versus the optimum en-route flight level from the perspective of the users.

We propose to introduce a new indicator based on point 1 by considering that the Drone Operator is willing to fly at the flight level requested in the Operation Plan as stated in §4.3, or also below that flight level. This second statement is justified by the fact that energy consumption will be less in lower flight levels. On the contrary, aspects such as the difficulties to reach the mission objective if the drone is flying lower are not considered.

The following table shows an overview of the proposed metrics which are directly based on mission efficiency indicators identified in §5.3. Two equity-related Focus Areas could be defined consistently with those in the Mission Efficiency KPA**, Fairness in cost of operating** and **Fairness in achieving mission goal**.

Ind.	Focus Area	Name	Description	Formula
EQU1	Fairness in cost of operating	Drone Operators fairness of Horizontal Drone Operation Efficiency	Ratio between the geometric and arithmetic mean of the efficiency indicator EFF1 across all operators.	$$\frac{(\prod_{j=1}^{m} MEAN(EFF1)_j)^{\frac{1}{m}}}{\frac{1}{m}\sum_{j=1}^{m} MEAN(EFF1)_j}$$ $MEAN(EFF1)_j$= mean efficiency of all flights of user j in the area. m=Drone Operators in the area.
EQU2	Fairness in cost of operating	Drone Operators fairness of Vertical Drone Operation Efficiency	Ratio between the geometric and arithmetic mean of the efficiency indicator EFF2 across all operators.	$$\frac{(\prod_{j=1}^{m} MEAN(EFF2)_j)^{\frac{1}{m}}}{\frac{1}{m}\sum_{j=1}^{m} MEAN(EFF2)_j}$$
EQU3	Fairness in cost of operating	Drone Operators fairness of Elapsed time airborne	Ratio between the geometric and arithmetic mean of the efficiency indicator EFF3 across all operators.	$$\frac{(\prod_{j=1}^{m} MEAN(EFF3)_j)^{\frac{1}{m}}}{\frac{1}{m}\sum_{j=1}^{m} MEAN(EFF3)_j}$$
EQU4	Fairness in achieving mission goal	Drone Operators fairness of Arrival time	Ratio between the geometric and arithmetic mean of the efficiency indicator EFF4 across all operators.	$$\frac{(\prod_{j=1}^{m} MEAN(EFF4)_j)^{\frac{1}{m}}}{\frac{1}{m}\sum_{j=1}^{m} MEAN(EFF4)_j}$$
EQU5	Fairness in achieving mission goal	Drone Operators fairness of cancelled flights	Ratio between the geometric and arithmetic mean of the efficiency indicator EFF5 across all operators	$$\frac{(\prod_{j=1}^{m} EFF5_j)^{\frac{1}{m}}}{\frac{1}{m}\sum_{j=1}^{m} EFF5_j}$$ $EFF5_j$= % cancelled flights of operator j. m=Drone Operators in the area.
EFF6	Fairness in cost of operating	Drone Operators fairness of optimum flight level reached	Difference between Drone Operators in terms of percentage of flights reaching the flight level requested in the Operation Plan or below.	$$\sqrt{\sum_{j=1}^{N}\frac{\left(x_{AUj}-\overline{x_{FP}}\right)^2}{n-1}} \quad (6)$$ $$x_{AUj} = \frac{\sum_{\forall flights \in AU_j} \cdot FL}{number\ of\ flights\ \in\ AU_j}\% \quad (7)$$ $\mathrm{FL} = 1$ if maxFL $\leq$ RFL; $FL = 0\ if\ maxF\ > RFL$ $$\overline{x_{FP}} = \sum_{j=1}^{N}\frac{x_{AUj}}{N} \quad (8)$$

Ind.	Focus Area	Name	Description	Formula
				$maxFL$ is the maximum flight level after the DCB measure. n is the number of AUs. RFL is the flight level in the Operation Plan.

Table 22: Summary of the equity indicators

6.5 Flexibility

6.5.1 DCB processes and flexibility

Actively monitoring flexibility of DCB measures will allow tracking of how well the guiding principles for U-space are upheld. Assuring flexibility in the DCB process will facilitate that U-space users can exploit emerging business opportunities to a maximum extent. The implications of DCB process elements on flexibility are further described below.

The potential impact of DCB measures on flexibility have already been introduced in §4.5. It was shown that the amount of available airspace capacity, i.e. the existing capacity buffers, and the spatial and temporal restrictions to drone missions influence on how much flexibility can be provided to Drone Operators. To provide as much flexibility to operators as possible. DCB solutions should maximize the available capacity whilst minimizing (spatial and temporal) restrictions on operations. This means aiming for “free-route” operations as much as possible.

The need of using Flexibility indicators is identified in two processes shown in Figure 20: 1) Assessment of DCB solutions and impact to Drone Operators, being necessary in each of the three DCB planning phases; 2) Validation of the Operation Plan, being necessary in the pre-tactical and tactical phases exclusively.

On one hand, potential DCB measures should be weighted in terms of their impact on the flexibility that Drone Operators will have in case of future business opportunities. This process will be performed by the Dynamic Capacity Management service. Assuming that capacity buffers will be addressed by the Capacity KPA, we will focus on defining indicators to show the differences in flexibility of DCB measures when the same capacity buffer is offered.

On the other hand, flexibility must be provided in the process of validating Operation Plan modifications. This is performed by the Operation Plan Processing service. Drone Operators provides a new Operation Plan or changes in existing ones after the implementation of DCB measures, i.e. after the RTTA. This process proposes alternatives to the Drone Operators which are aligned with the constraints imposed by the active DCB measures. To do this, the service must understand what the business opportunities are that the operators are trying to exploit. In order for this to work, the operator must formulate their flexibility requirements within the mission plan so that they can be considered when selecting DCB measures to implement.

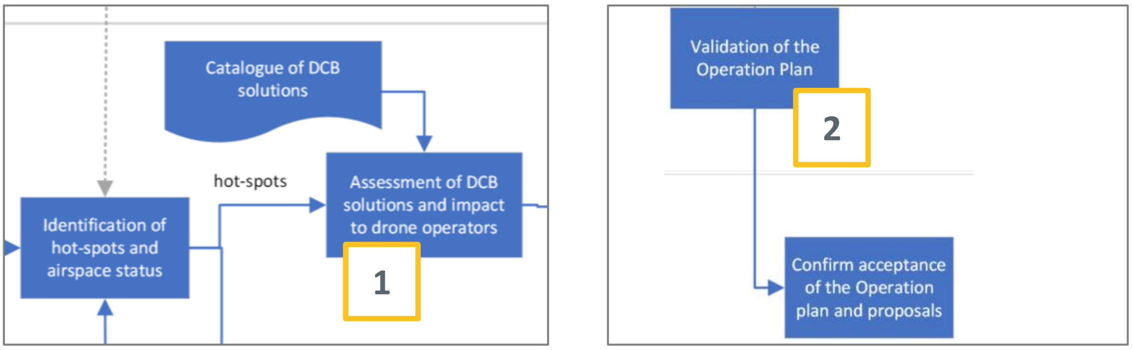


Figure 20: DCB processes which needs flexibility indicators in the strategic phase.

6.5.2 Definition of indicators

Flexibility already exists within the SESAR Performance Framework [29] and has established a series of indicators applicable to the ATM-domain:

1. Average delay for scheduled civil/military flights with change request and non-scheduled or late flight plan request;
2. Average delay for non-scheduled civil/mil flights delayed;
3. % of non-scheduled civil/mil flight arriving on time;
4. (Military) airspace reservations on short notice.

The existing indicators have several useful elements which could be applied to U-space DCB, for example the focus on both scheduled and non-scheduled flights, the notion of "delay" for drone flights which need to reach a specific destination at a specific time, as well as the inclusion of airspace reservations.

Non-scheduled flights could be likened to those who publish their mission plans after RTTA (such as short-notice package delivery flights). Airspace reservations on short notice would be considered as "geofence activations" for U-space purposes. However, the focus on "delay" as the only mission-relevant constraint is insufficient in addressing the needs of Drone Operators whose flights will be subjected to other mission and business constraints apart from "delay".

We have adapted the existing SESAR KPIs for flexibility to ones which are more applicable to U-space. These indicators put much greater focus on mission requirements which the user can define. Indicators will focus on extracting essential user mission requirements from the Operation Plans to assess the level of flexibility provided to Drone Operators in the process of designing alternatives that fulfil the constraints of existing DCB measures. These indicators addressing the process "Validation of the Operation Plan" are named as FLX1 to FLX3.

On the other hand, we need to define indicators that distinguish between two DCB measures which are providing the same capacity levels but different flexibility in order to support the process "Assessment of DCB solutions and impact to Drone Operators". As stated in §5.5, the main influence factor is the number of spatial and temporal restrictions which are imposed to the drone Operation Plans when implementing a DCB measure. This is the same influence factor identified in the Resilience KPA in §5.6. High number of restrictions makes difficult both to recover from unexpected perturbations, i.e. low resilience, and to change the Operation Plans in case of business opportunities, i.e. low flexibility. For this reason, we propose to use RES1 as a metric which is aligned with the resilience and the flexibility targets. This is named FLX4 in the table.

ID	Name	Description	Unit	Formula
FLX1	Imposed delay	Imposed delay for flight with mission plan changes or mission plan submission after RTTA.	[min]	-
FLX2	Number of restrictions	Number of restrictions on flight with mission plan changes or mission plan submission after RTTA.	[Nº]	-
FLX3	Requirements respected	Percentage of user mission requirements for flexibility respected	[%]	-
FLX4	Mean exit speed	This indicator computes the degrees of freedom of each drone complying with the existing restrictions - full freedom means that the drone can fly in x, -x, y, -y, z, -z axes -, and the speed at which the drone can move in each axis to get out of the area affected by a perturbation. This is an average for all aircraft in the area per time instant.	[m/s]	$\frac{\sum_{n}^{1} \sum_{i=\pm x,y,z} \mid V_i / 6 \mid}{n}$ Where n is the total number of drones in the area. Where V_i is the speed of the drone in the 6 directions (x, y, z, -x, -y and -z) taking into account drone performances and the existing traffic flow organization.

Table 23: Flexibility indicators for U-space DCB.

6.6 Resilience

6.6.1 DCB processes and resilience

Resilient DCB solutions will minimize the impact of disruptions on the overall traffic picture, and thus minimize associated costs.

Figure 3 shows the relevant DCB processes and U-space services in the strategic phase. Resilience indicators could support the decision-making in the following processes: 1) "Proposals for slight horizontal or vertical changes", process to be performed by the Strategic Conflict Resolution service. Those pair-wise solutions which are more resilient against perturbations could avoid subsequent iterations during the tactical phase; 2) "Assessment of DCB solutions and impact to drone operations", process to be performed by the Dynamic Capacity Management service. This is the most relevant process where resilience metrics could be used. DCB solutions with higher resilience could be probably prioritized in the strategic phase, especially in those areas where the probability of unexpected disruptions in the pre-tactical and the tactical phase is high.

Figure 4 shows the relevant DCB processes and U-space services in the pre-tactical phase. In addition to the processes described in the strategic phase, also existing in the pre-tactical, an additional process can also be identified. This is the process 3) "Identification of Operation Plans to be changed".

Theoretically, resilience metrics could help to identify those Operation Plans whose change could be affecting the resilience of an area. As an example, the deviation of a fixed wing drone to an area with only quadcopters could reduce the resilience of that area against perturbations.

Additionally, DCB solutions in the strategic phase are implemented provided that drone missions are not highly impacted. The reason for this is that the effectiveness of the DCB solution will be constrained by the high number of Operation Plan changes before the start of the pre-tactical phase. Apart from the assessment of the impact on the missions through the decision point "Is the DCB solution highly impacting the missions?", the resilience against disruptions could be another factor to be taken on board to decide on the implementation. Then, resilience could be taken on board in this process.

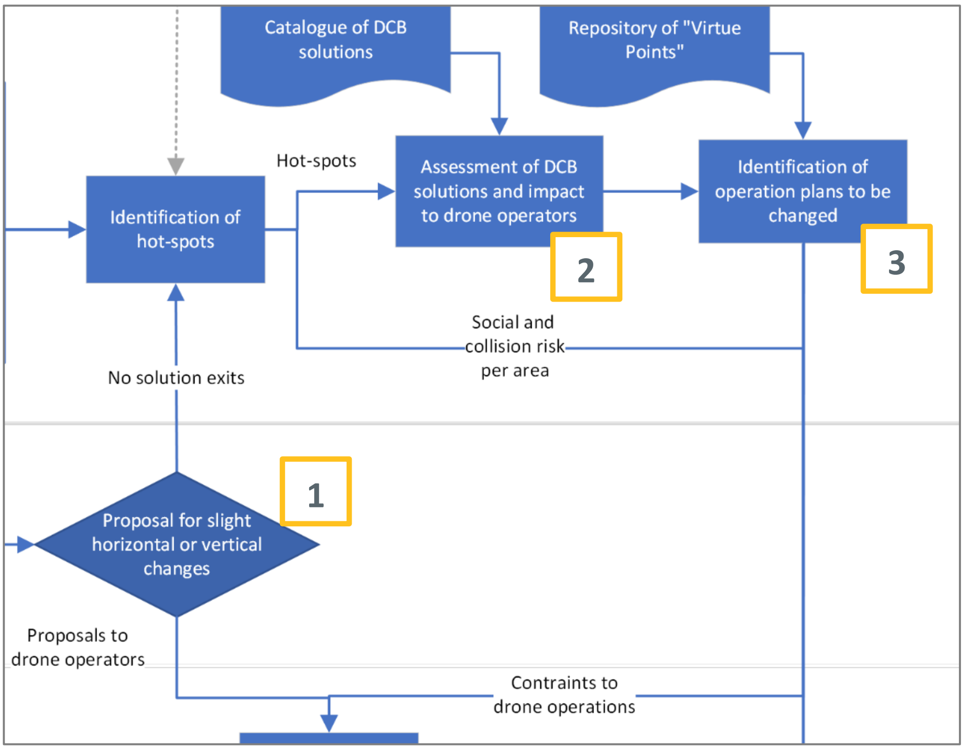


Figure 21.- DCB processes where resilience indicators are needed in the pre-tactical phase

6.6.2 Definition of indicators

The inclusion of resilience indicators in the DCB process has the added value of being able to select DCB measures based on their effectiveness to absorb external disruptions. As an example, it may be better to implement a DCB solution which is more resilient than others, given that this means that the performances of the system can be maintained with unexpected events such as environmental disruptions and drone emergencies. We will focus our indicators on supporting the decision-making in this process of "Assessment of DCB solutions and impact to drone operations".

Several influence factors were identified in §5.6 as elements which are linked to the Resilience KPA: the existing restrictions to drone operations – higher restrictions imply less resilience – is identified as the most relevant influence factor which could vary depending on the selected DCB measure. The behaviour of this influence factor is captured through the RES1 indicator.

Other factors such as the typology of drone operations – wider diversity implies less resilience – and the type of contingency plans of the drones – wider areas for contingencies imply less resilience – allow understanding the resilience of the system in nominal conditions, i.e. without imposing DCB measures.

For the influence factor related to the contingency plans, we have defined two indicators, RES2 and RES3. If the submission of contingency plans is a pre-requisite to access the airspace, RES3 will not be a valid indicator.

The following table provides a summary of all these indicators.

Ind.	Name	Description	Unit	Formula
RES1	Mean degrees of freedom	This indicator computes the degrees of freedom of each drone complying with the existing restrictions in order to get out of the area affected by a perturbation. This is an average for all aircraft in the area per time instant.	N/A	$\frac{\sum_{n}^{1} di}{n}$ Where n is the total number of drones in the area. Where di corresponds to the degrees of freedom of the drone taking into account drone performances and the existing traffic flow organization.
RES2	Mean number of drones impacted by a contingency	Number of drones affected per contingency divided by the total number of drones in the airspace This is an average for all aircraft in the area per time instant.	N/A	$\frac{\sum_{i=1}^{N} m_i}{N}$ Where i is one of the disruptions. Where N is the number of potential disruptions in the area. Where m is the mean number of drones affected by disruption i.
RES3	Number of available contingency plans.	Number of existing contingency plans in the airspace over the total number of drones in the area.	[conting. per drone]	$\frac{C}{N}$ Where N is the number of drones in the area. Where C is the number of submitted contingency plans.

