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DEMAND AND CAPACITY OPTIMISATION IN U-SPACE

This document is part of a project that has received funding from the SESAR3 Joint Undertaking under grant agreement No 893864 under European Union's Horizon 2020 research and innovation programme.

Abstract

DACUS D6.3 is the final report of the project. It details the work performed in the project as a whole, its technical deliverables and the key results that were obtained in relation to the services involved in the Demand & Capacity Balancing (DCB) process for U-space. This document focuses heavily on conclusions and recommendations that the project has gathered which are of relevance at U-space programme level.

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1 Executive Summary

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

The DACUS project has explored how DCB can be provided within a U-space environment, develop a Concept of Operations (ConOps) for drone DCB in urban airspace and develop models to test fundamental aspects of this concept.

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

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

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

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

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2 Project Overview

This section provides a high-level overview of the DACUS project's work, scope, objectives, and results. A more in-depth summary of the contents of the project is provided in the technical deliverables, which are listed at the end of this section.

2.1 Operational/Technical Context

The demand for autonomous flight operations is expected to increase rapidly over the next years in Europe[1]. This will lead to a high volume of drone traffic and the need for a safe management of simultaneous flight movements. To face this challenge, the European Commission supports the development of the U-space highly automated and digitalized service framework. Tailored to facilitate high-density operations of automated air vehicles in very low-level airspace it will provide a large array of services to drone users all around Europe. What makes it unique in aviation is that it will be entirely focused on general risk and performance requirements, will be inherently dynamic to respond to changes on demand and openly adopt technologies from other sectors to accelerate deployment – all without any human in the loop in internal processes as much as possible. U-space can be seen as a highly complex system of systems, which will need to be agile and readily available.

As demand for drones over populated areas explodes, there will be a need for limiting the number of operations. **Future Demand and Capacity Balancing (DCB) management processes in the context of U-space** shall assist concurrent flight planning by multiple drone operators to ensure availability of access to airspace, adequate balance between system capacity and demand of drone operations, and fair and prioritized access to airspace. Because of the ad-hoc and more dynamic nature of the drone mission trajectories, the system needs to deal with diverse and multiple changes affecting the flight plans that can be received at short notice. Dynamic separation would enable higher capacity, but at the prize of entailing higher complexity in the management of solutions provided by the DCB management processes and of more restrictive required capabilities of the drones operating in such volumes. These changes can be constrained by establishing procedures for separation which would be simpler to manage compared to dynamic volumes[2]

DACUS proposes a complete DCB solution for drone traffic management to address the expected demand in **urban environments**. This implies to consider both the overall risk over the population, and the social impact with regard to the noise and visual impact, among other factors impacting population.

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[1] European Drone Outlook Study. November 2016.

[2] IMPETUS U-space exploratory research Project, EC and SJU funded under Grant Agreement number 763807, "Information Management Portal to Enable the inTegration of Unmanned Systems", October 2017 to February 2020, led by CRIDA - IMPETUS D2.2 Drone Information Services version 00.01.00. July 2018.

DACUS has produced a DCB Operational Concept for U-space and a U-space Performance Framework to guide DCB decision-making, among other documentation. In addition, DACUS has developed conceptual models and algorithms as part of the DCB. Finally, DACUS has performed 4 different validation experiments to test the DCB Operational Concept and assess the designed models and algorithms.

2.2 Project Scope and Objectives

Then, DACUS aims at the development of a **service-oriented Demand and Capacity Balancing (DCB) process for drone traffic management**. This overall objective responds to an operational and technical need in European drone operations for a tangible solution integrating the functionalities of the SESAR U-space services for Drone Traffic Management (DTM) to produce timely, efficient, and safe decisions. The DCB process will be extended form strategic to tactical phase.

The overall challenge is to enable large number of operations in complex environments, such as urban airspace, without adversely affecting manned aviation, and addressing the problem of defining separation management. Therefore, DACUS addresses the three main application areas of the U-space topic in SESAR Exploratory Research 4: drone DCB concept, urban environment specification and separation management.

One key transversal element of the three areas is the development of a *capacity metric which is tailored to drone operational needs*, i.e., that is driven by safety and social & environmental impact, and which integrates all relevant influence factors (highly diverse traffic mix, Communication Navigation & Surveillance (CNS) performance, or population density to quote some).

In conclusion, DACUS intends to **integrate in a consistent DCB solution** the relevant demand and capacity **influence factors** (such as CNS performances availability), **definitions** (such as airspace structure), **processes** (such as separation management), and **services** (such as Strategic and Tactical Conflict Resolution). Therefore, to achieve the overall DACUS objective, five specific **objectives** are set, each one with the corresponding success criteria (S).

Objective 1- Develop a drone specific Demand and Capacity Balancing (DCB) process

Develop a **drone DCB process**, from strategic to tactical phase, **integrating uncertainty of planned operations** and guided by the definition of a **U-space performance scheme** that includes the development of metrics for airspace capacity appropriate for an environment with no human controller.

S1. Definition of a **complete DCB process** taking as inputs all critical influence factors (including uncertainty of both demand and capacity) and producing a clear set of measures for adjusting both capacity (via e.g., dynamic airspace management) and demand for the period of operation. DACUS will design a U-space **Performance Framework** that will guide decision-making, with special attention to the areas of safety, environment and efficiency.

Objective 2- Develop innovative U-space services and enabling models (e.g. Societal Impact model, Risk model) in support of DCB

Develop innovative **services algorithms** and **enabling models and technologies** as functional blocks of DCB process, able to support large number of simultaneous operations and to design and manage efficient and safe drone trajectories.

S2. Development of services algorithms that:

a. Cope with the defined airspace structure and rules.

b. Work together to provide a harmonized DCB and flight planning management.

c. Integrate all identified influence factors for capacity evaluation.

d. Build on the optimal balance between on-board and centralized separation intelligence and on dynamic separation minima.

The U-space services addressed are: Dynamic Capacity Management, Mission Planning Management, Flight Planning Management, Micro-weather, Strategic Conflict Resolution and Tactical Conflict Resolution. This success criterion also includes the development of enabling models and technologies in support of the services, such as a risk model for capacity estimation.

Objective 3- Define Very Low Level (VLL) airspace structure and rules and boundary conditions for urban environment

Define a **structure for Very Low Level (VLL) airspace and a set of airspace rules** that optimises the trade-off between capacity and safety, including the definition of areas where the **separation** will be procedural and areas where tactical separation will need to be applied, and takes into account factors such as noise impact amongst other Key Performance Indicators (KPIs).

S3. Definition of a complete **set of rules of the air, airspace structure** (addressing separation areas and role of separator) **and boundary conditions** (including public acceptance, business and regulatory aspects) for urban environment that allows unambiguous operations and requirements for the development of associated U-space services.

Objective 4- Optimise decision making between on-board capabilities and U-space separation services

Find the optimal **balance** between **on-board separation intelligence** and **U-space separation** service intelligence in tactical separation depending on the type of airspace (with or without conflict resolution in strategic and/or tactical phases), type of separation (drone-drone or drone-manned aviation), CNS performances and the separation process that applies in each type of airspace area.

S4. Obtain **simulation results** that allow the evaluation of diverse separation approaches in terms of drone performance indicators as defined in DACUS Performance Framework.

Objective 5- Refine Communication, Navigation and Surveillance, and Information (CNS-I) requirements for urban environments

Refine **Communication, Navigation and Surveillance (CNS) requirements** in support of tactical and procedural separation, with a focus on urban environment.

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S5. Produce a **refined set of CNS requirements** introducing changes with regards to current drone CNS references[3]. These changes must be substantiated by simulation results that produce evidence of the CNS performance needs to ensure safety while maximizing capacity, taking into account the defined rules of the air and separation procedure, the dynamic separation minima and the performance tolerances.

2.3 Work Performed

The overall work performed by the DACUS consortium (and its results and conclusions) can be divided into four distinct phases: Drone DCB Concept of Operations; Developments of conceptual models and algorithms in support of DCB; Validation experiments, and Definition of concepts and rules including applicable catalogues and frameworks. This is in line with the project scope and objectives defined in the grant agreement and covers some additional work to align the work with the U-space material which was elaborated in parallel.

2.3.1. Drone DCB Concept of Operations

The DACUS project has explored how DCB can be provided within a U-space environment, **developing a Concept of Operations (ConOps) for drone DCB in urban airspace** [2]. DACUS ConOps has been developed to be inherently service-oriented, permissive of implementing increasing levels of automation into the management of unmanned air traffic and open to a series of novel business models and use cases. The DCB process is focused primarily on drone operations in an urban environment, as this is the most complex application area, however these functionalities can be extended to other operating environments.