Table 24: Resilience indicators for U-space DCB

RES1. Mean exit speed.

An attempt to quantify the influence factor related to existing constraints to drone operations is to assess the **degrees of freedom that each drone** has so as it can react in compliance with existing constraints when an unexpected event happens. As an example, Figure 22 – left side - shows a quadcopter flying in an area with organization per layers. The option of exiting vertically the area will not respect the flow organization. Then, we can consider that this single drone has 4 over 6 degrees of freedom to react in compliance with the constraints. On the right side of the figure, we have a quadcopter in an area with organization in tubes. in the first case, the drone will have more difficulties to exit the affected area while maintaining the existing traffic organization scheme. Then, the solution with the organization in tubes will be less resilient provided that the demand is the same.

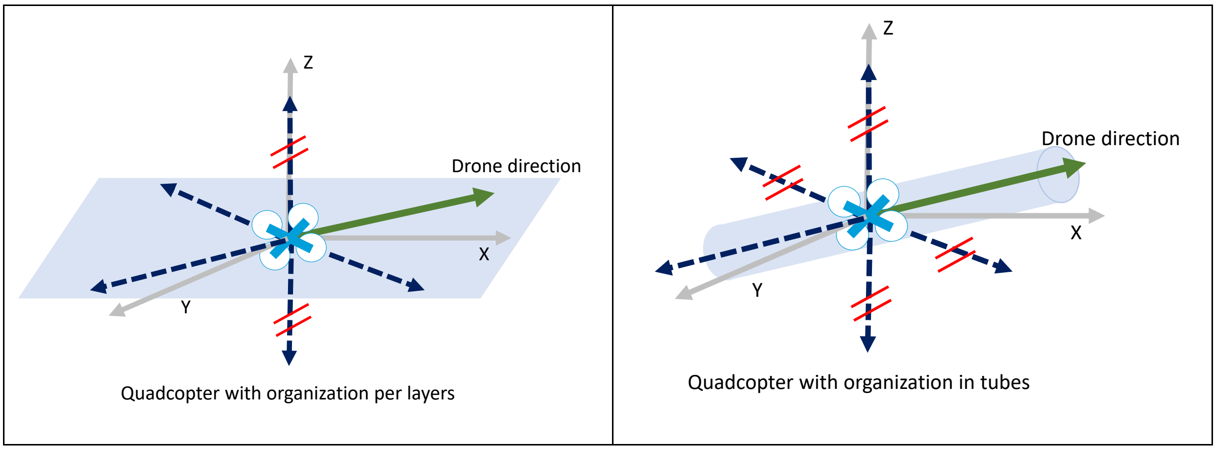


Figure 22 Degrees of freedom of a drone to get out of an area in compliance with restrictions

Then, the indicator is computed by looking at each single aircraft in the airspace, identifying the degrees of freedom of the drone complying with the restrictions - full freedom means that the drone can fly in its current direction, in the opposite direction and in the other perpendicular directions -.

This indicator approximates up to which point the drone operations can get out from the area of disturbances without infringement of the DCB restrictions in place and up to which point surrounding areas could also be affected.

RES2. Mean number of drones impacted by a contingency.

With respect to how to quantify the impact of the contingency plans, we will initially focus on the case of a drone emergency. Figure 23 shows the affected areas of each contingency plan of the drones in an airspace with organization of the traffic per layers. The **number of drones affected by this type of contingencies** could be different depending on the DCB measure in place. Then, indicators that quantify the number of affected drones in case of contingencies could capture this effect.

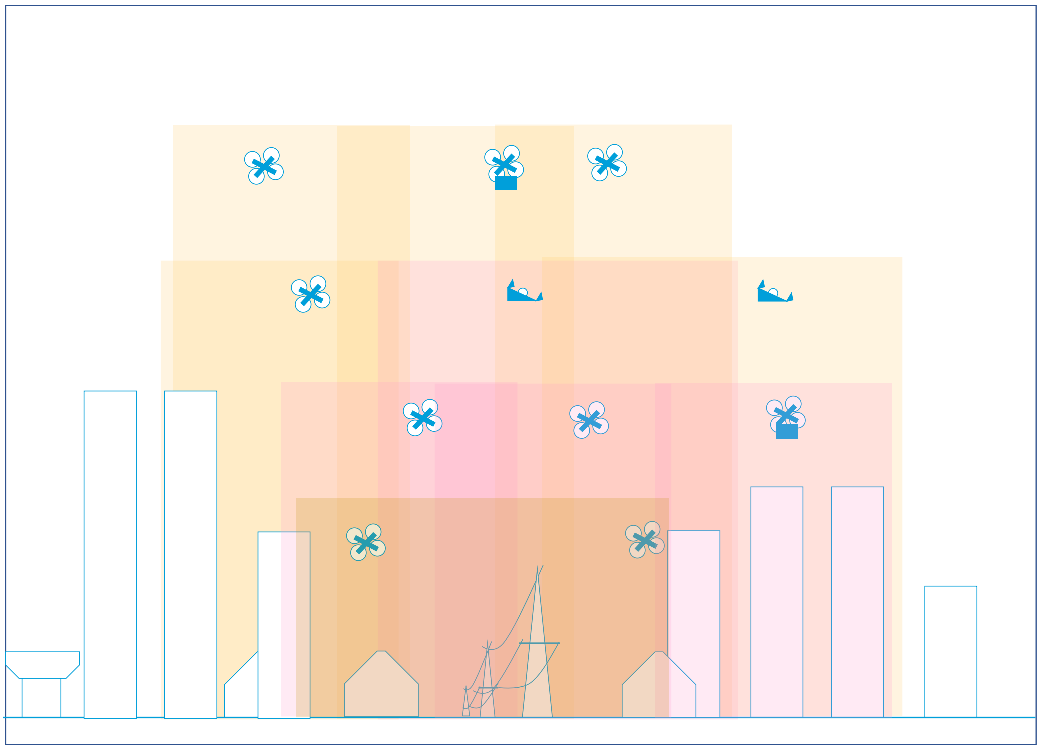


Figure 23 Overview of affected areas in case of activation of each contingency plans.

This indicator is computed by determining the number of drones affected in case of a contingency of each drone in the airspace, divided by the total number of drones in the airspace. Then, we are obtaining the average number of affected drones when a disturbance caused by a drone emergency taking place.

We could expand this indicator to other type of disturbances by identifying the number of affected drones affected by each disturbance that could happen in the airspace: navigation disturbances, communication disturbances, electromagnetic disturbances, meteorological disruptions, drone emergencies, service performance degradation or services emergencies, city-originated disturbances, airport-originated and ATM-originated disturbances. Some DCB measures will not vary the number of affected drones, but others do. As an example, a DCB measure imposing high navigation performances to fly in an area will imply that all drones in that area will be affected in case of a navigation disturbance.

RES3. Number of available contingency plans.

Another approach is to consider that not all drones in the area will have a contingency plan. This implies that the network will have more difficulties to overcome a disturbance caused by a drone without contingency plan. This indicator computes the number of existing contingency plans in the airspace over the total number of drones in the area. The more contingency plans are available to react to disruptions, the higher the resilience of the system.

7 Other KPAs in U-space

DACUS identified other KPAs which are relevant for U-space although they were not identified as facilitators of the decision-making in the DCB processes. This chapter describes those KPAs and why they are relevant for U-space.

KPAs in U-space	Definition	Focus areas
Privacy	This KPA may address peoples' privacy when drones are flying over them, the privacy of their houses and properties, and also the privacy of Drone Operators to execute their mission without sharing their business models with others.	Drone-to-drone privacy Citizens privacy
Security	This KPA addresses drone-related security incidents potentially resulting in traffic disruption.	Unauthorised drone operation in the surroundings of aerodromes and the resulting security risk to passenger carrying aircraft. Cyber security issues, hacking, communications blocking or even *weaponisation* of drones.

Table 25: Scope of other KPAs relevant in U-space.

7.1 Security

Given that there is expected to be a significant world-wide growth in the use of drones and that typically operations would be increasingly in the urban environment, the issue of security is an important aspect of future drone management planning. Additionally, as many vehicles are relatively low cost to acquire (e.g. compared to a commercial or even private airplane) and that they can be activated easily, anywhere and at any time, the issue of the misuse (intentional or otherwise) of a drone remains a critical topic to manage.

Furthermore, as drones will typically depend on either remote operators or even automated systems that rely heavily on the capabilities provided by the environment and infrastructure within which they fly, other security issues, such as hacking, service/communications blocking or spoofing are also a high risk to the security of drone operations. Finally, as the monitoring of drone operations is most likely going to rely on cooperative tracking/position reporting techniques and regulations for all vehicles to have remote identification is not expected in the EU before 2023 at the earliest, the security risk of an unidentifiable, or untracked operation remains a security issue.

Research studies [9][10] suggest that in addition to failure (technical or otherwise) of a drone system, the malicious use of drones is becoming more frequent, drone systems and the support infrastructure are vulnerable to cyber-attack or blocking, and can render them open to 'hijacking' more easily than a conventional aircraft. Moreover, drones are relatively easy to be *weaponised* (e.g., carry toxic gas, explosives or other potential weapon systems)

As illustrated in the figure below, an extended view of drone mission types can be easily identified by taking into account criminal or terrorism related usage.

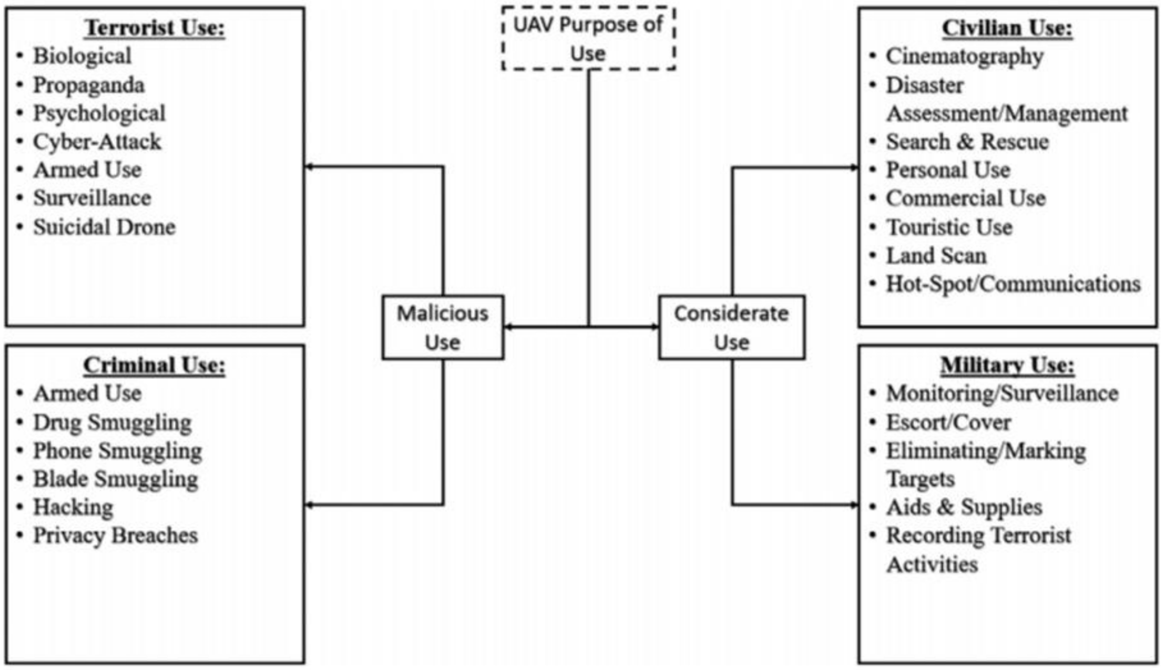


Figure 24: Extended view of Drone mission types from a security perspective [9]

However, security issues related to drone operations are not limited to malicious or intentional use. Security related problems can also occur unintentionally due to negligence, carelessness or even the recklessness of individuals.

The figure below summarises the potential causes of security related issues involving Drone operations:

Negligence	Clueless individuals, who do not know or understand the applicable regulations and restrictions. As a result, they fly their drones in sensitive or prohibited areas. Their attitude can be described as "clueless" and they have no intent to disrupt civil aviation.
	Careless individuals, who know the applicable regulations and restrictions, but breach them through either fault or negligence. As a result, they fly their drones in sensitive or prohibited areas. These individuals have no intent to disrupt civil aviation.
Gross negligence	Reckless individuals, who do know the applicable regulations and restrictions, but deliberately do not follow the rules in order to pursue personal or professional gain (e.g. aggressive spotters). Their behaviour can be characterised as "reckless", because they disrupt civil aviation by totally disregarding the consequences of their actions.
	Activists/ protesters are individuals who, regardless of whether they know the applicable regulations and restrictions, actively seek to use drones to disrupt aerodromes and flight operations. To maximise impact, these individuals might even act as a group. While their acts can have unintended consequences for aviation safety, they have no intent to endanger human lives.
Criminal/ terrorist motivation	Criminals and terrorists are individuals who, regardless of whether they know the applicable regulations and restrictions, actively seek to use drones to interfere with the safety and security of civil aviation. Because their acts are deliberate and show no regard for human lives and property, these individuals are to be regarded as being criminally motivated or even as terrorists .

Figure 25: Possible causes of security related issues due to Drone operations [11].

The intentional use of Drones to protest without the objective of causing loss of life, are also already commonplace, not least in the surroundings of aerodromes. London Gatwick was famously closed down for several days due to unauthorised Drone operations causing wide-scale disruption, and figures [11] suggest that this is far from an isolated incident.

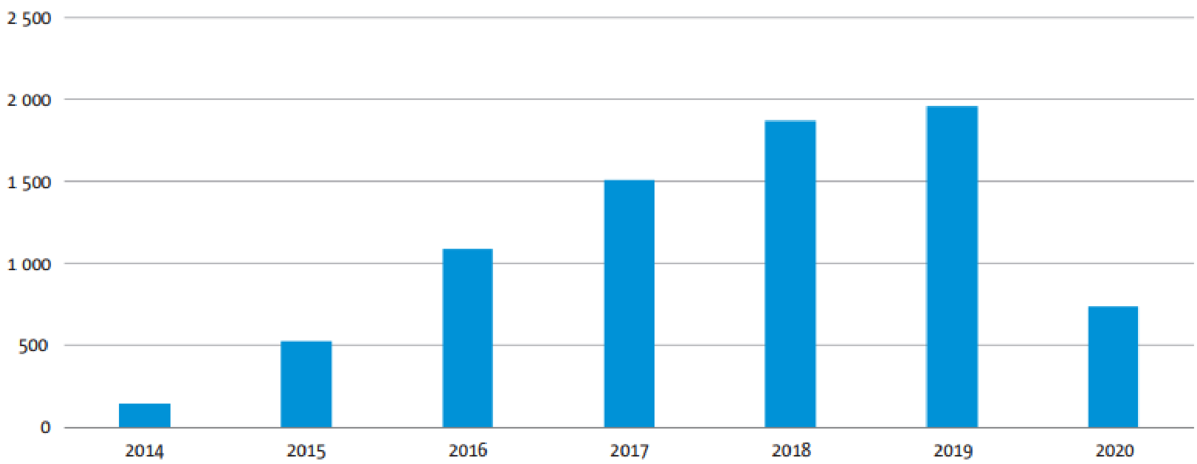


Figure 26: Reported UAS Airport Occurrences 2014-20 [11]

While a number of metrics, or proxies could be used to help measure security indicators or define performance targets, since in general drone operations that fall foul of security constraints are not able to be predicted and tend to lead to major disruption, even for a single event.

Indicators related to other failures (e.g., vehicle, technical, infrastructure etc.) which are not sufficiently critical to be classified as security violations are already covered in other KPA (e.g. safety, capacity, accessibility).