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

2.3.2. Developments of conceptual models and algorithms in support of DCB

DACUS project proposes different models and algorithms with regard to specific DCB processes, in particular: the generation of nominal and contingency-based probabilistic 4D trajectories [4], the calculation of foreseen demand based on AI [6], the calculation of demand prediction and uncertainty (considering large-scale contingency events and micro-weather conditions [5]), the determination of the overall ground and air collision risk in a U-space airspace, or the determination of the overall social risk impact over the citizens.

Those elements that are considered more mature at the end of the project are [7]: the **Collision Risk Model,** which quantified the air and ground risks as a limiting factor to determine the maximum

[3] TERRA U-space exploratory research Project, EC and SJU funded under Grant Agreement number 763831, “Technological European Research for RPAS in ATM”, October 2017 to February 2020.

number of drones in an urban area, and the **Societal Impact Model,** which measured the visual and noise effects over the population as another limiting factor.

Both models are integrated as key components of the **Dynamic Capacity Management (DCM) service** [3]. This prototype identifies hotspots and resolve them by applying Demand and Capacity Balancing (DCB) measures on one operation or the set of operations in an area. The DCM service can be launched at every planning phase. At the strategic phase, the DCM predicts the overall capacity in the whole U-space airspace, and compares it with the expected demand. At the pre-tactical phase, local imbalances or hotspots are identified and local DCB mitigation measures can be applied. Finally, the tactical phase will allow to monitor the operations in the air and take DCB measures in case of unexpected events such as the sudden reduction of CNS performances. In this phase, only few DCB measures can be applied (i.e. delay departure cannot be implemented if drone has already taken off, but other methods such as rerouting could still apply).

Figure 1: Main elements in the Dynamic Capacity Management.

The pre-tactical is the most relevant phase of the process because the demand is stable enough to take effective DCB decisions and implement DCB measures if necessary. In this phase, the majority of the demand is based on real operation plans. If no hotspot is identified when starting pre-tactical phase, the DCM can validate the existing operation plans. Otherwise, DCM will search for a suitable DCB measure that can minimise the number of hotspots. The selected measure is then submitted to the drone operators:

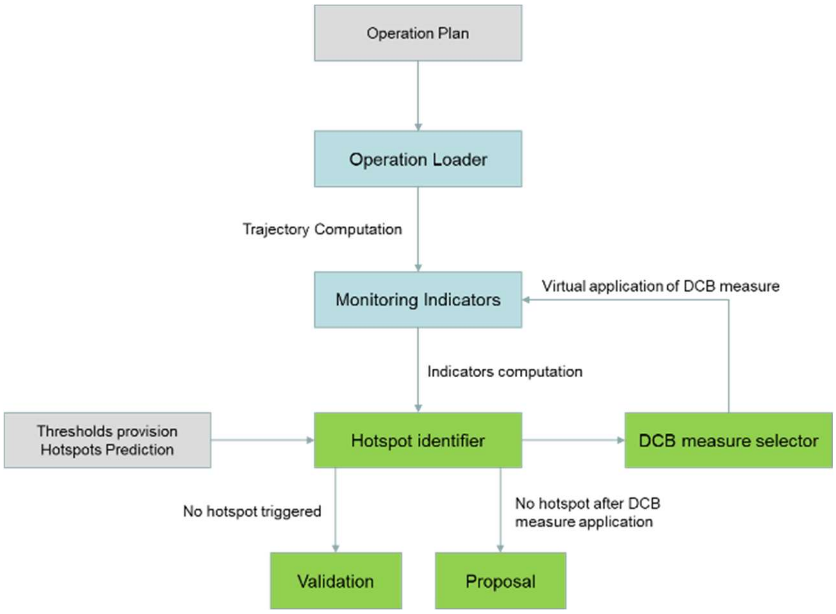

Figure 2-2: DCB measures for Hotspots.

The DCB measure selector has picked a measure from a catalogue. In order to improve the selection efficiency, scores have been defined by simple rules: on a defined score scale, the score increases if hotspots decrease after the application of a measure, and vice versa. For each DCB measure, several scores have been set, depending on the hotspot type (collision risk, noise impact, visual impact…).

2.3.3. Validation experiments

Simulations of the drone operations lifecycle at different phases of the planning process (strategic, pre-tactical, execution) were performed to demonstrate whether it was feasible to determine and react to demand and capacity imbalances, i.e., hotspots, using the new risk and social impact models. The appropriate DCB actions which may help to mitigate those imbalances were also evaluated. Hotspots were identified for suitable sized operating grid cells (typically 1km x 1km in size) using population density and other socially oriented data. On the other hand, the impact of the uncertainty associated to mission planning, weather effects as well as the activation of pre-defined contingency was also assessed at various steps of the planning process.

The experiments conducted in DACUS address two main topics: Firstly, to analyse how those services and the prototypes built to implement them can '**respond to the research challenges identified in the DACUS ConOps'** [1]; Second '**to assess the applicability of indicators included in the DACUS performance framework'** [14] (many of which are now included in the PJ19.4 Companion Document, so the added value is higher in the context of SESAR).

Specifically, DACUS has conducted the following experiments, detailed in DACUS D4.1 deliverable [10]:

- **Experiment #1: Assessment of social impact and automatic DCB measures –** considers the strategic and pre-tactical phases of the planning process, with the focus being on the application of the DCB services related to the management of ***Noise*** and ***Visual*** impact due to drone operations in urban environments. Thus, the main objective of this experiment is to test

the *feasibility* and the *reliability* of the use of Noise and Visual impact metrics for the DCM service.
The analysis also considers Noise and Societal Impact metrics correlation as well as the number of hotspots compared to the assigned thresholds. Finally, this experiment investigates the feasibility of proposing automatic DCB measures from DCM service calculation. Measures investigated in the experiment #1 scenarios include the *use of departure delays* to manage the number of flights in hotspot areas and the *modification of operating altitudes* to help reduce the noise and social impact hotspots identified by the DCM services.

- **Experiment #2: Route planning prototyping to represent uncertainty in demand** considers the nominal processes of *Flight Plan Processing*, *Contingency Planning* and the resulting *demand and uncertainty predictions* are validated. Furthermore, the influence of the demand and uncertainty predictions on the collision risk and efficiency are tested, as well as the feedback loop for additional information such as collision risk, weather conditions and efficiency indicators into the flight plan processing and its consequences for hotspot occurrence. The effect of weather conditions on vertiports capacity is also studied, including rerouting and/or cancellation of flights in response to weather constraints.
In scenarios that included unanticipated events which required contingency strategies to be actions (e.g., capacity reduction of losses of landing locations and/or degradation/failure of CNS) measures including *returning to base* using a set of nominal waypoints, *diversion to alternate landing locations* or *immediate landing* with suitable contingency volumes activated while landing occurs are evaluated.

- **Experiment #3: Collision Risk model and mitigation methods** applies the *collision risk model* in the strategic phase to test the effect of considering different CNS performances and defining different airspace structures and operating procedures to manage the maximum acceptable capacity in different scenarios.
Experimental scenarios estimate the maximum theoretical airspace capacity for various levels of traffic demand without any strategic measures being applied, and further investigate how collision risk can be reduced through the introduction of strategic conflict management measures. These measures consider how enhanced separation between aircraft, using increased conflict margins, or structuring operations using directional flight operating layers of various thicknesses can help to reduce the risk of conflicts in hotspot areas.

- **Experiment #4: Application of DCB measures in the pre-tactical & execution phases** uses a fast-time simulator to *validate the DCB process* in diverse scenarios and under nominal and sub-nominal operating conditions. It is focused on the tactical phase and the main objective is to analyse the *impact on the DCB process* when a perturbation occurs, as well as the *effectiveness of different DCB measures*. The effectiveness of different DCB strategies is assessed using the performance areas included in the DACUS Performance Framework [14].

Experiments #1 and #3 were designed to allow the team to validate and help calibrate the models and anticipated thresholds when analysing traffic from a risk/social impact-based perspective.

Once the models have been suitably calibrated and tested, the remaining **experiments #2 and #4** have applied the models and services in an operational context, alongside the other U-Space services and at different stages of the drone operations lifecycle (strategic, pre-tactical and tactical phases), and in representative European cities: Toulouse, Frankfurt, Madrid, Toledo.