Hence, given the distinct nature of security related incidents, it is not considered that the security KPA and associated KPI should be included in relation to the research being carried out into DCM within the DACUS project.

8 Conclusions and next steps

8.1 Overall conclusions

This document has elaborated on the necessity of incorporating several performance indicators into the U-space DCB process to improve decision making. The DACUS Performance Framework focuses on the utilization of real-time, up-to-date information for this process.

Although parallelisms with ATM are provided throughout the whole document, we identified early on that particularities of drone operations and U-space make it necessary to redesign not just existing ATM indicators, but even the very definition of the associated performance areas.

Areas such as Equity, Resilience or Flexibility are not used in ATM to take decisions during the DCB processes. DCB decisions are traditionally taken by monitoring capacity-related indicators and, in some cases, mission efficiency indicators. The characteristics of the drone operations or the envisioned environmental conditions in a certain period and area will make it necessary to prioritize more equitable measures, or with higher flexibility or resilience in respond to the dynamic changes in the demand and unexpected situations that can take place in U-space. Quantitative indicators are needed to predict the impact on these KPAs. However, it was found that the existing “lagging indicators” used in ATM (meaning those which can only be identified after flight operations have taken place), are insufficient to cover the needs of U-space DCB. The focus is therefore shifted towards using “leading indicators”, which could be used to proactively guide the decision making of the U-space DCB process in line with the established performance framework.

Capacity and Mission Efficiency indicators which are traditionally used in ATM for DCB decision-making need to incorporate new indicators and update the rationale of existing ATM indicators due to the complex and diverse nature of U-space flight operations. The trends in ATM of defining other indicators apart from the number of incoming aircraft per hour - such as occupancy or complexity metrics - to limit the number of operations is identified as a fundamental requirement in U-space. The variety of vehicles and the freedom to select the most suitable trajectories in a free route environment make necessary the redefinition of indicators in the Capacity KPA. These indicators will not quantify the number of drones, but the overall risk of collision derived from the operations. Instead of a static number of drone operations per hour, U-space will manage dynamic numbers that will be determined by the safety margins.

The Environmental & Social Impact KPA emerges as a new area to be specifically addressed by U-space. Noise and visual nuisance to citizens are identified as limiting factors of the admissible number of drone operations, especially in urban environments. New indicators to monitor this area have been defined. Those indicators rely on factors such as expected noise levels or population densities, which have never been considered in ATM.

In total, six key performance areas are detailed which have applicability to U-space DCB: Capacity, Mission Efficiency, Environmental and Social Impact , Equity, Flexibility and Resilience.

We found that the first two are more mature, although new challenges have been identified in the Capacity KPA with respect to the need of designing indicators focused on the safety margins, or in the Mission Efficiency KPA with respect to the need to design trajectories to compare the sequence of 4D volumes that will be provided by the Drone Operators.

Environmental & Social KPA is considered less mature than the first two because, although we succeed in defining quantifiable indicators, it is necessary to further investigate how to integrate them as part of the DCB decision-making processes. In addition, some aspects need to be further explored such as the assumptions related to the similarities in the annoyance between manned aircraft and drones, or the impact of subjective factors such as emotions, adaption and past experience or cultural and living expectations.

Equity, Flexibility and Resilience KPAs were identified as novel areas within the process of taking decisions in DCB. We consider them as the least mature areas because indicators were designed through the use of precursors, i.e. by identifying key influence factors and assuming that they are reproducing the trends of the KPAs.

The elaboration of these KPAs showed that, in order to make U-space DCB work, they cannot be addressed in isolation. Some examples: the notion of capacity in U-space is highly reliant on the definition of the Environmental and Social Impact KPA; Equity assesses the distribution of indicators defined for the Mission Efficiency KPA; Flexibility and Resilience are linked and mutually beneficial.

When looking at the sum of these KPAs in relation to the DACUS DCB process, we find that all KPAs can be used to support the selection of DCB measures to implement, as well as aid in the decision-making of other steps in the process. We were thus able to meet the objective of this deliverable to find a means to actively incorporate performance metrics into the DCB process. The next step in the process will then be to establish a framework which incorporates all of the identified metrics in a unified DCB decision-making process. This will be a challenging task, given that some DCB solutions will by default favour certain KPA indicators over others. In a best-case scenario, the U-space DCB concept should find a solution which creates an optimum balance of all metrics for any given imbalance situation. DACUS will perform several experiments to assess the feasibility of combining these indicators to take decisions in the DCB process. The consolidated performance framework and details on the applicability will be included in the final DACUS Concept of Operations.

As a point of particular interest for the refinement of the DACUS ConOps, we have identified that a combination of mission efficiency, flexibility and resilience indicators could be used to take decisions for the implementation of a DCB measure in the strategic phase. Due to the uncertainty of the demand in this phase, which could influence the effectiveness of the measure, only solutions which are not highly impacting the drone missions are recommended for implementation before the *Reasonable Time to Act (RTTA).* Mission Efficiency metrics will allow quantifying this potential impact. On the other hand, resilience and flexibility indicators will allow quantifying the behaviour of the DCB solution to unexpected disruptions or new changes proposed by the Drone Operators.

8.2 Conclusions per KPA

A summary of the most important insights which were gathered for each KPA is now briefly provided.

At high level, the concept of **Capacity** was found to be very similar to that of ATM. However, the capacity limit will not be constrained by the air traffic controller’s capability to safely separate aircraft, but rather by the ability of the tactical conflict resolution process to manage the density of aircraft to keep the risk of conflict acceptably low. Thus, the area is defined as the maximum number of drone operations that can be accommodated in a given airspace for a certain period whilst maintaining safety-related targets. As mentioned previously, measuring capacity as part of the DCB process is an important indicator. Our analysis found that we would need to be able to calculate the metric at (hyper)localized level in space and time due to the dynamic requirements of urban U-space operations – an implementation based on grid-cells would be the most useful application. Moreover, capacity metrics need to be based on quantifications of uncertainty, mission priorities, safety thresholds, and, most importantly, collision risk. Several indicators are defined to monitor the notion of "dense traffic" in airspace, taking on board third-party ground and air risk. Other highly relevant indicators were found to be those based on the parameter "minimum closing time" to provide safe avoidance manoeuvring. The categorization of the "minimum closing time" allows connecting the capacity with the performances of the Tactical Conflict Resolution service.

A preliminary assessment of the pros and cons of each indicator found that collision risk indicators have the added value of putting the emphasis on collisions with manned aviation, where pre-defined acceptable thresholds are already defined. On the contrary, there were some concerns about their applicability during the planning phase, given that minor changes in the foreseen trajectories could completely modify the overall collision risk figures in the airspace, and then, making difficult to take effective DCB decisions. On the other hand, indicators based on the "minimum closing time" make easier to stablish the direct link with the key factors impacting capacity through a categorization of the minimum time as a function of the Tactical Conflict Resolution performances, operation types, location, conspicuity, latency or weather data quality among other factors.

Environmental and Social Impact is an important KPA to capture the impact of U-space operations on society and wildlife. The KPA is particularly relevant to the step in the DCB process which concerns the monitoring of social risk indicators. Aircraft noise and visual impact were found to be the most dominant impact factors. One of the main challenges we faced during the elaboration of this KPA was the need of incorporating subjective indicators. Subjective indicators for annoyance and exposure to drones was not readily available for the metrics we wanted to incorporate (due to the novel nature of drone operations), which required us to fall back to ATM references for the time being. This can be easily updated once more specific values are available, given that the indicators we established are easy to parametrize. Another challenge was how to capture the global impact of noise and visual pollution over an area, which we managed to resolve in the calculation of Environmental and Social Impact indicators.

Indicators were elaborated based on exposure and annoyance levels caused by noise and visual pollution, and are calculated through a combination of planned trajectories, local population density and vehicle characteristics. Noise indicators are calculated based on acoustic and non-acoustic factors, and capture the cumulative exposure to noise over ground areas. A weighting scheme depending on the time of day was also incorporated. The calculation of visual pollution follows the same concept; however the value is based on the mission trajectory profile and drone appearance. Visual impact was also found to be very dependent on the perception of privacy. Thus, knowledge of the purpose of the mission could reduce this impact factor. In our assessment of this KPA, however, we were not able to identify how these metrics should flow into the selection process of a DCB measure, because no thresholds for determining Environmental and Social Impact hotspots have yet been defined, making it difficult to identify adequate DCB processes. This would need to be further elaborated in the future based on the results of the DACUS experiments.

Incorporating and measuring **Mission Efficiency** as a KPA was a challenging task, due to the diverse nature of "efficiency" in U-space. Therefore, we decided to expand on the existing ATM concept of efficiency with the inclusion of "lack of mission goals" as a specific focus area, alongside indicators for identifying the "cost of operating" within a given DCB solution. This allowed us to adapt our metrics for efficiency much more towards the drone domain. Given the large differences in business requirements and calculations of efficiency, providing a generalized efficiency metric across competing businesses was found to be unfeasible. We concluded to assume that the Operation Plans submitted by the Drone Operator prior to the application of a DCB measure present the optimum and most efficient profile for the mission they are trying to achieve. Efficiency comparisons must therefore compare the difference between the filed and regulated plans. The challenge was therefore to identify which elements of the mission plan would need to be compared to extract efficiency metrics. Through our analysis, we were able to identify the following:

- The extent to which the horizontal or vertical flight profile is made longer than originally planned. This can be used in the DCB process to assist in selecting from several possible rerouting options.

- Any impact which is detrimental to battery duration is also considered detrimental to mission efficiency. This refers to any manoeuvre that increases energy consumption, such as longer flight routes or higher flight speed. For instance, a DCB solution that lengthens the flightpath and then "solves" the problem of the longer elapsed time by requiring higher airspeed may actually be imposing a detrimental solution to an operator with limited battery capacity.

Mission plans which are based on 4D volumes may be linearized via a "line of best fit" to make this estimation. The intrinsic benefit of receiving 4D volumes lies in that mission uncertainties are already provided by the Drone Operator, which would alleviate the need to calculate probabilistic trajectories by the U-space system, and lead to more representative mission efficiency calculations. When using these metrics to compare between reference and DCB solution scenarios, it is crucial that the same minima must be used for both. DACUS is proposing an approach to estimate this "line of best fit". However, it is important to consider that these metrics may not apply for non-linear flight profiles, such as local inspection flights. If so, this would require further elaboration.

Equity focuses on the distribution of negative impacts among operators, depending on each mission type involved, assuming that the implementation of a DCB measure could impact some mission types more than others. Therefore, it is necessary to monitor imbalances in equity among Drone Operators according to the particularities of their missions. This will allow taking decisions in the DCB process which are more equitable by taking into account the specific characteristics and constraints of the missions. Our assessment found that fairness could be quantified by comparing the distribution of costs across operators using a normalized fairness metric. This metric is linked to the distribution of indicators of the Efficiency KPI among all airspace users involved in a DCB measure, which is determined by calculating the difference between geometric and arithmetic means of all efficiency metrics. A novel addition of this KPA with respect to the one in ATM is the emphasis on fairness in the cost of operating and fairness in achieving mission goals. The indicators defined for these focus areas allow us to pinpoint more precisely in which way a DCB measure is impacting the user. This assessment could improve the decision-making process when determining which DCB measure to implement. Other aspects regarding equity, such as the inclusion of virtue points, were not considered in this assessment and would require further analysis. The challenge is how to ensure that virtue points are equitably distributed taking into account the diversity of drone missions, user compliance and impact of a DCB measure.

The **Flexibility** KPA provides an indication of the adaptability of a DCB solution to accommodate internal changes, in particular modifications to the mission plans by Drone Operators to exploit business opportunities as they occur. This KPA is very much embedded in the processes of other KPAs in this Performance Framework and will be further elaborated in this section. To provide as much flexibility to operators as possible, DCB solutions should maximize the available capacity whilst minimizing (spatial and temporal) restrictions on operations. It was found that a higher capacity buffer would provide space to absorb dynamic changes to the traffic situation. The more capacity is provided over the expected demand, the more flexibility exists. Therefore, maximizing the amount of capacity utilizing metrics of the Capacity KPA will also have positive effects on the Flexibility KPA. This also means that, when potential DCB solutions of equal capacity buffers are compared, much more weight should be given to the one with lower spatial and temporal restrictions, in order to provide more flexibility.

Concerning spatial and temporal restrictions, any DCB solution which restricts movement in the airspace or increases the duration of restrictions is detrimental to flexibility. To achieve high flexibility, the aim should therefore be towards maintaining “free route operations” as much as possible. Flexibility can be incorporated into the DCB process in two parts. The first during the assessment of DCB measures to implement, by identifying the number of spatial and temporal restrictions imposed by a measure. This step is in common with the Resilience KPA, which also revolves around the identification and minimization of restrictions. This makes the reduction of restrictions on operators a powerful means to comply with the established performance thresholds in both KPAs.

The second part occurs during the process of proposing new Operation Plans to users. For this part to work the service must understand what the business opportunities are that the operators are trying to exploit. Therefore, it is up to the operator to formulate their flexibility requirements within the mission plan so that they can be considered when selecting DCB measures to implement. In this case, it would also be beneficial to track how much flexibility is actually being provided to the operator in the resulting alternative Operation Plan proposals sent by the system using lagging indicators. Such additional indicators would need to be developed once the concept behind “flexibility” is more mature.

The final KPA is a novel one and concerns the provision of **Resilience**. Resilience within the U-space DCB concept refers to the adaptability of a solution to external changes, by anticipating and reacting to sudden, troublesome or negative disruptions whilst maintaining overall system performance. U-space is moving away from certification and towards risk management. This makes the system much more vulnerable to disruptions, which the “resilience” KPA aims to address. Resilient DCB solutions can greatly reduce the risk of collision when unforeseen events occur on air traffic in the tactical phase of operations. We have elaborated some indicators to assist this process by identifying how well the DCB solutions can deal with unexpected changes to the environment and understand how much control over the network is kept during tactical disruptions. Our analysis has identified that the primary influence factor on resilience is the capability to reorganize traffic in case of disturbances. This is very much linked to identifying the degrees of freedom of the operations and the number of drones affected by a contingency. Any DCB solution which increases the number of restrictions on the movement of air traffic also implies less resilience. As a consequence, more resilient DCB solutions should also provide for more flexibility. Several indicators were identified to monitor this behaviour: One which approximates the degrees of freedom that a DCB solution allows drones to operate in, and another which identifies how many drones would be affected by a contingency. DCB solutions with higher resilience could be prioritized in the strategic phase, especially in those areas where the probability of unexpected disruptions in the pre-tactical and the tactical phase is high.

9 References

[1] ICAO. Manual on Global Performance of the Air Navigation System. Doc. 9893. 2009.

[2] ICAO. Global Air Traffic Management Operational Concept. Doc 9854. 2005.

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

[4] DACUS. Structures and rules in capacity constrained (urban) environments. D5.1. version 00.02.00. March 2021.

[5] IMPETUS. Technological and economic feasibility report. D5.2 version 00.01.00. December 2019.

[6] Golding, R., Metrics to characterize dense airspace traffic, Airbus UTM (formerly Altiscope), TR-004, 7 June 2018, https://storage.googleapis.com/blueprint/TR-004_Metrics_to_characterize_dense_airspace_traffic.pdf.

[7] Sunil, E.; Hoekstra, J.; Ellerbroek, J.; Bussink, F.; Nieuwenhuisen, D.; Vidosavljevic, A.; Kern, S.: Metropolis: Relating Airspace Structure and Capacity for Extreme Traffic Densities. In: ATM seminar. Available online at https://hal-enac.archives-ouvertes.fr/hal-01168662/file/498_Sunil_0126150624-Final-Paper-4-30-15.pdf.

[8] JARUS guidelines on Specific Operations Risk Assessment (SORA), 2nd ed. Joint Authorities for Rulemaking of Unmanned Systems, 2019.