The dependencies and inter-relationship between the various experiments is illustrated in the figure below:

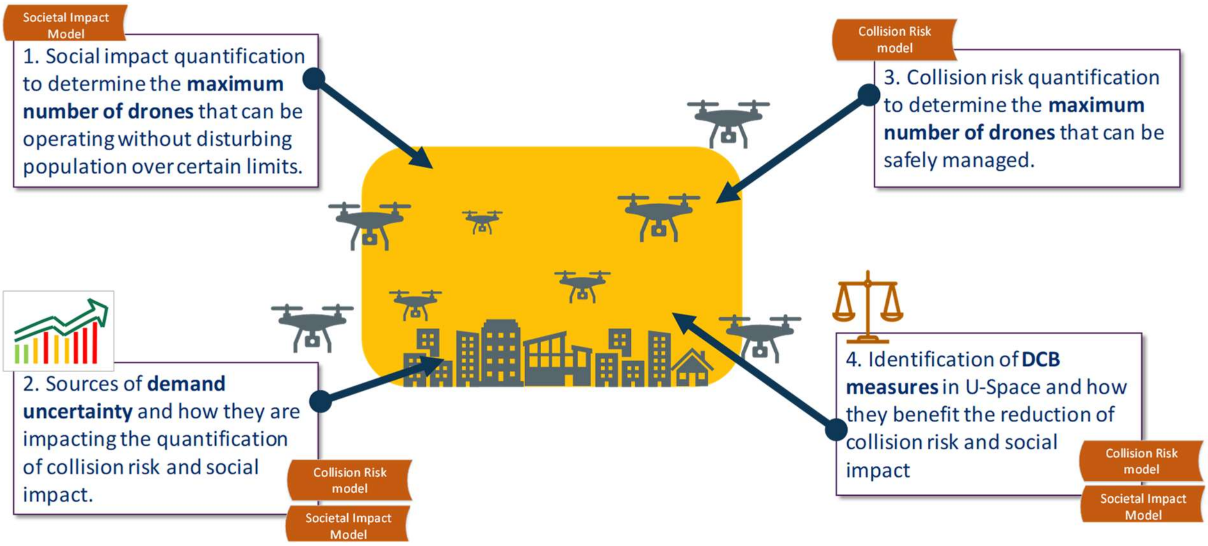

Figure 3: Relationship between DACUS experiments

To support the simulations, in addition to the collision risk and societal impact models, a model of the Tactical Conflict Resolution service is also included using the *droneZone* variant of the RAMS Plus model-based simulation platform. Whilst this is not strictly a part of the DCB function, it has allowed for tactical conflict situations following DCB actions to be measured, to determine if the performance of the tactical conflict management function (through pairwise flight resolution actions) were able to manage the remaining issues, and to determine the maximum number of operations that were feasible in different operating conditions (nominal, sub-nominal, bad weather etc).

2.3.4. Definition of concepts and rules, including applicable catalogues and frameworks

Several factors have capacity constraining effects on the very low-level airspace. DACUS project has analysed existing (JARUS, CORUS) and emerging European concepts of operation (CORUS-XUAM) in regard to their applicability in an environment subject to Dynamic Capacity Management. Since this scenario is expected to occur in complex environments already limited by inherent, capacity reducing factors and an above-average demand, the focus has been primarily on urban environments. Thus, DACUS has defined some rules and procedures that will serve as a support to enable a reliable framework for commercial applications of drones in urban environments.

Airspace structure and rules

As part of its objectives, DACUS has explored in DACUS D5.1 deliverable [12] the factors impacting drone operations in urban environments (ground, airspace, CNS and regulatory). Based on these factors, DACUS has identified a set of air rules and structures that should be implemented to comply with the safety, environment, and citizen’s acceptability requirements in urban areas.

DACUS project has described the ground environment in urban areas, taking into consideration aspects such as the population density, movement of the population during the day or the social impact of drone operations.

It has also provided a picture of the airspace around and above urban areas. It has considered all different kinds of operations which will occur, whether they are manned or unmanned, the different current ATM and future U-space that may structure the urban airspace.

In addition, an overview of the Communication, Navigation and Surveillance (CNS) performances in urban environments, at least at the state of current knowledge, has also been provided.

Finally, DACUS has depicted the regulatory framework as it is known today for manned and unmanned operations over urbanized areas, also providing the results of the several consultations performed through surveys and bilateral meetings alongside citizens, European cities' authorities, National safety agencies or representatives of France, Germany, Italy and Spain, and the European Aeronautical Safety Agency. Moreover, DACUS has described how the four National ANSPs see their national U-space and their involvement, including the roadmap of U-space services implementation for each country (Spain, Germany, Italy and France).

Three different approaches to airspace structures and related rules have been proposed: one with low drone operations constraints, one with middle constraints and the last one with the need of implementing high level of constraints.

Separation Management Process

DACUS has defined a Separation Management Process [13], where the scope was nominal and non-nominal conditions, leaving outside degraded conditions. This definition has included a set of principles and assumptions that have been followed during the whole separation management scheme. They have set the framework over which the process will be implemented.

In addition, to ensure that aircraft operates safely, as part of the separation process, a set of airspace structures and separation rules has been defined. It is essential to define airspace structures that can accommodate different demands while maintaining a certain level of safety, providing therefore procedural separation which minimises the tactical separation needs.

The separation responsibility has been another concept tackled by DACUS project. The separation management process envisaged will be at operation/mission level and dynamic to adapt to the demand and the airspace capacity to create a routing environment as "free" as possible. The starting point is an airspace in which the free route is applied, until due to the need of balancing the demand and the airspace capacity some constrains need to be introduced.

According to this framework, the proposed approach by DACUS has consisted of defining a set of criteria whose status or value will determine the level of centralisation of the separation management and the level of routing freedom that can be given to the vehicles.

Depending on the situation (set of values for the defined criteria), the Separation Management process will produce an applicable separation scheme, setting how the separation is implemented in terms of responsibility and applicable process.

In addition, DACUS has analysed the separation minima for drone operations [8], i.e., minimum separation that must be maintained between two aircraft in a given operational environment to keep the operations safe. Separation minima should be adapted depending on the characteristics of the airspace; this is what dynamic separation minima concept pretends.

Performance Framework

DACUS has designed a U-space DCB ConOps which follows a performance-based approach during the execution of the related processes. The selection of the DCB measures and other DCB decisions will be 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.

DACUS Performance Framework [14] starts by redefining our understanding of Key Performance Areas (KPAs) applicable to U-space, analysing the differences between ATM and U-space. Then, it describes 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.

DACUS has detailed representative indicators that allow the monitoring of drone operations in urban environments. It 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 has implemented some of these indicators in its experiments with the objective of understanding their applicability [11]. The most useful indicators have been included in the final DCB concept of operations [2].

2.4 Key Project Results

It is important that the knowledge developed within DACUS continues to exist beyond its life. Furthermore, it should be made accessible and usable to other parties, in research and industry, allowing further development and greater outcomes. Thus, exploitable outcomes, as key results of the activities described in the previous section, have been identified.

2.4.1. Drone DCB Concept of Operations

DACUS project has developed the ***DACUS DCB Concept of Operations (ConOps)*** [2]. The complete DCB process has taken as inputs critical influence factors (including uncertainty of both demand and capacity) and has described a set of measures for adjusting both capacity and demand for the period of operation. Developing this drone specific Demand and Capacity Balancing (DCB) process, DACUS has covered the Objective 1 defined in the Grant [27].

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

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

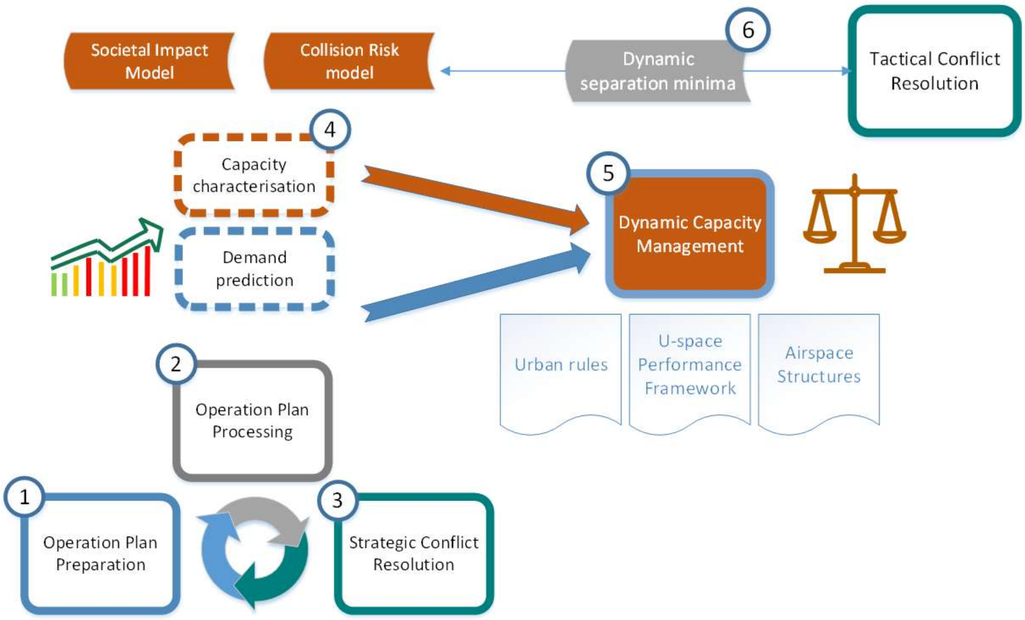

Figure 4. Overview of U-space DCB process

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

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

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 has been the inclusion of the "**consolidated demand picture" to separate the strategic phase from the pre-tactical phase**. This notion is entirely based on probabilistic estimations of traffic demand, which deviates from the predominantly deterministic and rigid approach to DCB currently employed by air traffic management.