[9] Security Analysis of Drone Systems: Attacks limitation and recommendations – Yaacoub, Noura, Salman, Chehab, 2020

[10] Civil unmanned aircraft systems and security – Huttunen, 2019

[11] Drone incident management at Aerodromes, Part 1: the challenge of unauthorised Drones in the surroundings of Aerodromes – EASA, 2021

[12] Ref: Gomez Lopez, D., "Análisis de Capacidad y Medio Ambiente en Escenarios U-space (translation: Analysis of Capacity and Environment in U-space Scenarios)", Master's Thesis, Universidad Politécnica de Madrid, Madrid, 2019 (Translated: Analysis of Capacity and Environment in U-space Scenarios).

[13] AMU-LED project. D2.2.010 High Level ConOps – Initial. March 2021.

[14] Urban Air Traffic Management Concept of Operations Version 1. EmbraerX and Airservices. 2020.

[15] U-space Blueprint. SESAR Joint Undertaking. June 2017.

[16] CORUS Consortium (2019): U-space Concept of Operations (H2020 – SESAR -2016-1, SESAR UTM Concept Definition, v03.00.02).

[17] Vascik, P. D., & Hansman, R. J. (2018). Scaling constraints for urban air mobility operations: air traffic control, ground infrastructure, and noise. In 2018 Aviation Technology, Integration, and Operations Conference (p. 3849)

[18] Lohn, A. J. (2017). What's the buzz? The city-scale impacts of drone delivery (No. RR-1718-RC).

[19] Vas, E., Lescroël, A., Duriez, O., Boguszewski, G., & Grémillet, D. (2015). Approaching birds with drones: first experiments and ethical guidelines. Biology letters, 11(2), 20140754.

[20] Mulero-Pázmány, Margarita; Jenni-Eiermann, Susanne; Strebel, Nicolas; Sattler, Thomas; Negro, Juan José; Tablado, Zulima (2017): Unmanned aircraft systems as a new source of disturbance for wildlife: A systematic review. In: PloS one 12 (6), e0178448. DOI: 10.1371/journal.pone.0178448.

[21] Rebolo-Ifrán, Natalia; Graña Grilli, Maricel; Lambertucci, Sergio A. (2019): Drones as a Threat to Wildlife: YouTube Complements Science in Providing Evidence about Their Effect. In: Envir. Conserv. 46 (3), S. 205–210. DOI: 10.1017/S0376892919000080.

[22] Bevan, Elizabeth; Whiting, Scott; Tucker, Tony; Guinea, Michael; Raith, Andrew; Douglas, Ryan (2018): Measuring behavioral responses of sea turtles, saltwater crocodiles, and crested terns to drone disturbance to define ethical operating thresholds. In: PloS one 13 (3), e0194460. DOI: 10.1371/journal.pone.0194460.

[23] Vas, Elisabeth; Lescroël, Amélie; Duriez, Olivier; Boguszewski, Guillaume; Grémillet, David (2015): Approaching birds with drones: first experiments and ethical guidelines. In: Biology letters 11 (2), S. 20140754. DOI: 10.1098/rsbl.2014.0754.

[24] Weston, Michael A.; O'Brien, Curtis; Kostoglou, Kristal N.; Symonds, Matthew R. E. (2020): Escape responses of terrestrial and aquatic birds to drones: Towards a code of practice to minimize disturbance. In: J Appl Ecol 57 (4), S. 777–785. DOI: 10.1111/1365-2664.13575.

[25] https://ansperformance.eu/methodology/horizontal-flight-efficiency-pi/

[26] https://www.icao.int/environmental-protection/Pages/Operational-Measures_Horizontal-Flight-Efficiency.aspx

[27] https://ansperformance.eu/methodology/en-route-vertical-flight-efficiency-pi/

[28] Fairness in Decentralized Strategic Deconfliction in UTM Antony Evans, PhD; Maxim Egorov and Steven Munn Airbus UTM, Sunnyvale.

[29] SESAR. D4.7 Performance Framework. PJ19.04. 2019.

[30] Hollnagel, E. (2006). Resilience-the Challenge of the Unstable. In E. Hollnagel, D. D. Woods and N. Leveson (Eds.), Resilience Engineering: Concepts and Precepts (pp.9-17) Farnham, Surrey, UK: Ashgate Publishing.

[31] Singh, C.S., Soni, G. & Badhotiya, G.K. Performance indicators for supply chain resilience: review and conceptual framework. J Ind Eng Int 15, 105–117 (2019).

[32] "Operation Efficiency Assessment Model of Route Network in Terminal Area" Zhang et al. Aerosp. Technol. Manag. vol.7 no.4 São José dos Campos Oct./Dec. 2015.

[33] SJU PJ19 Performance Framework (2017) - Deliverable ID: D4.1.

[34] Airbus report on Managing UAS Noise Footprint.

[35] EASA (2021): Study on the societal acceptance of Urban Air Mobility in Europe. Online verfügbar unter https://www.easa.europa.eu/sites/default/files/dfu/uam-full-report.pdf, zuletzt geprüft am 25.05.2021.

[36] TU Berlin (2020): Traffic solution or technical hype? Representative population survey on delivery drones and air taxis in Germany [Sky Limits Project Results Report]. Online verfügbar unter https://skylimits.info/wp-content/uploads/2020/06/Sky-Limits-_Results_Survey_english.pdf, zuletzt geprüft am 25.05.2021.

[37] H.P. (Huib) van Essen (CE); B.H. (Bart) Boon (CE); S. (Steve) Mitchell (ERM); et. al. (2005): Sound Noise Limits. Options for a uniform noise limiting scheme for EU airports. Delft. Online verfügbar unter https://ec.europa.eu/transport/sites/transport/files/modes/air/studies/doc/environment/2005_01_sound_noise_limits.pdf, zuletzt geprüft am 25.05.2021.

[38] Commission, European (2002): Position paper on dose response relationships between transportation noise and annoyance (EU's Future Noise Policy, WG2–Dose/Effect 20).

[39] Chabot, Dominique; Bird, David M. (2012): Evaluation of an off-the-shelf Unmanned Aircraft System for Surveying Flocks of Geese. In: *Waterbirds* 35 (1), S. 170–174. DOI: 10.1675/063.035.0119.

[40] Christie, Katherine S.; Gilbert, Sophie L.; Brown, Casey L.; Hatfield, Michael; Hanson, Leanne (2016): Unmanned aircraft systems in wildlife research: current and future applications of a transformative technology. In: *Front Ecol Environ* 14 (5), S. 241–251. DOI: 10.1002/fee.1281.

[41] Hodgson, Jarrod C.; Mott, Rowan; Baylis, Shane M.; Pham, Trung T.; Wotherspoon, Simon; Kilpatrick, Adam D. et al. (2018): Drones count wildlife more accurately and precisely than humans. In: *Methods Ecol Evol* 9 (5), S. 1160–1167. DOI: 10.1111/2041-210X.12974.

[42] Jone, G. P.; Pearlstine, L. G.; Percival, H. F. (2006): An Assessment of Small Unmanned Aerial Vehicles for Wildlife Research. In: *Wildlife Society Bulletin* 34 (3), S. 750–758. DOI: 10.2193/0091-7648(2006)34[750:aaosua]2.0.co;2.

[43] Linchant, Julie; Lisein, Jonathan; Semeki, Jean; Lejeune, Philippe; Vermeulen, Cédric (2015): Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges. In: *Mammal Review* 45 (4), S. 239–252. DOI: 10.1111/mam.12046.

[44] Watts, Adam C.; Perry, John H.; Smith, Scot E.; Burgess, Matthew A.; Wilkinson, Benjamin E.; Szantoi, Zoltan et al. (2010): Small Unmanned Aircraft Systems for Low-Altitude Aerial Surveys. In: *Journal of Wildlife Management* 74 (7), S. 1614–1619. DOI: 10.2193/2009-425.

[45] https://en.wikipedia.org/wiki/O._Winston_Link

[46] https://en.wikipedia.org/wiki/Norfolk_and_Western_Railway#Coal

[47]Towards a continuous Demand and Capacity Balancing process for U-space. Innovative approach to implement dynamic separation criteria in Tactical Conflict Resolution and Dynamic Capacity management services as part of the U-space ecosystem. P. Sánchez-Escalonilla, D. Janisch, C. Forster, M. Büddefeld, H. Eduardo. SESAR Innovation Days 2020.

[48]AURORA. Final Project Results Report. D6.4 version 00.01.00. March 2018.

Appendix A Research initiatives and studies addressing performances indicators

This appendix summarizes several on-going and completed research initiatives on subjects considered relevant to performance indicators that can be used in the U-space demand and capacity balancing process.

9.1 Capacity

Ref: Altiscope, Metrics to characterize dense airspace traffic, TR-4, June 2018.

Summary: The paper proposes two metrics to determine when the traffic in flight is dense. The author shows that these metrics are better than the absolute number of vehicles for determining dense operations. Metrics were tested in simulated environments. The author suggests that traffic can become "dense" at low traffic volumes.

Literature title:	Metrics to characterize dense airspace traffic
Summary: Pages 1 – 9	The two metrics are based on the **Closing time**. This is the distance from the ownship to another aircraft, divided by the speed at which the other aircraft is moving toward the ownship, which gives the amount of time required for the other aircraft to reach the ownship. 1.- **Minimum closing time (Cap01)**. This is computed by looking at all the aircraft in the airspace, measuring their closing time, and selecting the smallest. This measure approximates the amount of time that the ownship will have to react and manoeuvre to the situation when it must manoeuvre to avoid another aircraft. 2.- **Number of close aircraft (Cap02)**. This is determined by computing the minimum closing time for all aircraft in the airspace and counting the number that have a minimum closing time less than 15 seconds. The paper assesses how this parameter can change based on aircraft capability. Metrics were evaluated with four different traffic patterns that progressively introduce more organization in the traffic patterns. The first conclusion was that the more that all these aircraft are on similar headings the better these measures of the effect of density are.
Summary: Pages 10 – 16	The paper also assesses how much of their flight time should the UAVs doing avoiding manoeuvres. Results suggest that "dense" traffic, meaning traffic where flights interact often enough that they spend more than perhaps 10% of their time manoeuvring to avoid collision, occurs even at very low numbers of aircraft when the traffic is not organized. The rationale for the selection of this threshold is not properly justified.
Obs.	Pros and cons of the metrics are identified in the following bullets:

Literature title:	Metrics to characterize dense airspace traffic
	• Pros.- Each aircraft in the airspace will have a minimum closing time and number of close aircraft. N drones with t1, t2...tn. An average value in each airspace is needed. If the whole airspace is divided in cells, the **“average minimum closing time” per cell** could be used to have a heatmap to identify the areas with higher risk. • Cons.- Both are instantaneous indicators. Probably they should be implemented by integrating these instantaneous values for a given period to be determined. Time window to be determined as it is foreseen that current ATM 20-minute slots should be reduced. • Cons.- Need to determine how many collision avoidances manoeuvres in each instant and specially during the operation without impacting the fulfilment of the missions. Need to complement with other indicator that shows the acceptable % of flight time executing avoidance manoeuvres or the number of acceptable resolution manoeuvres per operation along the execution of the flight. The paper considers acceptable a 10% of the flight time, but arguments for this selection are needed. • Pros.- Though the speed profile, the diversity of business models are in some way considered. • Cons.- Need to determine the average minimum closing time per cell that can be acceptable. • Cons.- Need to complement with other indicators that allow distinguishing between traffic samples with more manned aviation or not. • Cons (Cap02).- Need to assess if 15 seconds is a parameter that can be accepted to monitor potential collision threats. This will be determined by the performances of the tactical conflict resolution service.

Altiscope, Metrics for Near-Miss Events: Understanding Airprox, NMAC and “Inadequate Separation”, Airbus UTM (formerly Altiscope), TR-002.

Summary: This white paper aims at identifying a global metric for tracking “near-miss” incidents for drone operations. Three separate metrics used by regulators today were compared. All three are qualitative, even if specific proximity information is available from radar or surveillance replay data. The paper concludes that while these metrics may provide an appropriate starting point for evaluating UAV near-miss severity and risk, developing an appropriate benchmark rate will require further research and awareness of local regulatory expectations.

Literature title:	Metrics for Near-Miss Events: Understanding Airprox, NMAC and “Inadequate Separation”
Summary **Pages 1 –2**	The paper recommends that the UAS industry use the **ICAO Airprox A+B** metric as a starting point to develop a new, quantitative metric appropriate to high-density UAV operations.

Literature title:	Metrics for Near-Miss Events: Understanding Airprox, NMAC and "Inadequate Separation"
	ICAO defines an Airprox (Air Proximity Hazard) as an event in which either a pilot or a controller feels there was an increased risk of collision between two aircraft. The aircraft involved do not need to be talking to air traffic controllers to report an Airprox encounter. Airprox reports are categorized by severity, after the fact, using a qualitative process and whatever information is available from controllers and pilots. 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.
Summary: **Page 5**	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. It may only be sufficient to a point, and we expect that there will be a need to develop a new, **quantitative metric that can be applied globally when evaluating proximity events between UAVs**. Such a metric would have added value to industry and regulators when defining specific separation minima between vehicles or "well-clear" distances. And it would be useful in assessing airspace capacity, throughput, and efficiency. In a future UAV environment, this framework would enable reporting by fleet managers or even automated reporting from vehicles themselves based on quantitative proximity or closure rate measures.
Obs.	Useful metric to assess historical data. However, its use for the prediction of DCB hot-spots is not clear as no historical data is available.

Ref: Gomez Lopez, D., "Análisis de Capacidad y Medio Ambiente en Escenarios U-space (translation: Analysis of Capacity and Environment in U-space Scenarios)", Master's Thesis, Universidad Politécnica de Madrid, Madrid, 2019 (Translated: Analysis of Capacity and Environment in U-space Scenarios)

Summary: This is a Master thesis document which proposes a series of performance indicators to be used in U-space, with specific emphasis on capacity and environmental impact

Literature title:	Analysis of Capacity and Environment in U-space Scenarios [translated]
Summary **Pages 60 – 72**	This document proposes a combination of existing ATM capacity indicators as well as several novel indicators for U-space capacity. These indicators are summarized below:

U-space indicator	Focus area	Influence factors
Variation of the number of flights accommodated near hub per unit of time	Terminal capacity	All
Variation of the number of flights accommodated per unit of time	En-route capacity	All
Peaks in allowed departures per hour – hub	Terminal capacity	- Number of platforms - Size of platforms - Departure sequencing - Separation minima
Peaks in allowed arrivals per hour – hub	Terminal capacity	- Number of platforms - Size of platforms - Arrival sequencing - Separation minima
Reduction of non-accommodated traffic	Terminal capacity	All
Number of prevented hub capacity losses	Hub loss of service	-
Hub recovery time from non-nominal conditions	Hub loss of service recovery	-
Number of prevented airspace capacity losses	Air space loss of service	-
Airspace recovery time from non-nominal conditions	Airspace loss of service recovery	-
Minutes in delay	Failure in airspace/hub service	-
Number of cancellations	Failure in airspace/hub service	-

Literature title:	Analysis of Capacity and Environment in U-space Scenarios [translated]		
	Percentage of extra flight distance	En-route capacity	All
	Percentage of extra en-route flight time	En-route capacity	All
	Percentage of extra flight time near hub	Terminal capacity	All
	Percentage of extra flight manoeuvres	En-route capacity	All
	Number of accommodated flights	En-route and terminal capacity	- Management of separation minima - Complexity - Deconfliction service - Entry/exit sequencing
	Ratio of flights per day	En-route and terminal capacity	- Management of separation minima - Complexity - Deconfliction service - Entry/exit sequencing
	Maximum number of conflicts per hour	En-route and terminal capacity	- Management of separation minima - Complexity - Deconfliction service
	Maximum duration of conflicts	En-route and terminal capacity	- Management of separation minima - Complexity - Deconfliction service

Ref: Vishwanath Bulusu∗ and Raja Sengupta, Valentin Polishchuk and Leonid Sedov, "**Capacity Estimation for Low Altitude Airspace**", 2017

Summary: This paper uses a threshold based mathematical definition to estimate capacity for future UAS traffic in low altitude uncontrolled airspace based on safety and performance considerations. It is motivated by the need to assess the impact of large-scale proximity unmanned aircraft operations on communities and existing manned airspace.