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

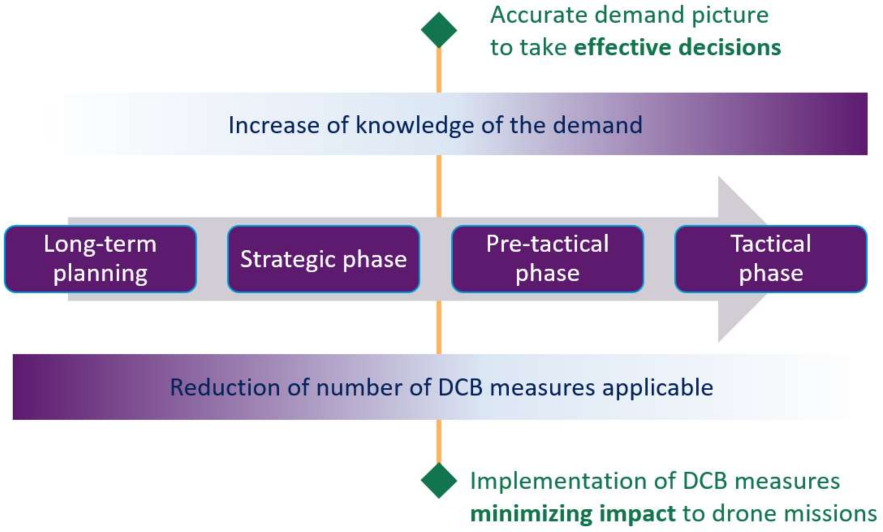

Figure 5. DCB planning phases.

One of the key challenges of DCB in U-space is to define **new metrics to determine how many drones can be safely managed by the U-space system in a given airspace**. In contrast to ATM, this limit will not be constrained by the air traffic controller's capability to safely separate aircraft. The U-space capacity will be limited by the ability of the tactical conflict resolution process to manage the density of aircraft in order to keep the risk of conflict acceptably low, and by the various constraints on drone operations defined by external actors. Drone components related to its remote control and positioning capabilities, environmental factors as well as navigation, communication and surveillance data provision will have an influence on this risk of conflict, which in turn affects capacity.

Given the proximity of drone operations to the general public as well as ground infrastructure, a special emphasis was placed by DACUS on including **risk and social indicators as an integral part of the DCB process**. This will assure that overall flight safety and the safety of third parties remains acceptably

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high and assuring that social impact factors (such as noise, pollution and visual impact) will remain below an acceptable threshold.

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

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

2.4.2. Developments of conceptual models and algorithms in support of DCB

To support the DCB process decision making, DACUS main developments [7] have been the ***Collision Risk Model***, which quantified the air and ground risks as a limiting factor to determine the maximum number of drones in an urban area, and the ***Societal Impact Model***, which measured the visual and noise effects over the population as another limiting factor. Developing these innovative enabling models and technologies, DACUS project has covered the Objective 2 defined in the Grant [27].

These developments have been developed and tested in order to:

- Quantify the air and ground risk as a limiting factor to determine the maximum number of drone operations in a certain urban airspace, considering how the performance of the U-space Tactical Conflict Resolution service[4] and the CNS systems are impacting the risk level.
- Quantify the social impact, including visual and noise effects over population, as another key factor to limit the number of operations.
- Design drone operation plans taking into consideration the existing demand and its associated uncertainty.
- Quantify the effectiveness of mitigation measures, such as organization of flows or rerouting, to solve imbalances when demand exceeds airspace capacity.

[4] Further details about this relation are included in DACUS deliverables D3.2, D3.3 and D3.4.

Both models were successfully combined in experiments performed in Frankfurt and Madrid. Social impact model used a 2D grid of 1km² cells grid. **The grid enables to identify and comprehend source of social impact hotspots**, and cells of this size were also appropriate to implement local DCB measures resolving social impact imbalances.

This social impact grid was consistently integrated with the one proposed by the collision risk model, which displayed a 0.5km² cells-grid both in 2D and 3D. Possibly, due to the size of the cells and the criteria to identify hotspots, **collision risk values were highly sensitive to pair-wise interactions** among drone operation plans that are in the same cell at the same period. These potential collisions should be solved through strategic conflict resolution actions, without the need of implementing DCB measures.

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

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

Key results of the Collision Risk Model

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

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

In addition, the displacement of operations due to the delays caused by the contingency event leads to a higher appearance of hotspots. There are some contingencies that change the overall set of social and collision risk hotspots more critically than others - In particular, the closure of a vertiport for 1 hour and GNSS disruptions such as those related to misleading satellite information for 1 hour. At the same time, micro-weather information indicates that the flyable volumes and layers of the airspace can be additionally reduced depending on the type of UAS. In consequence, drone operations can be further densified given a stable demand.

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

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

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

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

The maturity assessment of the Collision Risk model as a capability which is part of the Dynamic Capacity Management service is summarized in Table 1.

Key results of the Societal Impact Model

Four indicators –**based on Noise and Visual annoyance and exposure** – were used by the social impact model to **determine a pseudo-maximum number of UAS operations per cell**. The distinction between noise and visual impacts remains important as they behave in a slightly different way, even if they are highly correlated to the number of drones and the population density in a cell. However, the distinction between annoyance and exposure is more complex: For noise impact, annoyance, and exposure are highly correlated and could be merged as one indicator. For visual impact, annoyance, and exposure these are also highly correlated for areas with a high population density, but they exhibit more complex patterns at low population density.

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

On the other hand, the need to **consolidate acceptable thresholds** was also identified. It should be taken into account that the diverse business models for drone missions are impacted differently by the social impact thresholds due to the different distribution of operations in the city.

Maturity assessment of Collision Risk and Societal Impact Model

The maturity assessment of the Collision Risk model and the Societal Impact model as capabilities which are part of the Dynamic Capacity Management service are summarized in the following tables.

In addition, the assessment of the overall Dynamic Capacity Management service was also performed. It should be mentioned that Performance benefits (PER.V1.1) was not fully achieved because the demand prediction function was not completely tested, i.e., the benefits of having a more reliable demand based on machine learning and artificial intelligence could not be tested. It is recommended not to include this function in the short-term implementation of the Dynamic Capacity Management service.

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MATURITY CRITERIA TRL4. COLLISION RISK MODEL AS A CAPABILITY OF THE DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
OPS.TRL4.1	Have relevant U-space services supported by the U-space capability been refined and updated?	Achieved	The DACUS project has been focused on the DCB process, defining, and testing how the DCM service should work. Dependencies with other services such as Flight Plan Authorisation service were identified. D1.2, D2.1
SYS.TRL4.1	Is the U-space capability definition (after consolidating the project results) described and aligned to CORUS ConOps and U-space architecture principles?	Achieved	The model is described in deliverables D3.2 and D3.4. No inconsistencies with the ConOps
SYS.TRL4.2	Have critical functions/components of the U-space capability been identified?	Achieved	The functions and components are described in D3.2 and D3.4
SYS.TRL4.3	Has a prototype of the U-space capability been produced?	Achieved	The model has been developed (D3.2) and tested (D3.3, D3.4, D4.2)
SYS.TRL4.4	Have laboratory tests (based on a prototype) verified the technical feasibility of the U-space capability?	Partial	Collision risk model works as expected, but it is very demanding and would require refinement to process big data samples.
SYS.TRL4.5	Have laboratory tests (based on a prototype) shown that the U-space capability fulfils the critical U-space service(s) essential requirements?	Achieved	DACUS has developed laboratory tests, providing results of the Collision Risk Model for several samples of traffic in different scenarios, and the results have been applied by the DCM to detect imbalances (D4.2).
SYS.TRL4.6	Have laboratory tests (based on a prototype) shown (and reported) that the U-space capability is technically feasible?	Partial	Collision risk model works as expected, but it is very demanding and would require refinement to process big data samples. DACUS has reported the results of the collision risk model in D4.2 and it was also used in D3.3 and D3.4.
SYS.TRL4.7	Have laboratory tests (based on a prototype) verified that the integration of the U-space capability (system enabler) with other related U-space capabilities is technically feasible?	Partial	The collision risk model has been able to process input data from the demand models and to provide results to identify imbalances. However, the tests have been done off-line with no on-line calculation of imbalances based on new inputs.

MATURITY CRITERIA TRL4. COLLISION RISK MODEL AS A CAPABILITY OF THE DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
SYS.TRL4.8	Are initial U-space functional and non-functional requirements documented after project activities?	Partial	Basic Requirements are described in D3.2
PER.TRL4.1	Does the safety assessment show evidence that the U-space capability do not negatively impact safety?	Partial	A dedicated safety assessment document (D5.4) was produced to identify the safety assessment activities required for the DACUS solution to achieve V1. In addition, safety is intrinsic to the collision risk model as the objective of this model is to identify the level of risk derived from potential collisions between UAS.
PER.TRL4.2	Does the security assessment show evidence that the U-space capability do not negatively impact security?	Not Achieved	No Security Assessment has been developed
PER.TRL4.3	Do the project results provide evidence that the Cost Benefit Analysis (CBA) of deploying the U-space capability will be positive?	Partial	Although no CBA was developed, the solution proposed by DACUS will support the development of the overall CBA of U-space airspaces as defined in the 2021/664 regulation by defining an approach to determine the maximum number of drone operations in U-space airspace, and thus, determining the expected benefits. Without this, restrictions with regards to the number of operations will be higher, reducing benefits.
S&R.TRL4.1	Have applicable standards been identified?	Achieved	No relevant standards have been found.
S&R.TRL4.2	Do the project results provide material to support the update of available standards or the development of new ones (if required)?	Partial	D3.2 and D4.1 describe the requirements for data sharing among the different capabilities of the DCM service.
S&R.TRL4.3	Have applicable regulations been identified?	Achieved	D3.2 identifies the regulation and reference material to define a TLS.
S&R.TRL4.4	Do the project results justify the need to update a regulation or the creation of a new one?	Partial	The project results justify the need to update SORA assessments with quantitative models and the need to define a Target Level of Safety (TLS) in U-space airspace.

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MATURITY CRITERIA TRL4. COLLISION RISK MODEL AS A CAPABILITY OF THE DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
TRA.TRL4.1	Are there recommendations proposed to be addressed during TRL-6 related activities?	Partial	Deliverable D6.3 describes the recommendations.
VAL.TRL4.1	Has laboratory-scale testing of a U-space capability (system enabler) prototype been completed in a simulated environment?	Partial	DACUS has developed laboratory tests, providing results of the Collision Risk Model for several samples of traffic in different scenarios, and the results have been applied by the DCM to detect imbalances (D4.2). However, the model is very demanding and would require refinement to process big data samples. Additionally, the models have been tested off-line.
PRG.TRL4.1	Have representative stakeholders contributed to identify functional and performance requirements for the U-space capability?	Not Achieved	Neither operators nor USSP representatives were involved to identify functional and performance requirements.

Table 1. Maturity assessment of the Collision Risk Model.

MATURITY CRITERIA TRL4. SOCIETAL IMPACT MODEL AS A CAPABILITY OF THE DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
OPS.TRL4.1	Have relevant U-space services supported by the U-space capability been refined and updated?	Achieved	CORUS ConOps shall consider that "Population density map service" shall provide dynamic data. Dependencies with other services such as Flight Plan Authorisation service were identified. D1.2, D2.1
SYS.TRL4.1	Is the U-space capability definition (after consolidating the project results) described and aligned to CORUS ConOps and U-space architecture principles?	Achieved	The model is described in deliverables D3.2. No inconsistencies with the ConOps
SYS.TRL4.2	Have critical functions/components of the U-space capability been identified?	Achieved	The functions and components are described in D3.2.
SYS.TRL4.3	Has a prototype of the U-space capability been produced?	Achieved	The model has been developed (D3.2) and tested (D4.2)

MATURITY CRITERIA TRL4. SOCIETAL IMPACT MODEL AS A CAPABILITY OF THE DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
SYS.TRL4.4	Have laboratory tests (based on a prototype) verified the technical feasibility of the U-space capability?	Partial	The model perfectly technically works. Time required to calculate hotspots and DCB measures efficiency depends on the amount of data, architecture of the system and machine power involved.
SYS.TRL4.5	Have laboratory tests (based on a prototype) shown that the U-space capability fulfils the critical U-space service(s) essential requirements?	Achieved	DACUS has developed laboratory tests, providing results of the Model for several samples of traffic in different scenarios, and the results have been applied by the DCM to detect imbalances (D4.2).
SYS.TRL4.6	Have laboratory tests (based on a prototype) shown (and reported) that the U-space capability is technically feasible?	Partial	The model is very demanding and would require refinement to process big data samples or wide areas. The areas involved in the model concern only city's areas, the model could be tested with extended surfaces.
SYS.TRL4.7	Have laboratory tests (based on a prototype) verified that the integration of the U-space capability (system enabler) with other related U-space capabilities is technically feasible?	Achieved	The model was integrated in a platform with other functionalities of the DCM and U-space services. Use of UCIS platform allows to use the model fed by a simulated "drone operation plan processing service" or "Flight authorization service", for instance.
SYS.TRL4.8	Are initial U-space functional and non-functional requirements documented after project activities?	Partial	Basic Requirements are described in D3.2
PER.TRL4.1	Does the safety assessment show evidence that the U-space capability do not negatively impact safety?	Not Applicable	The model itself does not encompass any safety considerations. It has been included in the collision risk model which embeds ground and air risk.
PER.TRL4.2	Does the security assessment show evidence that the U-space capability do not negatively impact security?	Not Achieved	No security assessment was performed.
PER.TRL4.3	Do the project results provide evidence that the Cost Benefit Analysis (CBA) of deploying the U-space capability will be positive?	Partial	Although no CBA was developed, the solution proposed by DACUS will support the development of the overall CBA of U-space airspaces as defined in the 2021/664 regulation by defining an approach to determine the maximum number of drone operations in U-space airspace, and thus, determining

MATURITY CRITERIA TRL4. SOCIETAL IMPACT MODEL AS A CAPABILITY OF THE DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
			the expected benefits. Without this, restrictions with regards to the number of operations will be higher, reducing benefits.
S&R.TRL4.1	Have applicable standards been identified?	Achieved	Standards for drone operation plan data have been identified and used (WGS-84 and GeoJson). For the connection of the service, standards HTTP and OpenID connect were used.
S&R.TRL4.2	Do the project results provide material to support the update of available standards or the development of new ones (if required)?	Not applicable	Applicable standards were identified and used, without the need of new ones.
S&R.TRL4.3	Have applicable regulations been identified?	Achieved	The model uses EASA current regulations on U-space framework.
S&R.TRL4.4	Do the project results justify the need to update a regulation or the creation of a new one?	Partial	A regulation on noise and visual impact of drone operations should be created, or noise limitation for operation in the open category probably updated.
TRA.TRL4.1	Are there recommendations proposed to be addressed during TRL-6 related activities?	Partial	Deliverable D6.3 describes the recommendations.
VAL.TRL4.1	Has laboratory-scale testing of a U-space capability (system enabler) prototype been completed in a simulated environment?	Achieved	The model was tested with real data for the geographical environment, dynamic population density map, drone operation plan, drone characteristics, and drone operation types based on real economic environment.
PRG.TRL4.1	Have representative stakeholders contributed to identify functional and performance requirements for the U-space capability?	Not Achieved	Neither operators nor USSP representatives were involved to identify functional and performance requirements.

Table 2. Maturity assessment of the Societal Impact Model.

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MATURITY CRITERIA OF U-SPACE SOLUTION V1. DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
OPS.V1.1	Is the U-space service definition (after consolidating the project results) aligned with the applicable version of CORUS Concept?	Achieved	DCM service as defined in DACUS is similar to the CORUS one. Nevertheless, DACUS DCM has been improved by detailing the functions of the service, the relation with the other services in U-space and the indicators to support decision-making. The DCB (Demand and Capacity Balance) process has been described in D1.1, D1.2.
OPS.V1.2	Have potential (sub)operating environments been identified where the U-space service could be deployed?	Achieved	The most important operating environment identified for DCM service implementation is the urban one, but it is commonly admitted that a DCM service could be useful in other environments, where the traffic demand makes it necessary. Environments have been described in D1.1, D1.2 and D5.1.
OPS.V1.3	Have all stakeholders been identified, their needs and expectations for the U-space service discussed and documented?	Partial	Stakeholders were identified and their needs understood. However, it is not possible at this stage to quantify these expectations and needs. This is specially the case of social impact model. Acceptable thresholds for noise and visual impacts have been selected arbitrarily. Thus, these values do not come from, for instance, citizen expectations or city councils. In the case of the collision risk model, DACUS assumes that that stakeholders' needs are summarized in the Target Level of Safety (TLS). See D1.1, D1.2 and D5.1 for stakeholders' identification.
SYS.V1.1	Does the U-space service proposed architecture align to the U-space architecture principles?	Achieved	The architecture is consistent with CORUS. See D1.1, D1.2 and D2.1
PER.V1.1	Is there a documented description (and if available qualitative evidence) of the potential impacts of the U-space service on SESAR Key Performance Areas (KPAs)?	Achieved	Firstly, DACUS has defined a U-space performance framework as the main reference to understand the benefits of implementing a DCM solution. Second, DACUS has tested the benefits of the solution by using the indicators included in the performance framework (most of them included in the later U-space companion document by SESAR PJ19). The benefits of having a more reliable demand based on machine learning and artificial intelligence could not be tested. It is recommended not to include this function in the