Literature title:	Capacity Estimation for Low Altitude Airspace
Summary **All pages**	We simulate unmanned traffic over urban areas and estimate metrics focused on safety and performance efficiency. The effect of increasing traffic density on the

Literature title:	Capacity Estimation for Low Altitude Airspace
	metrics shows that safety is potentially the most critical capacity determining factor of the two. Performance metric for efficiency was "**Change in Direct Operating Cost**" as proposed by Krozel et al. This metric considers the added effect of Cost for Extension of Travel Distance and Travel Time. Safety metric was based on the potential collisions. The paper refers to MITRE, "SUAS gaps being worked by SARP," UTM Convention, 2016, Research Panel Presentation. MITRE proposes a maximum loss of 1 UAS flight per 1000 flight hours over urban areas, e.g., the metric could "**Total Loss of Flight per Flight Hour**" with an acceptable limit of 0.001.
Obs.	Proposed metric seems to be obtained by exploiting historical data. For DCB process, this metric is similar to the collision risk.

Ref: Metropolis project. Paper "The Influence of Traffic Structure on Airspace Capacity". June 2016

Summary: Metropolis was an FP7 project, investigating the effect of airspace structure on capacity and safety. This project proposes the investigation of radically new airspace design concepts for scenarios, which are extreme when compared to today in terms of traffic density, complexity, and constraints. 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. METROPOLIS assesses the application of a "layers" concept to structure drone traffic based on headings has the lowest number of intrusions and lowest complexity of all tested airspace structures.

Literature title:	Metropolis project
Summary **All pages**	Metropolis calculates the **conflict rate** as a factor that takes into account the number of aircraft that can be met in each airspace, and the probability for each possible pair to come within the **minimum separation distance** of each other. This is computed by considering the relative velocity between each pair of aircraft and the angle between both velocities. Thus, a decrease of the conflict rate in each airspace implies a capacity increase. The management of relative speed vectors allows managing capacity. Consequently, Metropolis considers that **geo-vectoring** – managing magnitude and 3D direction of the speed vectors in an area – allows increasing the capacity. In the paper, three categories of dependent variables are used to compare the concepts: safety, efficiency, and stability. Safety metrics focus on the ability of an airspace concept to maintain safe separation between aircraft. Separation performance is measured in terms of the number of intrusions and conflicts. Here,

Literature title:	Metropolis project
	intrusions are defined as violations of minimum separation requirements, while conflicts are defined as predicted intrusions, i.e., when two (or more) aircraft are expected to violate separation requirements within a predetermined `look-ahead' time (60 seconds in this research). Intrusions do not imply collisions. Therefore, in addition to counting the number of intrusions, **it is important to consider the severity of an intrusion**. The severity of an intrusion is dependent on the path of an aircraft through the protected zone of another. The efficiency of the concepts is analyzed using the work done metric. This metric considers the optimality of an aircraft's trajectory, and therefore has a strong correlation with fuel/energy consumption. Resolving conflicts may cause new conflicts at very high traffic densities due to the scarcity of airspace. The stability of the airspace as a direct result of conflict resolution manoeuvres has been measured in literature using the Domino Effect Parameter.
Obs.	Speed and angle are identified as key factors to be taken on board in the indicators. Further research is needed to understand if it possible to define any intuitive indicator capturing the Domino Effect. It could be relevant to distinguish between intrusions and collisions, thinking on the maximum number of intrusions that can be managed by the Tactical Conflict Resolution service.

Ref: AMU-LED project and High Level ConOps – Initial (March 2021)

Summary: AMU-LED is a Very Large-Scale Demonstration (VLD) project funded by SESAR Joint Undertaking (SJU) under the European Union's Horizon 2020 research and innovation programme that aims to demonstrate the safe integration of different types of manned and unmanned aircraft operations in urban environments to realise increasingly sustainable smart cities. AMU-LED will allow UAM stakeholders to assess safety, security, sustainability and public acceptance of various use cases applicable to logistics and urban transport of passengers. The results of the project will be showcased through a set of tests and flight demonstrations in the United Kingdom, The Netherlands and Spain.

Literature title:	AMU-LED D2.2.010 High Level ConOps - Initial
Summary **Page 60**	AMU-LED proposes key indicators that will be used for evaluating the effectiveness, suitability and performance of the systems and relevant technologies and operational procedures. An initial list involving 12 key performance areas are considered to reflect the overall UAM performance, taking into account the existing UTM and UAM programmes across the world, as well as the SESAR JU high-level performance framework. These key performance areas include safety, capacity, environment, access and equity, efficiency, flexibility, interoperability, predictability, security, privacy, decentralisation and social acceptance.

Literature title:	AMU-LED D2.2.010 High Level ConOps - Initial
	With respect to capacity, it mentions vertiport capacity, airspace capacity, route/corridor capacity, **vertiport distribution and spare capacity**. These two last points were not included in DACUS but no more details about the definition of the indicators are included in the document.
Obs.	Vertiport distribution is a factor which could be taken on board in our focus area addressing Terminal airspace. This will allow to monitor the overall terminal capacity and how this capacity is distributed on the ground.

9.2 Social Impact

Ref: Maris et al, 2007. Evaluating noise in social context: the effect of procedural unfairness on noise annoyance judgments. J Acoust Soc Am. 2007 Dec;122(6):3483-94. doi: 10.1121/1.2799901.

Summary: An experiment showed that treating people nicely dramatically reduced their annoyance from noise.

Literature title:	Evaluating noise in social context: The effect of procedural unfairness on noise annoyance judgments
Summary:	Participants listening to noise are simply given aircraft noise rather than their choice of noise (unfair treatment), or are politely told they will listen to aircraft sound (neutral procedure). All are exposed to aircraft sound (50 or 70dBA Leq). Results show that noise annoyance ratings are significantly higher in the unfair relative to the neutral conditions.

Ref: Schreckenberg et al, 2017. Attitudes towards authorities and aircraft noise annoyance: Sensitivity analyses on the relationship between non-acoustical factors and annoyance. Presented at 12th ICBEN Congress on Noise as a Public Health Problem, Zürich, 2017

Summary: Sensitivity analyses of attitudinal and annoyance data from the NORAH study were carried out to clarify the potential of non-acoustic factors to reduce annoyance. Considerable differences in exposure-response curves for aircraft noise annoyance were found depending on 'trust in authorities', ‘perceived procedural fairness’ and 'expectations regarding air traffic impact'.

Literature title:	Attitudes towards authorities and aircraft noise annoyance: Sensitivity analyses on the relationship between non-acoustical factors and annoyance
Summary:	Sensitivity analyses of attitudinal and annoyance data from the NORAH study were carried out to clarify the potential of non-acoustic factors to reduce annoyance. Considerable differences in exposure-response curves for aircraft noise annoyance were found depending on 'trust in authorities', ‘perceived procedural fairness’ and 'expectations regarding air traffic impact'.

Ref: CORUS Consortium, "**U-space ConOps Annex H: Social Acceptance Indicators**", SESAR Joint Undertaking, ed 00.01.01, 2019

Summary: The principal objective of these social acceptance indicators is to contribute to convert these expectations in facts. More specifically we can list the objectives of the SAI in:

- Provide an assessment tool to measure the deployment of drones.
- Help to detect any unbalance situation and to propose regulations to avoid unfair situations.
- Check the necessity of funding.
- Be transparent with the drone inconveniences.
- Serve as a performance evaluation tool either for new drone technologies, new airspace organization or changes in legislation.
- Extend the safety culture also across Drone Operators, pilots, and industry.
- Assess the level of compromise of the airspace safety.
- Help citizens to have a funded opinion about drones.
- Drones will have an impact both on society (societal impact) and the individuals that compose it (social impact). Societal impact will come from changes to the way things are done, whether it is a more sedentary lifestyle from having on-line shopping delivered to one's door, the use of air-taxi drones to move about. Social impact will concern things like noise, fear of accident, even visual pollution, as well as other questions such as privacy that are dealt with in other KPAs.

One major factor to be taken into consideration is what is known as the "non-acoustic" factors of noise. People who think could be difficult to complain about things such as a fear of a drone falling on their kids' school playground, or fear of being spied upon by the state (or their neighbour), tend to complain about noise instead. Similarly, there are other factors such as economic benefit, or perhaps a feeling of increased safety from increased state surveillance, that reduce complaints about noise.

Literature title:	**[CORUS: U-space ConOps Annex H: Social Acceptance Indicators]**
Pages [6]	To consider all aspect of social impact we propose three indicators that we named as safety (**SAI_SA**), economic (**SAI_EC**) and political (**SAI_PO**): • **SAI_SA** is the Safety indicators and measures the benefits/risks that drones pose to rest of air space users and to people on ground. • **SAI_EC** is an Economic indicator that measures the accomplishment of economical expectations of the new emerging drone market. • **SAI_PO** encompasses any other social issue, named as Political, which includes aspects such as the citizens' affectations from the drones' noise, the privacy potential compromise, the visual impact etc. SAI_PO also includes the increase of governments and administrations complexity and new management requirements. Moreover SAI_PO includes the potential affectation (positive and negative) on emergency situations resulting from the introduction of

Literature title:	[CORUS: U-space ConOps Annex H: Social Acceptance Indicators]
	drones. Finally, environmental considerations are included also as part of the impact of drones for future generations and Earth preservation.]

SAI	Stakeholder	ID	Benefits	Risks
ECONOMICAL	Drone operator	SAI_EC01	Fast and easy implementation of a mission	Complex and slow the implementation of a mission
		SAI_EC01.1	Increase of the potential number of missions	Reduction of the potential number of missions
		SAI_EC01.2	Full access to VLL airspace	Limitations to VLL airspace access
		SAI_EC01.3	Low management effort	High management effort
		SAI_EC01.4	Flexibility in last minute changes	Limitations to last minute changes
		SAI_EC01.5	Capacity of operating multiples drones	Complexity of operating multiples drones
		SAI_EC02	Low cost of onboard equipment	High cost of onboard equipment
		SAI_EC02.1	Few and affordable non-mission devices	Large number or high cost of non-mission devices
		SAI_EC02.2	Seamless integration of non-mission devices	Complex integration of non-mission devices
		SAI_EC02.3	No impact of non-mission devices in the mission	Impact of non-mission devices in the mission
		SAI_EC02.4	Improvements due to U-space services	Cost of U-space services
		SAI_EC03	Low cost of ground station and personnel	High cost of ground station and personnel
		SAI_EC03.1	Integrated and affordable non-mission systems on ground	Large number or high cost of non-mission systems on ground
		SAI_EC03.2	Availability of additional personnel and/or training	Large number or high cost of additional personnel and/or training
		SAI_EC04	Good insurance	Insufficient insurance
		SAI_EC04.1	Affordable insurance	High cost of insurance
		SAI_EC04.2	Ease to contract insurance	Difficult to contract insurance
	End-Users	SAI_EC05	Availability of drone services	Limitations to drone services
		SAI_EC05.1	Affordable	Too expensive or exclusive
		SAI_EC05.2	Wide offer	Monopoly
	Industry & suppliers	SAI_EC06	Creation of a new and growing economical sector	Destruction of some economical sector
		SAI_EC06.1	Creation of new enterprises	Reduction of existing enterprises
		SAI_EC06.2	Creation of new jobs	Reduction of existing jobs
		SAI_EC06.3	Economical benefits	Economical losses

SAI	Stakeholder	ID	Benefits	Risks
POLITICAL	Environment	SAI_PO01	Preserve natural life (wild animals, forest, ...)	Danger natural life (wild animals, forest, ...)
		SAI_PO02	Reduction of CO2 Emissions	Increase of CO2 Emissions
		SAI_PO03	New application in live science and environment (reduce pesticides, water management, ...)	New application will stress the environment (extra-production, high use of resources...)
	Citizens	SAI_PO04	Substitution of more noisy vehicles	Noise increase
		SAI_PO04.1	Very quiet	Too loud
		SAI_PO04.2	Not noticeable	Too disturbing
		SAI_PO04.3	Very infrequent	Too repetitive
		SAI_PO05	Reinforcement of privacy laws	Privacy compromised
		SAI_PO05.1	Self-protection (own recordings at my home)	Someone else recording my home
		SAI_PO05.2	Creation of new stringent laws to penalize privacy violators thanks to drones	Someone else can record me anyplace
		SAI_PO06	Reinforcement of liability laws	Non-Liability
		SAI_PO06.1	Increase of transparency	Problems in identifying owner of drone
		SAI_PO06.2	Improved rules for claims	Complexity of damage claims
		SAI_PO07	Positive visual impact	Negative visual impact
		SAI_PO08	Increase of leisure activities	Decrease of leisure activities
	Emergency & police	SAI_PO09	Potential for saving humans in danger	Potential of creating additional danger
		SAI_PO09.1	Convenience for using drones in emergencies	Possible threats created by drones
		SAI_PO09.2	Reduction of emergency response time	Increase of emergency response time
		SAI_PO010	Efficient tools for law-enforcement	Difficulties in law-enforcement to non-legal drones
	Administration	SAI_PO11	Potential for administration reorganization	Increase of administration complexity
		SAI_PO11.1	Increase of public services	Increase of citizens complains

SAI	Stakeholder	ID	Benefits	Risks
SAFETY	Airspace users: VFR, Passengers	SAI_SA01	Easy access to new and cheap airspace services	Increase of VFR flight preparation and airspace complexity
		SAI_SA02	Perception of decreased risk	Perception of increased risk
		SAI_SA03	Availability of new COTS equipments/services	Cost of additional equipments/services
		SAI_SA04	Extended airspace access	Limitations to airspace access
	ATM, Airports, Safety Agencies	SAI_SA05	Opportunity for digitalization and automation	Increase of complexity
		SAI_SA05.1	Increase of safety thanks to geofencing	Increase of NOTAMs/geofences notifications
		SAI_SA05.2	Increase of technological providers	Danger due to lack of interchange standards
		SAI_SA05.3	Confusion with new regulations	Improvements to existing airspace safety regulations
	IFR, airlines	SAI_SA06	Improve maintenance using drones	Potential damage from drones
		SAI_SA07	Improved situation awareness with drones info	Lack of situation awareness about drone flights

Ref: Miedema, H., & Oudshoorn, C. (2002). Position paper on dose response relationships between transportation noise and annoyance. EU's Future Noise Policy, WG2–Dose/Effect, 20.

Summary: This position paper aims to provide guidance on the dose-effect relation to be used for the assessment of numbers of people annoyed by noise. It summarises recommended **descriptors of noise exposure and of annoyance** and recommends dose-effect curves, together with formulae. The dose-response functions and their curves recommended here are only to be used for aircraft, road traffic, and railway noise and for assessment of long-term stable situations.

Literature title:	**Position paper on dose response relationships between transportation noise and annoyance**
Summary, Page 2:	**Descriptor 1, Noise exposure**: Lden is defined in terms of the "average" levels during daytime, evening, and night-time, and applies a 5 dB penalty to noise in the evening and a 10 dB penalty to noise in the night. The definition is as follows:

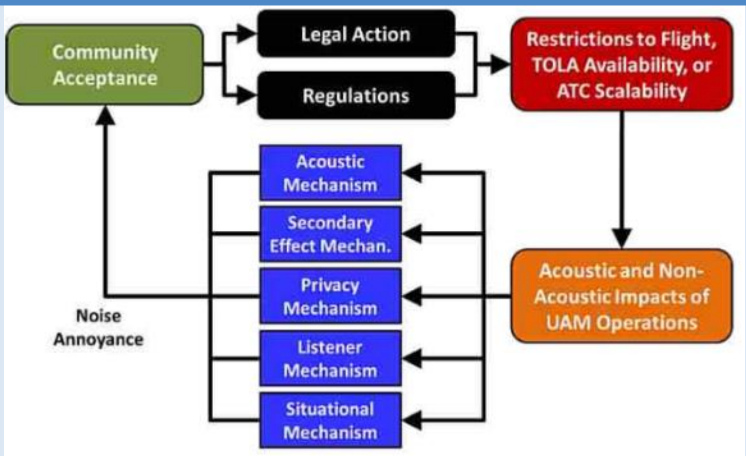
Literature title:	Position paper on dose response relationships between transportation noise and annoyance
	$$Lden = 10\lg\left[(12/24).10^{LD/10} + (4/24).10^{(LE+5)/10} + (8/24).10^{(LN+10)/10}\right]$$
Summary, Page 3:	**Descriptor 2, Annoyance:** This Position Paper recommends that the percentage of persons annoyed [%A], or the percentage of persons highly annoyed [%HA] be used as the descriptor of noise annoyance in a population. These descriptors of annoyance are derived from transforming various annoyance scales to a 0 to 100 basis and using a cut-off at the scale value 50 (for %A) or 72 (for %HA), respectively.