MATURITY CRITERIA OF U-SPACE SOLUTION V1. DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
			short-term implementation of the Dynamic Capacity Management service. Performance Framework is D5.3. Results are included in D4.2.
PER.V1.2	Has a V1 Human Performance assessment been performed and documented?	Not Applicable	Out of DACUS experiments scope. DACUS is assuming an automatic U-space system.
PER.V1.3	Has a V1 Safety Performance assessment been performed and documented?	Partial	A dedicated safety assessment document (D5.4) was produced to identify the safety assessment activities required for the DACUS solution to achieve V1.
PER.V1.4	Has the V1 security assessment been carried out?	Not Achieved	No Security Assessment has been developed.
PER.V1.5	Has been a V1 environmental assessment been performed and documented?	Partial	DACUS shows benefits in terms of noise reduction, but no systematic environmental assessment was performed. D4.2 includes the results.
PER.V1.6	Is there any qualitative estimation or orders of magnitude of deployment costs of the U-space service?	Partial	Although no CBA was developed, the solution proposed by DACUS will support the development of the overall CBA of U-space airspaces as defined in the 2021/664 regulation by defining an approach to determine the maximum number of drone operations in U-space airspace, and thus, determining the expected benefits. Without this, restrictions with regards to the number of operations will be higher, reducing benefits.
S&R.V1.1	Have applicable standards been identified?	Not applicable	No applicable standards exist yet for UA maximum noise emission, maximum size or maximum TLS accepted in an area. EASA open category of operation provides maximum noise emission for C1, C2 and C3 UAS classes, but operation types considered in DACUS will generally be in the specific or certified categories.
S&R.V1.2	Have needs for update/create standards been identified?	Partial	Recommendations for standardization and regulation are included in section 3.2.2.

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MATURITY CRITERIA OF U-SPACE SOLUTION V1. DYNAMIC CAPACITY MANAGEMENT SERVICE			
Criteria ID	**Criteria**	**Satisfaction**	**Rationale - Link to deliverables - Comments**
TRA.V1.1	Are there recommendations proposed to be addressed during V2 related activities?	Achieved	Yes, they are identified in D4.2 and in D2.1. An example, need to identify how DCB measures can be efficiently combined, or need to define what should be considered as a social or collision risk hotspot (period overloading thresholds...)
VAL.V1.1	Are the relevant R&D needs identified and documented?	Achieved	Yes, they are identified in D2.1.
VAL.V1.1	Has the project performed appropriate validation activities at V1 level to support the definition of the U-space service? e.g., fast time simulations, expert groups	Achieved	Up to four different validation activities were performed. See D4.2.
PRG.V1.1	Have dependencies with other U-space services been identified and documented?	Achieved	Dependencies are identified in D1.1 and D1.2.

Table 3. Maturity assessment of the Dynamic Capacity Management.

As conclusion of the maturity assessments, it could be extracted that the DCM prototypes (Collision Risk and Societal Impact models) have reached a Technology Readiness Level (TRL) of 3, due to TRL4 is not fully achieved. For the DCB solution as a whole, the Dynamic Capacity Management service has reached V1.

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2.4.3. Validation experiments

Four validation experiments have been performed regarding the use of risk assessment and social impact prototypes that have been developed during the DACUS project operating at different stages of the Demand-Capacity Management (DCM) process for drone operations in the urban environment (U-Space), including strategic, pre-tactical and execution phases [11].

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

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

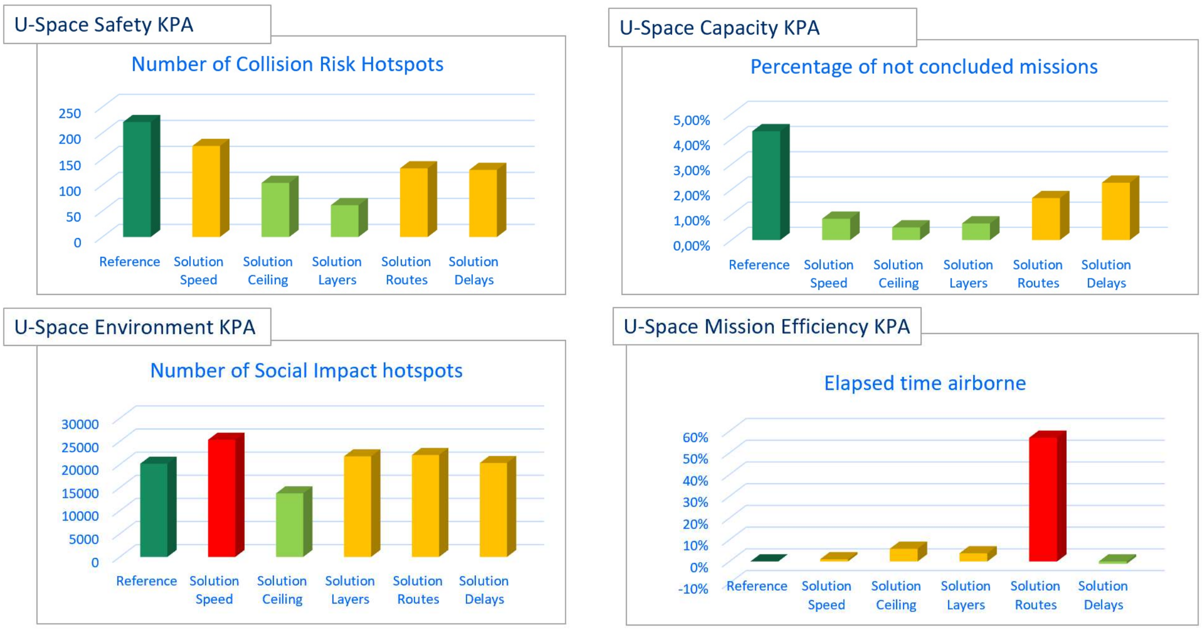

Figure 6: Results of the implementation of pre-tactical DCB measures in Madrid VLL airspace

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

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

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

The use of **delays on the ground** is shown to be effective in deconflicting some trajectories that are in conflict before taking off. It was seen that this DCB measure also reduces the social impact hotspots, although its effectiveness is associated to the displacement of drone operations out of the peak hours.

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

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

In addition, the **prioritization of drone operations within the DCB process** has been tested in the experiments as well. The underlying assumption for the need of providing some sort of prioritization mechanisms was shown within the DACUS experiments, where social impact capacity thresholds were found to be more detrimental for specific types of drone missions than others.

The inclusion of "Virtue Points" as part of the DCB ConOps seems to make sense. However, since this concept was not tested as part of the DACUS experiments it is still to be defined whether or not to include this concept within the process, or another method to maintain equity among operations needs to be found. And, if this concept is considered feasible, investigate how to manage its impact on capacity.

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

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

2.4.4. Definition of concepts and rules, including applicable catalogues and frameworks

It appears that **the current airspace and ground structures may be not adapted to drone operations in urban environment**. All the structures have been designed for quite big aircraft mainly dedicated to transportation of passengers and goods.

Aircraft flying over urban environment have specific authorizations to fly under the minimum height or they fly in the vicinity of an airport on pre-defined routes under the control of ATC. Manned aircraft are alone in the sky. They will have to share the volumes with unmanned aircraft, we do not know yet if manned and unmanned operations would have to be strictly segregated. Intentions were initially to integrate unmanned operations, with service such as the collaborative interface with ATC when the unmanned operation occurs in an airspace under the responsibility of an ANSP.

Whatever the solution, **temporary or permanent airspace structures reserved to drone operations will have to be implemented**, simply because some drone operations are totally different from those performed by manned aircraft, or at least will occur more often (e.g., building inspection, photography) over urbanized areas.

If manned aviation has at its disposal the airport runway(s) and some heliport, there is no ground structure dedicated to drone operations. The use of drones, particularly owing to their limited size (compared to manned aircraft) and VTOL configuration, allow them to operate in the middle of buildings with reduced infrastructures. Nevertheless, even these reduced infrastructures will be hard to build without impacting current ground structures, specifically when talking about old cities and their heritage.

Envisaged dedicated structures will also come from trade-offs between how and for what the drone is used. Having the possibility to take-off and land from everywhere would foster the drone market, whereas having limited structures, such as hubs for packages deliveries, may limit the demand.

The needs in communication, navigation and surveillance are key factors for drone operations. Some existing networks are available today for drone usage, but issues, some already known, other which studies are on-going, could negatively impact the drone market by limiting the number of drone operations in a same volume. Even if the results are positive for drone, **costs linked to some technologies implementations may slow down the market by limiting the demand and the capacity**.

Regarding the regulatory aspects, including the societal impact of drone operations in urban environment, safety considerations are clearly a challenge, but noise, visual impact, and security aspects are keys. **The different surveys show that national and local authorities will have to deal with their citizens**, however very interesting in what drones could bring to their daily lives.

The lack of data and information create a lot of uncertainties about how drone operations over urbanized areas will be possible. Lots of projects and studies are in progress, including the European regulation which will for sure impact the vision we can have today.

The market itself is uncertain and the number of recreational drones has not reached the forecast. Would it be the same for professional users?

If several assumptions must be made to draw a picture of drone operations, from strongly impacting to opening the possibilities, answers to some questions would help:

- Will drone operations be integrated or segregated from manned operations?
- What will be the investments in ground and CNS structures and who will make them (e.g., USSP, ANSP, cities)?
- Will the citizens accept drone operations in term of noise and visual pollution, as well as the safety and security aspects?
- Will the European regulation be constraining to drone operations in urban environment for certified and specific categories of operations (e.g., development of more standard scenarios)?
- How much citizens' information on drone capabilities and services offer will increase or decrease their desire to use drones?

All these points will influence the capacity of an airspace volume, the demand generated by the potential customers and at the end the need in demand and capacity balancing as well as the DCB measures that might be put in place.

Regarding the airspace structure, after all literature review, DACUS has considered **non structured airspace as the general concept**, **introducing layered structures when the demand is close to reach the maximum capacity** for non-structured airspace. Additionally, tubes can be considered as necessary in environments with a high level of constraints [12].

Finally, concerning the work performed through the elaboration of the ***DACUS Performance Framework*** [14], 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.

2.5 Technical Deliverables

Reference	Title	Delivery Date[5]	Dissemination Level[6]
Description			
D1.1	Drone DCB concept and process	12/02/2021	Public
DACUS D1.1 describes the Concept of Operations for "Demand and Capacity Balancing" for drones within an urban environment. This process is supported by an extensive literature study and background information on the operational environment in which it takes place. Given the novel nature of drone operations in a civilian setting, several parallels of the proposed solution and the existing air traffic management environment are provided. Finally, the document serves as guidance material for the DACUS project.			
D1.2	Final optimized drone DCB	05/08/2022	Public
DACUS D1.2 updates the preliminary deliverable Drone DCB concept and process (D1.1), taking into account all the work performed during the DACUS project. The document serves as guidance material for the implementation thereof within U-space.			
D2.1	DCM Service architecture & prototype	09/07/2021	Public

[5] Delivery data of latest edition

[6] Public or Confidential

DACUS D2.1 summarises the set of prototypes in support of the DCM Services architecture and U-space services and capabilities, to be developed by the consortium members and that will be utilised during the validation experiments as outlined in D4.01.			
D2.2	Drone trajectory management framework prototypes	09/07/2021	Public
DACUS D2.2 summarises the set of prototypes for drone trajectory management framework, to be developed by the consortium members and that will be utilised during the validation experiments as outlined in D4.1.			
D2.3	Prototype of services to support large number of simultaneous operations	09/07/2021	Public
DACUS D2.3 summarises the architecture for the micro weather service and the prototype to be developed by the consortium members and that will be utilised during the validation experiments as outlined in D4.1.			
D3.1	AI Demand Prediction Model	14/05/2021	Public
DACUS D3.1 allows consortium members to declare the AI demand model that has been created within work package 3, that will be integrated in the U-space services to be developed in WP2. The model developed in WP3, described in this document and D3.2, have been verified and are available to feed the Demand and Capacity Management serviced to be developed in WP2. They could also be used by other WP2 services, adapting them conveniently.			
D3.2	Capacity Models in support of DCB	09/08/2021	Public
DACUS D3.2 allows consortium members to declare the Capacity models that have been created within work package 3, that will be integrated in the U-space services to be developed in WP2. The model developed in WP3, described in this document and D3.1, have been verified and are available to feed the Demand and Capacity Management serviced to be developed in WP2. They could also be used by other WP2 services, adapting them conveniently.			
D3.3	Dynamic Separation Minima	21/12/2021	Public
DACUS D3.3 defines a method to set the Dynamic Separation Minima in DACUS Project. For that, the steps followed to achieve it and the models developed to this end are presented as well as the results of the experiments carried out. The Dynamic Separation concept is part of the Separation Management Process, that plays an important impact in the Demand and Capacity Balance process that is being developed by DACUS.			
D3.4	Refined CNS Criteria	12/08/2022	Public
DACUS D3.4 reviews the CNS Requirements evaluated in the DACUS Deliverables D3.3 and D4.2, based on the Collision Risk Model for the Strategic Phase (random trajectories) and analyses to what extend they remain applicable for the Pre-Tactical Phase (real trajectories based on flight plans), considering different traffic scenarios.			
D4.1	Scenarios for validation experiments	23/07/2021	Public
DACUS D4.1 details a set of operational scenarios which will allow the team to perform a series of validation experiments aimed at testing the suitability and performance of the various prototype algorithms under nominal and sub-nominal operating conditions, as well as to support the analysis of separation intelligence balance and refinement of CNS requirements linked to separation minima criteria.			
D4.2	DACUS Validation Report	10/10/2022	Public

EUROPEAN PARTNERSHIP

Co-funded by the European Union

DACUS D4.2 provides the Validation Report (VALR) relating to a series of experiments that aimed at testing the suitability and performance of prototype Demand-Capacity Management (DCM) tools working in nominal and sub-nominal operating conditions to manage proposed drone operations in the U-Space environment.			
D5.1	Structures and Rules in Capacity Constrained (urban) Environments	15/03/2021	Public
DACUS D5.1 provides information which currently characterize ground, airspace, CNS and regulatory environments and linked to drone operations in urban areas. Those characterizations will allow to propose a set of DCB measures in each domain based on the identified potential flexibilities that could benefit to the DCB process. Additionally, they will allow defining the set of air rules and structures that should be implemented in urban environments to comply with the safety, environment and citizen's acceptability requirements in urban areas.			
D5.2	Separation Management Process Definition	27/07/2021	Public
DACUS D5.2 provides the definition of the scope of Separation Management, linking it to the DCB process. Through the definition of a set of Principles and assumptions, the process is contextualised. Finally, this deliverable defines a set of separation rules and responsibilities and a catalogue of applicable airspace structures, as well as the list of criteria for their application.			
D5.3	Performance Framework	10/11/2021	Public
DACUS D5.3 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 are tested in the DACUS experiments.			
D5.4	Safety Assessment	14/12/2022	Public
DACUS D5.4 is a new deliverable not initially included in the Grant. It contains the safety assessment activities to be carried out in order to generate the evidence needed to ensure that the solution proposed within the DACUS project achieves V1 maturity level. The safety assessment allows the definition of Safety Criteria and will support the derivation of Safety Requirements such that the concept design is capable of meeting the Safety Criteria.			

Table 4: Project Deliverables

3 Conclusion and Recommendations

3.1 Conclusions

3.1.1 Conclusions on maturity of the SESAR solutions and supporting services/capabilities

As in ATM nowadays, the management of airspace is crucial to ensure safety and efficient operations. Due to the expected high increase of demand for autonomous flight operations, especially over urban environments where population density is higher than the rural one, **a Demand and Capacity Balancing process through the Dynamic Capacity Management service is critical** to ensure availability of access to airspace, adequate balance between system capacity and demand of drone operations, and fair and prioritized access to airspace.

Thus, DACUS has developed a complete service-oriented DCB solution from detection to resolution, to facilitate drone traffic management in urban environments, reaching a maturity of **V1 on the Dynamic Capacity Management service**. The solution includes:

- A U-space Demand and Capacity Balancing Concept of Operations, following a performance-based approach.
- Conceptual models and algorithms in support of DCB, where the **Collision Risk Model and the Societal Impact Model have reached a maturity of TRL3**.
- Validation experiments to demonstrate whether it is feasible to determine and react to demand and capacity imbalances, i.e., hotspots, using the Risk and Societal Impact models developed. DCB actions which may help to mitigate those imbalances have been also evaluated.
- A U-space Performance Framework, which details representative indicators that allow the monitoring of drone operations in urban environments, covering capacity, environmental & social impact, mission efficiency, equity, flexibility and resilience areas. Validation experiments have helped to identify the most useful indicators.