Ref: Vascik, P. D., & Hansman, R. J. (2018). Scaling constraints for urban air mobility operations: air traffic control, ground infrastructure, and noise. In 2018 Aviation Technology, Integration, and Operations Conference (p. 3849).

Summary: This paper characterizes the mechanisms through which the noise constraints manifest in a UAM system, and to evaluate how fundamental technical, ecosystem, or operational factors influence to what extent each constraint may limit UAM system scaling.

This research proposes a two-staged approach to understanding scalability limitations due to community acceptance. First, the **percentage of individuals highly annoyed in a community** was determined to be a salient metric for community acceptance. Annoyance was found to be subject to five mechanisms describing the acoustic, secondary effect, privacy, listener, and situational properties of the aircraft operation. Second, **the probability that an operational limitation is created** was proposed as a salient metric to capture the conversion of poor community acceptance to actual limitations for UAM operations as a result of public action.

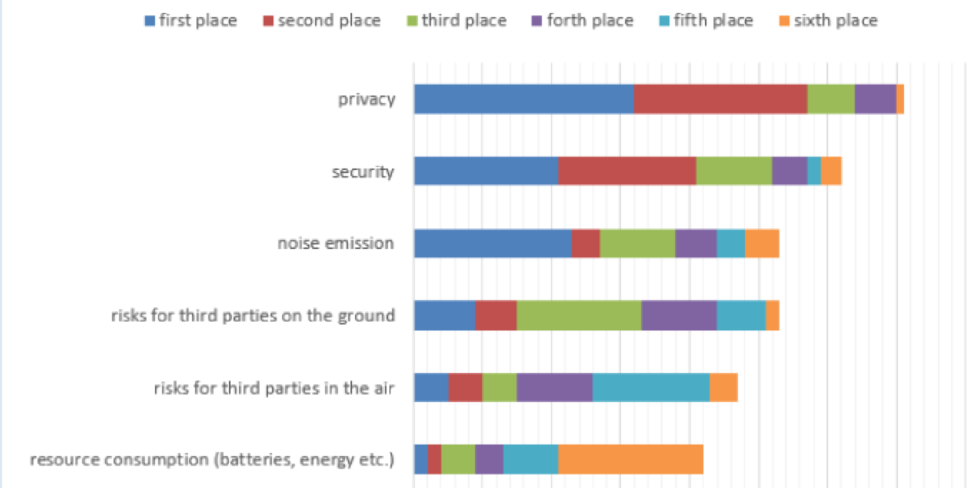
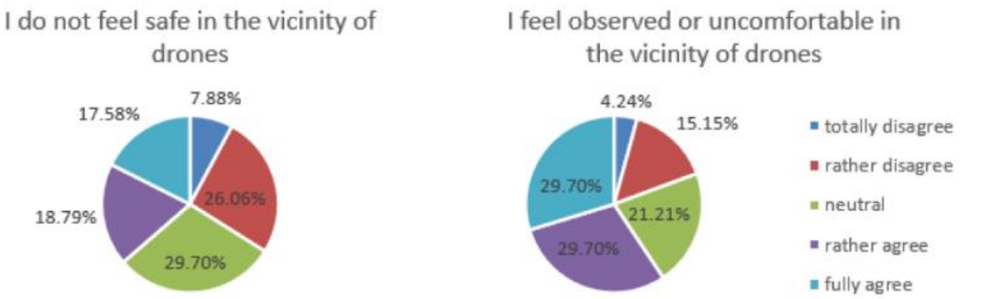
Literature title:	Scaling constraints for urban air mobility operations: air traffic control, ground infrastructure, and noise
Summary, Page 14-16:	**Mechanism and Factor Influence Mapping**: The most frequently discussed negative impacts of aircraft noise are: • Speech Interference • Sleep Disruption • Fear/Startle • Health Impacts • Economic impacts. Noise and community acceptance influence diagram:

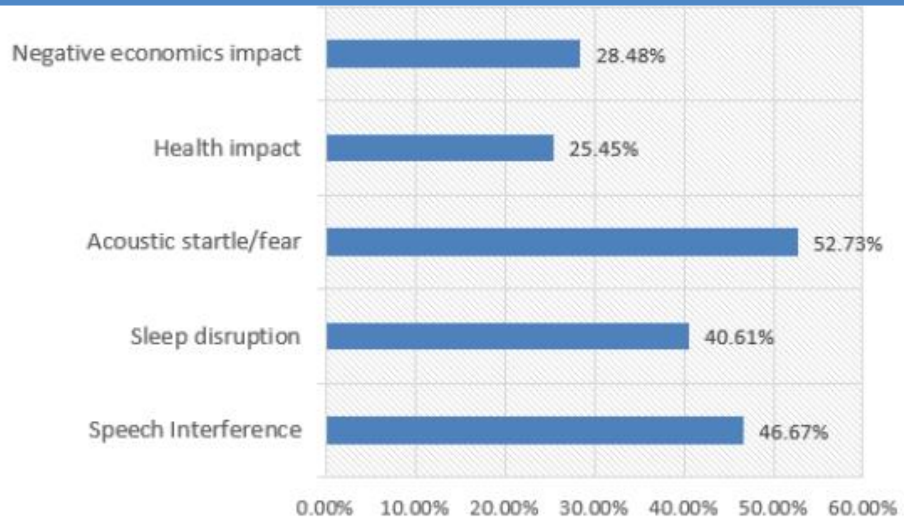
Literature title:	Scaling constraints for urban air mobility operations: air traffic control, ground infrastructure, and noise
	
Summary, Page 18-19:	**Metric 1, Percentage of the community that is "highly annoyed":** A traditional "dose-response" function is used to translate the noise exposure generated by some number of UAM operations into a percentage of the community that was likely to be highly annoyed. The conversion from number of operations to noise exposure explicitly takes into account three of the acoustic influence factors including loudness of each flight, the duration of the exposure from each flight, and the number of flights that occur in the time period.
Summary, Page 20-19:	**Metric 2, Probability a UAM operational limitation emerges:** relates the percentage of highly annoyed community members to the probability that an operational constraint would manifest. The conversion of community annoyance to operational limitations requires public action in the form of legal or regulatory action by the communities.

Ref: DACUS Consortium, "Survey on the acceptance of drones", 2021.

Summary: This survey aimed to scale acceptance of EU residents (N = 165) on commercial drone operations. Although most respondents (70.3%) did not use drones personally, a third of them (33.94%) were interested in drones and 28.48% were neutral. In general, they have a positive attitude towards the operation of drones.

Literature title:	Survey on the acceptance of drones
Summary:	**Priority of concerns about the operation of drone**: In a ranking of six possible concerns on drone operations, noise emission ranked third together with risks for third parties on the ground:

Literature title:	Survey on the acceptance of drones
	
	Feeling in the vicinity of drones: When asked how they feel in the vicinity of drones, 59.4% of the respondents reported that they felt uncomfortable and 36.37% felt unsafe: 
	Estimation of noise levels: In this survey the noise level in dBA made by a large quadcopter drone at 100m AGL was given, which is 55 dBA. In order to help the participants better understand the meaning of this noise level, a noise scale table below compares the commonly used noise level in decibels to everyday examples of noise. More than a third of the respondents thought such noise level at this height is not disturbing (38.18%), which is basically the same as the number of opponents (40%).
	Estimation of negative impacts of aircraft noise: When asked in which area they are concerned about the noise impacts of civilian drones, over half of the respondents mentioned acoustic startle/ fear (52.73%), followed by speech interference (46.67%) and sleep disruption (40.61%). Concerns about health problems (25.45%) and negative economic impacts (28.48%) caused by drones' noise were mentioned less frequently. As a whole, a large majority of respondents selected at least two subjects of impacts expected from drones' noise emission:

Literature title:	Survey on the acceptance of drones
	

Ref: Altiscope, Managing UAS Noise Footprint, Airbus UTM (formerly Altiscope), TR-007.

Summary: This paper identifies urban air mobility (UAM) noise challenges and analyzes potential solutions for managing noise to ensure sustainable growth. To accommodate high-density UAS operations, a balanced approach is proposed that encompasses many solutions and identifies potential trade-offs for flights over noise-sensitive areas. To manage urban air mobility noise, public perception and annoyance levels are discussed.

Literature title:	Managing UAS Noise Footprint
Summary, Page 4-5:	Noise Impact Factors: The following are findings of aviation noise impact that may hold true for UAS operations: • 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 UAS, 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.

Literature title:	Managing UAS Noise Footprint
	• 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
Summary, Page 6-7:	**Indicator 1, Short-Term Annoyance**: To describe short-term annoyance, or in other words a single aircraft noise event, the Sound Exposure Level (SEL) is used, measured in dBA. For a maximum decibel level of an aircraft event, Lmax is used (The maximum noise level (Lmax) is a measurement of the peak level of a noise event).
Summary, Page 8:	**Indicator 2, Long-Term Annoyance**: To describe the long-term noise impact, we use Day-Night Levels (DNL) . Single event noise levels specified in the previous section and ambient noise levels make up hourly LAEq (total sound energy measure over a defined period of time) that is then used to calculate DNL. Therefore, DNL is a representation of noise levels over a day with added dB penalties to account for the higher sensitivity to noise at night (10 pm to 7 am) and the expected night time decrease of background noise levels
Summary, Page 14:	**Noise Mitigation, Operational Limitations:** • Preferential Routes • Optimized Arrival and Departure Procedures • Dispersing Operations • Alternating Routes • Hovering **Operating Restrictions:** • Curfews • Movement limits • Noise Quotas • Non-Addition Rules • Nature of flights • Enforcing Restrictions and Limitations

Ref: Lohn, A. J. (2017). What's the buzz? The city-scale impacts of drone delivery (No. RR-1718-RC)..

Summary: This study develops a series of analytical expressions (equations) that can be used to compare the scale of the challenges to understanding the potential societal impacts of large delivery operations in urban environments. These equations can be used to explore the effect on aerial congestion and privacy for a range of cities and operating conditions.

Literature title:	The city-scale impacts of drone delivery
Summary, Page 18:	Aerial Congestion and Privacy: The number of drones flying overhead depends on distance from a drone delivery center. The number of flights that go at least as far as a given radius from the nearest center is the total number of flights minus those that are delivered within that radius. And the amount of time a drone spends at that radius decreases if the drones travel faster. Combining these two concepts, the number of drones that can be expected overhead is expressed as: $$N_{overhead} = \frac{2N_o p}{TD}(1 - {r^2}/{R^2})\frac{l^2}{2rv}$$ r is the distance from the nearest drone center, R is the maximum radius of the area serviced by the drone center, and l is the maximum horizontal distance from the drone at which the drone may be a concern. For congestion, l may be the radius for which sense-and avoid is required, and for privacy, l may be the field of view of common cameras. Importantly, the expected number of drones overhead decreases as the number of drone centers increases, because the number of drones being launched per center decreases; however, the expected number of drones overhead is complicated by the increase in the number of locations from which they are being launched. A more useful metric is the fraction of the city that has more than a specified expected number of drones overhead at any given time

Ref: Vas, Elisabeth, et al. (2015). Approaching birds with drones: first experiments and ethical guidelines (No. RR-1718-RC). Biology letters, 11(2), 20140754.

Summary: The researchers from this studied the impact of **drone colour, speed and flight angle** on the behavioural responses of mallards, and of wild flamingos and common greenshanks in a wetland area.

Literature title:	Approaching birds with drones: first experiments and ethical guidelines
Summary:	They performed 204 approach flights with a quadricopter drone, and during 80% of those they could approach unaffected birds to within 4 m. Approach speed, drone colour and repeated flights had no measurable impact on bird behaviour, yet they reacted more to drones approaching vertically. They recommend launching drones farther than 100 m from the birds and adjusting approach distance according to species.

Ref: Rebolo-Ifrán, N, et al. (2019). Drones as a threat to wildlife: YouTube complements science in providing evidence about their effect Environmental Conservation, 46(3), 205-210.

Summary: The paper uses information available from the scientific literature on the effects of drones on wildlife and complement it with Internet (YouTube) information to evaluate whether recreational activities using drones produce behavioural responses from wildlife.

Literature title:	Drones as a threat to wildlife
Summary, Page 2:	The literature search resulted in 30 published articles in which the effects of drones on wildlife were recorded (including birds, mammals and reptiles), and where only 50% were actually designed to detect those impacts. Twenty of these articles (66.7%) found some behavioural effect on the species as a result of drone use. Most publications (77.8%) that evaluated the effects of drones on birds showed some behavioural change.

9.3 Mission Efficiency

Ref: DATASET2050 consortium, 2017. DATASET2050 D5.1 Mobility Assessment.

Literature title:	DATASET2050 D5.1 Mobility Assessment
Summary: Pages 20-22	Provides a brief definition of efficiency as relates to passenger mobility. While not necessarily applicable to DACUS, the concept of "unproductive time" could be useful - i.e. the time wasted through waiting for processes such as registration and approval of flights.

9.4 Access & Equity

Ref: DATASET2050 consortium, 2017. DATASET2050 D5.1 Mobility Assessment.

Summary: This document provides documentation on the mobility assessment metrics and methods used by the DATASET2050 project that examined door-to-door mobility for air passengers. As well as describing key performance areas, attributes, indicators, and metrics incorporated into the project's model, it gives details about mobility metric computation, modelling methodology, visualisations used etc.

Literature title:	DATASET2050 D5.1 Mobility Assessment
Summary: Pages 12-17	This gives a good description of the concepts of **access and equity**, although related to air-passenger mobility. It can be built upon for providing KPIs in DACUS. In addition to defining the three sub-divisions given in the introduction to this section, this document gives a reminder that there are many social sectors or aspects that must not be overlooked: • people with disabilities. • people from different social backgrounds.

Literature title:	DATASET2050 D5.1 Mobility Assessment
	• city dwellers – more numerous - are often prioritised to the detriment of those who live in the countryside. • other gender, health, sexuality, lifestyle, ethnicity, political opinion, religious or philosophical conviction questions.

Fairness in Decentralized Strategic Deconfliction in UTM Antony Evans, PhD;1 Maxim Egorov and Steven Munn Airbus UTM, Sunnyvale, CA, 94086

Literature title:	**Fairness in Decentralized Strategic Deconfliction in UTM Antony Evans, PhD;1 Maxim Egorov and Steven Munn *Airbus UTM, Sunnyvale, CA, 94086***
Summary: **Pages [a] – [b]**	In this paper, simulation is used to explore how a FCFS (first come first serve) approach to strategic deconfliction in UTM – based on when operators file their flight plans – performs in terms of fairness. Fairness is quantified by comparing average ground delay across operators and by calculating a normalized fairness metric that accounts for operator cost of delay. Two scenario types are simulated: (1) two package delivery operators serving a common region from separate warehouses; and (2) two air taxi operators serving the same network of 7 vertiports. Results indicate that, for a decentralized FCFS approach to strategic deconfliction based on when operators file their flight plans, there may be a significant imbalance in delays between operators based on how far in advance they are able to file ahead, and on traffic demand levels. To ensure fairness at envisioned traffic densities it may therefore be necessary to constrain how early flight plan requests can be prioritized over later requests – similar in concept to a freeze horizon in TBFM.

9.5 Flexibility & Resilience

Learning lessons in resilient traffic management: A cross-domain study of Vessel Traffic Service and Air Traffic Control

Literature title:	**Learning lessons in resilient traffic management: A cross-domain study of Vessel Traffic Service and Air Traffic Control**
Summary: **Pages 7 – 9**	**Resilience capabilities within ATC and VTS** There are **four main capabilities (learn, monitor, respond, anticipate)**, which a system requires to maintain operation under anticipated and unanticipated events. • Learn: Learning within the **ATC domain** is largely reactive based on **standardised reporting structures and mainly focused on what went wrong**. Furthermore, as

Literature title:	Learning lessons in resilient traffic management: A cross-domain study of Vessel Traffic Service and Air Traffic Control
	there are international procedures for how a service is provided, the **learning is almost solely procedural and centralised at a state or country level**. This is in contrast with how learning takes place within the **VTS domain**. Within this domain, although there are international guidelines, **learning within the organisation is the responsibility of the national administration, often with heavy focus on local knowledge, leading to differences in operator training and in how services are provided**. Additionally, good seamanship (rules about safe and reasonable behaviour at sea) and experiences as an active seafarer and as a VTSO are essential for the learning, especially when it comes to learning from positive examples, not only from accidents. • <u>Monitor</u>: Monitoring is a critical element of **ATC**, particularly for the Arrival and Approach function where aircraft are closely spaced (compared with the en-route environment) and are subject to frequent speed and altitude changes. Controllers must be able to monitor traffic situations that change on a very short timescale. It is therefore essential that controllers **continuously monitor the traffic situation using equipment and data that updates in sufficient time for them to respond to emerging situations**. This is primarily achieved using both primary and secondary radar systems (including transponders and ADS-B) which are updated every few seconds. **VTSOs** identify traffic monitoring as one of the most essential tasks of their work as it is a precondition to be able to provide any kind of service level to the participating vessels. During the monitoring task the VTSO uses integrated radar and Automatic Identification System (AIS) information, as well as the VHF communication and databases at hand to obtain information on the traffic and its movements and intentions. **The vessels' inertia leads to a significantly slower system, but this is largely compensated for by the close proximity ships operate in**. Monitoring also highlights the importance of **knowing what to look for**. In both domains the study visits showed that the operators base their judgements heavily on their experience as a traffic monitoring entity and their overall expertise within the domain. Situations are identified as normal or abnormal based on how the traffic frequently behaves. • <u>Respond</u>: The ability to respond quickly is critical within the ATC domain given the short timescales involved. This is **important on both organisational and individual levels**. An Air Navigation Service Provider **(ANSP) must respond very quickly to** unexpected disruptions in operations (e.g. **technical failures, accidents, and atmospheric disturbances**). Some require responses in seconds, others in hours, and may range from individual decisions to a complete reorganisation of the system. Because of the different timescales and extent of the effect, **controllers**

Literature title:	Learning lessons in resilient traffic management: A cross-domain study of Vessel Traffic Service and Air Traffic Control
	may not always be able to follow a standard procedure and may have to rely on intuition and past experience. For example, an ATCo can choose to remove an aircraft from following a standard published arrival route and initiate tactical radar-vectoring, increasing capacity and flexibility at the cost of workload and complexity. It is the decision of an individual controller when to start radar-vectoring an aircraft, which introduces a lot of normal variability into the system. The ability to respond is equally important for a VTS operator. When the situation changes significantly he must inform all ships affected. It is the responsibility of the VTSO to ensure that all ships adapt to the new situation. **Although the vessels do not travel with the same speed as aircraft, response times in the VTS domain can also be a matter of seconds depending on the manoeuvring capabilities of the traffic participants** in the determined area. Further, as there are no or only a few objective measures for monitoring the traffic movements, **responding relies heavily on the individual operator and his/her prior experience as a seafarer** rather than, as in ATC, being dependent on standardised procedures. • Anticipate: The m**ost important aspects of anticipation within the ATC domain are capacity and weather planning**. These two factors determine how traffic will be handled and ultimately managed by the operator, e.g. splitting a sector into minor control areas. An ATCO has access to comprehensive information concerning all aircraft that will enter his/her sector within a given timeframe, which includes the planned altitude, speed and route followed by the aircraft. Furthermore, the ATCo needs to constantly anticipate deviations that may occur within the system (normal and unexpected). A deviation may be the result of a flight crew not complying with an issued clearance, a missed approach to land or an emergency developing on-board an aircraft. There are several warning tools that help the ATCo to identify potential problems, such as the Short-Term Conflict Alert (STCA) tool, which predicts a potential loss of separation between an aircraft pair. Anticipation within the VTS domain is very limited. **Since VTS cannot control the vessel, VTSOs tend to keep their planning horizon short**. Ships report at the border of the VTS area. Monitoring starts from there. Some tools, such as automated Closest Point of Approach (CPA) calculations, can be used but their effectiveness is limited. Anticipation is largely based on extensive experience, not on the process, procedures, or tools. An airport's capacity for handling aircraft is more than ten times higher than ports handling ships.
Summary: **Pages 9 – 10**	**System properties** Due to the contrasting ways that the ATC and VTS systems are organised, the largest differences are observed when comparing the system properties. • Buffering capacity: ATC operates with a focus on traffic capacity. By allocating flight levels, routes,

Literature title:	Learning lessons in resilient traffic management: A cross-domain study of Vessel Traffic Service and Air Traffic Control
	and creating holding areas, control can constantly balance availability and demand. **Planning assures optimal use of the capacity and the buffering assures that sufficient spare capacity is available should a critical situation develop**. **Within VTS, buffering capacity is realised by the ships autonomously**. Only when traffic becomes dense, or when delays become too long, ships can be directed towards an anchorage area. Buffering capacity is available in the navigable water, but it is not planned for as planning is often restricted to berth allocation. • Flexibility/stiffness: ATC is a rather inflexible system due to the highly organised structure. Sector boundaries and routes are fixed, flight levels allocated, control areas sharply defined, and arrivals and departures fully procedural. VTS is highly flexible. Very little is predetermined, and expertise is used to optimise traffic movements on an individual level, based on experience. • Performance margins: In the ATC domain, all safety margins are pre-set, guaranteeing a high level of safety. All traffic is well separated from each other within the environment. The **margins are defined in space, time, speed, and all other variables decided to be of importance**. In contrast, within the VTS domain, the margins are largely undefined. Only deep-draught ships have very specific safety margin requirements. Nevertheless separation largely remains an individual decision based on "good seamanship". As a result, no safety level can be guaranteed beforehand, and risk assessment and handling remain rather pragmatic.

Ref: Singh, C.S., Soni, G. & Badhotiya, G.Key Performance indicators for supply chain resilience: review and conceptual framework. J Ind Eng Int 15, 105–117 (2019)

Summary: This paper discusses supply chain resilience and identifies indicators which can help in increasing the performance and making a supply chain resilient. Although it is aimed at supply chain management, several of the indicators provided here could be applied to the DACUS PF.

Literature title:	Key Performance Indicators for traffic management and Intelligent Transport Systems
Pages 31 – 32	The **safety level of transport infrastructure** (road or track section, intersection, railway station) is defined by the **number of accidents** on one hand, and by the **impact of the accidents** on the other. Accident numbers are straightforward to obtain; the quantification of the impact is mostly measured as the number of people injured or killed. The main factors influencing road injuries are:

Literature title:	Key Performance Indicators for traffic management and Intelligent Transport Systems
	exposure (the amount of travel), **accident rate** (the risk of accident per unit of exposure) **accident severity** (the outcome of accidents concerning injuries). Given these factors, there are four different **ways to reduce the number of injuries** and fatalities in road accidents: • reducing exposure to the risk of accident by **reducing the amount of travel**, • **shifting travel** to means of transport with a lower level of risk, • reducing the **accident rate** for a given amount of travel, and • reducing accident severity by **improving the protection of road users**.

Index	Elements	Description
Traffic accidents	• Daily traffic volume on link • Daily traffic volume on junction • Number of casualties on link on an average day • Number of casualties on junction on an average day	Traffic accidents are the most suitable form of evaluating the safety level of a transport network. The KPI for road traffic accidents considers the fact that each city has its own traffic and accident characteristics. As such, the importance of decreasing a specific type of accidents can be adjusted by using a higher weight "w".
Direct safety impact of applications	• Number of system interventions on link on an average day • Number of system interventions on junction on an average day	The key feature of applications with direct safety impact is the number of system interventions. Many system interventions indicate a lower safety level due to the higher frequency of interactions between road users, leading to a critical situation or to an accident. The KPI can be calculated separately for different transport modes according to the goals of the applied measure.
Indirect safety impact of applications	• number of detected critical situations on link on an average day. • number of detected critical situations on junction on an average day.	This category of applications targets the reduction or avoidance of situations with various negative impacts including safety. Due to the very complex interaction of road users in urban environments it is difficult to assign safety impacts solely to traffic management and ITS applications. The validity of the results improves, though, if other major influences are considered.
Indirect safety impact of applications on	• number of detected critical levels-of-service	Urban-motorway-related traffic management and ITS applications with an indirect impact on safety aim at harmonising traffic and preventing

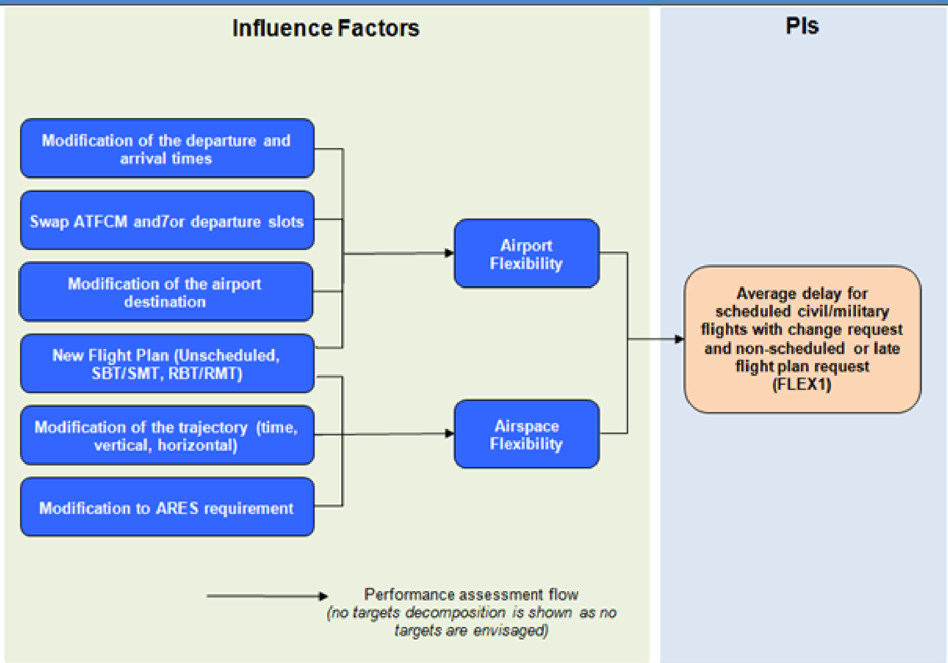
urban motorways	on link on an average day. • number of detected unstable traffic situations	congestion. Their safety impact is mostly positive since unstable traffic conditions are a major cause of accidents. In some cases, though, a decrease of safety levels can occur, as technology-based enhancements come into conflict with fixed parts of the system.
Car-to-infrastructure-communication-related applications	• number of sent-out driver warnings on link on an average day, referring to a critical situation. • number of sent-out driver warnings on junction on an average day, referring to a critical situation	Car-to-infrastructure communication systems aim at the direct warning of dangerous situations and conflicts for drivers. The number of sent-out warning messages can be used as a significant figure for evaluating their safety impact.

Ref: SESAR. D4.7 Performance Framework. PJ19.04. 2019

Summary: It represents a framework to support the goal of ensuring that the programme develops the operational concept and technology needed to meet the performance ambitions described in the 2019 edition of the ATM Master Plan.

Literature title:	**PJ19.04 D4.7 Performance Framework**
Summary: **Pages 21 – 23**	The Flexibility KPA addresses the ability of the ATM System and airports to respond to changes in planned flights and mission. It covers late trajectory modification requests as well as ATFCM measures and departure slot swapping and is applicable to military and civil airspace users covering both scheduled and unscheduled flights.

Literature title:	PJ19.04 D4.7 Performance Framework



PIs	Unit	Calculation	Mandatory
FLX1 Average delay for scheduled civil/military flights with change request and non-scheduled or late flight plan request	Minutes	Total delay for scheduled flights with change request and non-scheduled or late filling flights |AOBT – SOBT|, divided by number of movements	YES
FLX2 Average delay for non-scheduled civil/mil flights delayed	Minutes	Total delay for non-scheduled flights delayed |AOBT – SOBT| divided by number of movements	NO
FLX3 % of non-scheduled civil/mil flight arriving on time	%	% Arrival so that |AIBT – SIBT| < +/- 3 min.	NO

Literature title:	**PJ19.04 D4.7 Performance Framework**			
	FLX4 ARES allocation at short notice	N°.	N°. ARES allocated vs. N°. ARES requested at short notice by military with less than one hour notice	NO

Ref: ICAO. Doc 9883—Manual on Global Performance of the Air Navigation System. ICAO: Montreal, QC, Canada.

Summary: This manual addresses the basic performance management terminology and techniques that are the "common denominator" between all performance planning/management applications in ATM.

Literature title:	**ICAO Doc 9883: Manual on Global Performance of the Air Navigation System**
Summary: **Page 71**	Definition of Flexibility: Flexibility addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times thereby permitting them to exploit operational opportunities as they occur.
Summary: **Page 115**	Indicators of Flexibility according to ICAO: — Number of rejected changes to the number of proposed changes (during any and all phases of flight) to the number of flights plans initially filed each year. — Proportion of rejected changes for which an alternative was offered and taken.

Ref: Praetorius, G., van Westrenen, F., Mitchell, D. L., & Hollnagel, E. (2012). Lessons learned in resilient traffic management: A cross-domain study of Vessel Traffic Service and Air Traffic Control. Human Factors : A View from an Integrative Perspective : Proceedings HFES Europe Chapter Conference Toulouse 2012

Summary: In this article the area of traffic management within the maritime and aviation domains is addressed from a Resilience Engineering perspective. Focus is placed on the arrival part of a mission. The comparison is based on information collected during two study visits at VTS centres and one study visit at an ATC centre. The two organisations are described with the help of the Resilient Engineering capabilities: to respond, to monitor, to anticipate, and to learn. Furthermore, it is discussed how VTS and ATC adapt to cope with the complexity encountered during daily work.

9.6 Privacy

Privacy concerns related to the use of drones come from two directions:

- The general public concerned by the use of drones for state-sponsored surveillance or simply a nosey or perverted next-door neighbour;
- Drone Operators worried that declaration of their operations could lead to divulging industrial secrets to their competitors etc.

The application of the European Union's General Data Protection Requirements (GDPR) will likely form a major part of this KPA in respect of the second of these two areas.

A lot has been written about drones and public privacy and public concern about privacy. In the context of a demand capacity balancing process, any public impact is going to be at best a secondary effect and may be neither measurable nor manageable. Of more immediate interest is the material used in the DCB process itself – the flight plans of individual drone flights. The following focuses on the extent to which these can remain private and why this is desired.

Anecdotal remarks on drone operation privacy.: In the CORUS project consultations with stakeholders in 2017 and 2018 sometimes led to comments about inspection operations – that if the competitors knew a particular structure owner is ready to pay for drone inspection, then other drone inspection companies will approach the structure owner. These remarks were heard several times, but this is no statistics were gathered. Hence there is a general desire to share the minimum information between Drone Operators. This desire is well described in the design of the inter-USS, the machinery being developed to detect conflicts in federated UTM/U-space. See:

- https://interussplatform.org/ "The Inter-USS Platform accomplishes these functions without requiring any personally identifiable information and enables USSs to share data only when necessary";
- https://github.com/interuss/dss "…to share information while protecting operator and consumer privacy";
- https://cp.catapult.org.uk/wp-content/uploads/2020/12/01296_Open-Access-UTM-Report-V4.pdf "Confidentiality: All approved systems and processes need to ensure that information is not accessible or disclosed to unauthorised parties or systems";
- https://www.airmap.com/airmap-wing-other-uss-demonstrate-astm-standard-network-remote-id-us-switzerland/ "…while still protecting the operator's right to privacy".

Likewise, comments were made to CORUS in several situations about security of operations. Operators of wide-ranging flights like mapping expressed concerns about "vigilante" actions to counter real or imagined threats that involve attempting to harm the drone, the operator, or the drone operation customer. This same principle of sharing minimum but sufficient information is seen in the design of remote-id systems. For example:

- https://sn.astm.org/?q=features/drones-move-mainstream-ja20.html "and does not infringe upon the privacy of the UAS operator, associated businesses, and clients";
- https://www.unmannedairspace.info/uncategorized/wing-works-with-atms-on-remote-data-sharing/ "Providing transparency and privacy by providing third parties with information to identify a drone while ensuring that information is shared only when necessary";
- https://wing.com/resource-hub/articles/faa-utm-research/ "but without violating customer privacy".

Hence it should be taken as a general principle that the DACUS processes should share the minimum sufficient data.

ISO/IEC 29100 Information technology — Security techniques — Privacy framework

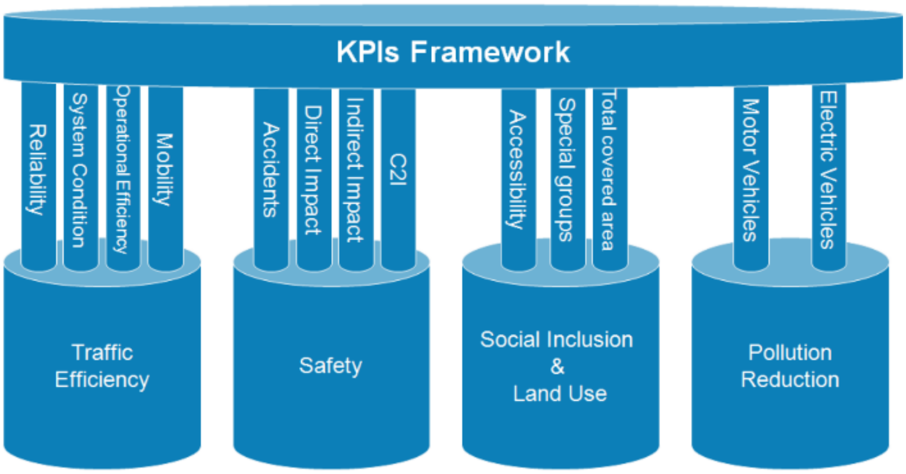
Literature title:	ISO/IEC 29100 Information technology — Security techniques — Privacy framework
Summary: Pages vi -	From the introduction: “This International Standard provides a high-level framework for the protection of personally identifiable information (PII) within information and communication technology (ICT) systems. It is general in nature and places organizational, technical, and procedural aspects in an overall privacy Framework." While this standard applies principally to ICT systems, its tenets hold for many other domains. In any case, many of the privacy concerns in DACUS will be of an ICT nature relating the second of the two areas given above.
Summary: Pages 1-4	Terms and definitions: anonymity, identity, personally identifiable information (PII), pseudonymisation, secondary use, etc.
Summary: Pages 5-19	Chapter 4 gives the requirements of a privacy framework: “The following components … make up the privacy framework described in this International Standard: • actors and roles. • interactions. • recognizing PII. • privacy safeguarding requirements. • privacy policies; and • privacy controls.” Chapter 5 describes the privacy principles of the standard: “The privacy principles described in this standard were derived from existing principles developed by a number of states, countries and international organisations. This framework focuses on the implementation of the privacy principles in ICT systems and the development of privacy management systems to be implemented within the organisation’s ICT systems. These privacy principles should be used to guide the design, development, and implementation of privacy policies and privacy controls. Additionally, they can be used as a baseline in the monitoring and measurement of performance, benchmarking and auditing aspects of privacy management programmes in an organisation."

9.7 Safety

Ref: CONDUITS Consortium, "Key Performance Indicators for traffic management and Intelligent Transport Systems", Seventh Framework Programme, Imperial College London, v. 2, 2011

Summary: Although it is aimed at terrestrial urban traffic management performance monitoring, the document does provide a good overview of performance indicators for measuring Intelligent Transport Systems (ITS) in urban environments. These indicators could be adapted to serve the DACUS performance framework.

The aim of the report is to define a common evaluation framework for the performance of traffic management and ITS in the form of a set of Key Performance Indicators (KPIs), and to present guidelines as to its application. Four strategic themes of urban traffic management and ITS are tackled: traffic efficiency; traffic safety; pollution reduction; and social inclusion and land use.



Performance indicators for supply chain resilience: review and conceptual framework

Literature title:	Performance indicators for supply chain resilience: review and conceptual framework
Summary: Pages 4 – 5	**Indicators for Supply Chain Resilience** The focus of SCR is to cope with the temporary disruptive events. It is simply described as the capacity to prepare the plan and construct the network of the supply chain that can envision **sudden troublesome or negative occasions and will adaptively react to interruptions** while keeping up command over the network and structure of supply chain. • Collaboration: In the supply chain, collaboration simply means that supply chain operations are planned and executed jointly by two or more autonomous firms for mutual benefit. **Collaborative partnership helps to anticipate the disruption and manage risks**

Literature title:	Performance indicators for supply chain resilience: review and conceptual framework
	efficiently. In a situation of disaster, collaboration can keep supply chain organizations together. A risk can be mitigated through a high level of collaborative work across supply chains. **Incentive alignment and decision synchronization are the two major contributions** of supply chain collaboration and critical for successful responses to organization-level disruption. • Sustainability: Sustainability in supply chain management is by and large characterized as **utilizing the resources that are able to mitigate present problems without using the resources that should be used by the future ages to mitigate their own problems**. Sustainability helps for better quality choice and reduction in the wastes and dangers of the whole organizations. • Agility: Supply chain agility can be characterized as the **capacity to quickly react to an erratic change in supply and demand**. An agile supply chain has increased velocity to rapidly adapt to unpredicted changes in demand or supply, and acceleration to increase the response time. It is seen that flexibility requires agility to react quickly to random occasions and maintain an alternate advantage in an unverifiable condition. Supply chains can diminish the risk related to stock by managing a large level responsive supplier. • Redundancy: Redundancy includes the **vital and serious utilization of extra stock that can be conjured amid an emergency** to adapt, e.g., request surges or with supply deficiencies. It is additionally stated that redundancy includes the duplication of limit with a specific end goal to proceed with operations amid a disruption and that it can along these lines likewise be viewed as a course to flexibility. Further, redundancy is like a buffer stoke; sometimes it can be expensive methods for building resilience because it accounted the holding cost. • Flexibility: To be resilient, a supply chain should be flexible and it is characterized as the **capacity of a supply chain to adjust according to the required necessities of its partners and environmental condition in the smallest amount of time**. Flexibility can be applied both to an organization and to the complete supply chain. In this way, flexibility makes supply chain resilient by upgrading brief versatility amid turbulence. A flexible supply chain will help to fast reaction and recovery. • Visibility: Supply chain visibility is defined as the **ability of supply chain manager to see from one end to another and can find the place of disruptive event**. Visibility is an intercession apparatus that permits managers the opportunity to react rapidly to interruptions or unsettling influences in view of exact, continuous evaluation. Visibility portrays the necessity for straightforward structures and procedures to recognize requirements and interruptions rapidly and to have the capacity to actualize changes in a successful way. Visibility fills in as a notice procedure that gives valuable time to firms to adjust their capabilities to limit problematic effect. It additionally gives information about the current status of working resources and

Literature title:	Performance indicators for supply chain resilience: review and conceptual framework
	environment of the supply chain by utilizing key execution pointer measurements to monitor execution. • IT capability/information sharing: In supply chain, sharing the right information is very desirable and it reduces the risk in the supply chain. In the present dynamic and indeterminate supply chain environment, to minimize the risk in the supply chain, it is essential to form a group of active partners and right information should flow among all partners of that particular group. Information sharing also plays a vital role in minimizing the bullwhip impact. • Robustness: Robustness is the **capacity of the supply chain to oppose change and involves a proactive expectation of progress before it happens**. Building robustness requires strategic planning to construct supply chain network. For that, it is needed to design a value-creating supply chain network which will be able to maintain the operation before and after the unwanted event. A robust supply chain can work in spite of a few unsettling influences, as it withstands and adapts to stuns by holding its dependability when changes occur. • Awareness/sensitiveness: **Sensitiveness can be defined as anticipating the actual demand. Awareness includes comprehension of supply chain vulnerabilities and making arrangements for such occasions**, and it requires capacity to perceive a conceivable disturbance by detecting and translating occasions through early cautioning systems, and congruity arranging. These practices will help in mapping of the supply chain vulnerabilities in order to stay away from, contain or control chance. At the same time, these practices require coordination, information sharing and learning between supply chain accomplices to proactively create and increase the level of circumstance awareness in expecting disturbances.

Ref: Altiscope, Metrics for Near-Miss Events: Understanding Airprox, NMAC and "Inadequate Separation", Airbus UTM (formerly Altiscope), TR-002

Summary: This white paper aims to identify a global metric for tracking "near-miss" incidents for drone operations. Three separate metrics used by regulators today were compared. All three are qualitative, even if specific proximity information is available from radar or surveillance replay data.

The paper concludes that while these metrics may provide an appropriate starting point for evaluating UAV near-miss severity and risk, developing an appropriate benchmark rate will require further research and awareness of local regulatory expectations.

Ref: Peter Sachs, A Quantitative Framework for UAV Risk Assessment, Version 1.0, Report TR-008, 2018

Summary: This model calculates risk using inputs from six categories (additional details in Annex A). These categories are the same ones identified in Altiscope's fault tree sensitivity analysis as having the greatest influence on the risk of loss of control of a UAV resulting in a crash or collision:

- The flight's location, time, duration, etc.

- Vehicle, model and performance characteristics;
- Operator experience;
- Wind and weather conditions;
- Vehicle maintenance;
- Battery performance.

Additional input categories allow the model to predict the chance of a flyaway and the likelihood and severity of an airborne collision and of killing someone on the ground:

- RF spectrum and communications link characteristics;
- GNSS coverage and obstacles/terrain that result in degraded navigation accuracy;
- Historical flight track information;
- People density and exposure.

Airspace density therefore can be dynamically and temporally represented. Assuming all other risk factors are constant, less-dense areas become "depressions" in the surface and areas close to their maximum capacity for the fleet mix in the region become increasingly higher peaks. This draws vehicles toward valleys and away from peaks until the vehicles flying through dense hotspots exit the area and density levels trend toward an equilibrium for that airspace.

9.8 Security

Ref: International Standards Organisation, 2011. Information technology — Security techniques — Privacy framework. First edition 15/12/2011. ISO, Switzerland.

Summary: "This International Standard provides a high-level framework for the protection of personally identifiable information (PII) within information and communication technology (ICT) systems. It is general in nature and places organisational, technical, and procedural aspects in an overall privacy framework." (from the introduction).

9.1 UTM ConOps and performance expectations

The main conclusions of these projects were considered during the development of the DACUS concept and are listed below.

Australian UATM

Performance Expectations/Benefits (In ICAO KPA Terms):

Services expectations	Expectations	Flight planning and authorization services	Flow management service	Dynamic Airspace Management Service	Conformance monitoring service
Safety	Strategic segregation and/or separation of UAM aircraft from other types of aircraft, other eVTOLs and on-ground obstacles; reduced workload for ATC in managing UAM aircraft.	Pre tactical deconfliction of UAM vehicles near vertiports and along outes/corridors.	Pre-tactically deconflicts traffic arriving at and departing vertiports ads reduces the amount of time in the air through ground-based holding.	Minimises airspace safety risk by controlling airspace access.	Real-Time and systemic awareness of operations that could impact the safety of the low-level airspace environment.
Environment	The ability to position routes over less noise-sensitive areas (e.g. Highways, train tracks, rivers).	Adherences to environmental or noise obligations regarding vertiports near routes/corridor usage.	Reduces the airborne holding and decreases flight noise, as there will be less of a requirement to hold on approach to a vertiport. Flow Management also minimises the amount of	Provides a mechanism for noise sharing through the use of alternative routes/corridors.	

			energy that needs to be consumed.		
Capacity	Vertiport airspace design and procedures, which will maximise the capacity of the vertiport while maintaining appropriate levels of safety, noise, privacy and other risks or impacts.	Planned use of vertiport FATO resources ensuring the greatest use of the limited resources to maximize capacity.	Ensures that the greatest capacity is achieved from the available vertiport infrastructure and airspace by other UAM vehicle movements.	Enables additional routes/corridors can be made available where possible, even if not in an ongoing manner.	
Flight efficiency	Increased efficiency due to the reduced likelihood of conflicting traffic.	Timed use of vertiport FATO resources and the use of routes/corridors minimising the airborne holding of UAM vehicles.	Minimizes the time required to be airborne, thus ensuring that flight efficiency is not impacted by other UAM vehicle movements.	Ensures that the most efficient routes/corridors can be made available where possible, even if not in an ongoing manner.	Know historical use of airspace provides information to assist in improving future use.
Flexibility	Provision of flexibility when traffic loads need to be dissipated to ensure operational continuity and/or efficiency of traffic flow.	The ability to plan in advance, request on demand and make changes to flight requirements.	Enables flight plans to be updated as required due to changes in the operational environment.	Allows airspace that otherwise would have to remain reserved if it could not be made available dynamically to be used periodically.	

Predictability	Knowledge of where UAM vehicles can fly and increased likelihood of airspace access.	Assurance of vertiport FATO accessibility for departure and arrival and route/corridor availability.	Ensures that a flight plan can be reliably implemented without impact from other UAM vehicle movements	Provides a system for identifying what airspace is available at what time. Supports business	
Access and equity	Greater access to controlled airspace through the use of dedicated airspace structures and routes.	Assurance that all airspace users can gain access to the low-level environment.	Ensure that pilots and fleet operators can gain access in a transparent manner to the shared resources of vertiports and airspace.	Ensures the greatest possible availability of airspace whilst enabling prioritisation of airspaces access	
Participation and collaboration	Provision of a structured means by which new vertiport infrastructure can be considered.				
Global interoperability	Standardised structures and procedures for the UAM industry used in different countries.				

Below is the list of indicators and metrics that will be essential for assessing the overall performance of the UAM environment as well as the effectiveness of technologies and procedures that are used to implement the services described in the CONOPS. Monitoring this indicators and metrics will be important after implementation to ensure UAM operations and the airspace remain optimised.

- Vertiport capacity;
- Vertiport demand;

- Vertiport utilisation;
- Vertiport distribution;
- Vertical and horizontal separation;
- Airspace capacity;
- Airspace demand;
- Route/corridor capacity;
- Route/corridor demand;
- Flight route efficiency;
- Flight route throughput;
- Flight 4D compliance/non-compliance;
- Safety occurrences near vertiports;
- Safety occurrences in controlled airspace;
- Safety occurrences outside controlled airspace;
- Compliance with environmental obligations;
- Airspace access authorisation approval rate.

UK Catapult

Catapult fundamental principles.

- Collaboration between all interested parties, not just individual suppliers;
- A transparent and published decision-making process that is reviewed by subject matter experts;
- A transparent and published feedback and ratification process to ensure quality.

Airspace differentiation.

- Uncontrolled airspace
- Controlled airspace
- Restricted airspace

- FRZ: prohibited areas, restricted areas, danger areas;
- TFR: Geo-fences, Geo-cages (Urgent TFRs; Normal TFRs).

Key services.

Strategic deconfliction among the shared flight plans with justified, transparent, and fair deconfliction procedures.

Deconfliction procedures are mandated by airspace regulator and be supported by all UTMSPs.

Transparent decisions, inspectable by operators and supporting UTMSPs.

Evolve. a prioritization scheme: lifesaving activities, national security, life support, all other.

Flight permissions in controlled airspace, examples like LAANC, based on machine automation, with new interfaces between ATM and UTM for fair and equitable access to controlled airspace.

Dynamic flight restriction management for the dynamic segregation of drone operations, by UTMSP providing geofencing on TFRs.

Segregating airspace around UAS operations like in the FAA's UAS volume reservation concept.