In addition, DACUS has analyse the operational environments in which this solution could be implemented, and the constraints associated to its implementation. This is included in two documents that contain:

- Set of air rules and structures that should be implemented to comply with the safety, environment, and citizen’s acceptability requirements in urban areas.
- Definition of the separation management process in the context of U-space and the link between separation and DCB processes.

3.1.2 Conclusions on technical design, feasibility and architecture

DACUS consortium tried to be agnostic to the type of U-space architecture in place (centralized, co-federated, fully-federated) in the definition of the DCB process. On the other hand, DACUS did not perform specific research on the best architecture to implement the Dynamic Capacity Management service, e.g., centralized vs. decentralized architectures. However, the consortium considers that it would add complexities to develop a completely decentralized service with several USSPs competing to provide it. Appendix B shows the architecture for the different phases taken as reference in DACUS project to elaborate the deliverables, develop the algorithms, and perform the validation experiments.

3.1.3 Conclusions on performance and benefits assessment

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 establish 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.

3.1.4 Conclusions on requirements

Table 5 shows the conclusions on requirements, extracted from the main developments in DACUS project (Collision Risk and Societal Impact models).

Identifier	Title	Requirement	Status	Rationale	CAT-PER	CAT-SAF	CAT-INT	CAT-ACC	CAT-SEC	SESAR Solution Identifier	U-space Service name (Foundation package service (U-space CONOPS Ed3) linked to Reg. (EU) 2021/664 (EASA service mandatory & EASA service mandatory depending on member state))				
											Geo-awareness (U1) ** Geo-awareness	Operation plan processing (U2) *** UAS flight Authorization	Risk analysis assistance (U2)	Population density map (U2)	Dynamic Capacity Management (U3)
REQ-DACUS-D32.COLR.0001	Flight Plan Data to estimate maximum capacity based on collision risk in the pre-tactical phase	The collision risk model (through DCM service) shall receive from the UAS Flight Authorisation service information on UAS operation plans and UAS characteristics	<in progress>	In order to determine the specific 4D cells where the demand could be greater than the capacity, it is necessary to have information of planned trajectories.		X				<DACUS-01>		X	X		X
REQ-DACUS-D32.COLR.0002	Population Density and Sheltering Data to estimate maximum capacity based on collision risk in the pre-tactical phase	The collision risk model shall be provided with dynamic population density map and sheltering factor of the area the model is applied on, with a resolution equal or greater than the minimum cell size considered by the model (250m x 250m)	<in progress>	The fatality risk depends not only on the UAS collision and failure risks, but on the population that could be affected by the UAS crashing on to the ground, which is a function of the population density and the protection provided by existing structures to the people on the ground (sheltering factor).		X				<DACUS-02>			X	X	X
REQ-DACUS-D32.COLR.0003	Target Level of Safety	The collision risk model shall be notified by the DCM service with the maximum acceptable fatality and collision risk in a certain U-space volume	<in progress>	The maximum capacity will be reached when the collision/fatality risk equals the Target Level of Safety (TLS) defined.		X				<DACUS-03>			X		X

Identifier	Title	Requirement	Status	Rationale	CAT-PER	CAT-SAF	CAT-INT	CAT-ACC	CAT-SEC	SESAR Solution Identifier	U-space Service name (Foundation package service (U-space CONOPS Ed3) linked to Reg. (EU) 2021/664 (EASA service mandatory & EASA service mandatory depending on member state))				
											Geo-awareness (U1) ** Geo-awareness	Operation plan processing (U2) *** UAS flight Authorization	Risk analysis assistance (U2)	Population density map (U2)	Dynamic Capacity Management (U3)
REQ-DACUS-D32.COLR.0004	Data coherence among the capacity models	The collision risk and social impact models feeding the DCM service shall use common geographic projections and common grids.	<in progress>	A common grid and geographic projections are essential to be able to identify cells with capacity imbalances by the DCM service		X		X		<DACUS-04>			X		X
REQ-DACUS-D32.COLR.0005	4D collision risk hotspots and sustained risk	The collision risk model shall identify 3D cells where the fatality risk is greater than the TLS instantaneously (e.g. 1 minute) or close to the TLS, in average, during a greater time frame (e.g. 30 minutes)	<in progress>	Collision risk hotspot are beyond the TLS, but a sustained value of risk below the TLS, but close to it, is also an indicator of capacity overflow		X				<DACUS-05>			X		X
REQ-DACUS-D32.COLR.0006	Collision risk capacity hotspots update time	The collision risk shall provide the 4D hotspots and average risk per cell information to the DCM service at least 15 minutes (TBD) before the departure of the flights	<in progress>	Capacity overflow information shall be updated providing time enough to take adequate demand restriction measures.		X				<DACUS-06>			X		X
REQ-DACUS-D32.SOCI.0001	Type of data required for social impact model	Societal impact model(through DCM service) shall receive from the UAS Flight authorisation service information on UAS operation plan and UAS characteristics	<in progress>	These data are required for social impact calculation.				X		<DACUS-06>		X			

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Identifier	Title	Requirement	Status	Rationale	CAT-PER	CAT-SAF	CAT-INT	CAT-ACC	CAT-SEC	SESAR Solution Identifier	U-space Service name (Foundation package service (U-space CONOPS Ed3) linked to Reg. (EU) 2021/664 (EASA service mandatory & EASA service mandatory depending on member state))				
											Geo-awareness (U1) ** Geo-awareness	Operation plan processing (U2) *** UAS flight Authorization	Risk analysis assistance (U2)	Population density map (U2)	Dynamic Capacity Management (U3)
REQ-DACUS-D32.SOCI.0002	Type of data required for social impact model	Societal impact model shall be provided with dynamic population density map of the area the model is applied on	<in progress>	Social impact thresholds are a combination of noise emission and number of UAS with number of persons in a cell. Dynamic population density data allows to calculate real time impact.				X		<DACUS-07>				X	
REQ-DACUS-D32.SOCI.0003	DCM service position in U-space service architecture	DCM service shall be centralized to have an overview of the whole traffic coming from several USSP	<in progress>	Several DCM services would require long coordination and negotiations before proposing a final decision.			X			<DACUS-08>					X
REQ-DACUS-D32.SOCI.0004	social impact model data processing	Social impact model (through DCM service) shall be able to receive data from several USSP	<in progress>	Social impact calculation requires to have the whole traffic.			X			<DACUS-09>					X
REQ-DACUS-D32.SOCI.0005	Thresholds flexibility in the social impact model	Social impact model shall allow to modify the visual and noise impact thresholds	<in progress>	What is acceptable in terms of social impact may differ in time (e.g., week days or week-end days) or in value.				X		<DACUS-10>					X

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Identifier	Title	Requirement	Status	Rationale	CAT-PER	CAT-SAF	CAT-INT	CAT-ACC	CAT-SEC	SESAR Solution Identifier	U-space Service name (Foundation package service (U-space CONOPS Ed3) linked to Reg. (EU) 2021/664 (EASA service mandatory & EASA service mandatory depending on member state))				
											Geo-awareness (U1) ** Geo-awareness	Operation plan processing (U2) *** UAS flight Authorization	Risk analysis assistance (U2)	Population density map (U2)	Dynamic Capacity Management (U3)
REQ-DACUS-D32.SOCI.0006	UAS operation plan data to DCM service	DCM service shall be provided with the latest information on UAS operation plan	<in progress>	This is required as any modification in the UAS trajectory or the type of UAS involved could avoid a hotspot creation.				X		<DACUS-11>					X
REQ-DACUS-D32.SOCI.0007	Geo-awareness data provision to DCM service	DCM service shall be provided with the latest information from geo-awareness service	<in progress>	DCB measures shall take into account portions of airspace which are forbidden to UAS.		X				<DACUS-12>	X				X
REQ-DACUS-D32.SOCI.0008	DCB measure efficiency	DCM service shall propose the DCB measure that reduces the most visual and noise impacts	<in progress>	DCB shall propose the best measure in term of efficiency without considering calculation time for instance.				X		<DACUS-13>					X
REQ-DACUS-D32.SOCI.0009	DCM DCB measure ranking proposal	DCM service shall be able to propose a ranking of the DCB measures efficiency	<in progress>	This would serve as a statistic data base to be used by the DCM service to automatically select the most efficient measure, to save time.	X					<DACUS-14>					X

Identifier	Title	Requirement	Status	Rationale	CAT-PER	CAT-SAF	CAT-INT	CAT-ACC	CAT-SEC	SESAR Solution Identifier	U-space Service name (Foundation package service (U-space CONOPS Ed3) linked to Reg. (EU) 2021/664 (EASA service mandatory & EASA service mandatory depending on member state))				
											Geo-awareness (U1) ** Geo-awareness	Operation plan processing (U2) *** UAS flight Authorization	Risk analysis assistance (U2)	Population density map (U2)	Dynamic Capacity Management (U3)
REQ-DACUS-D32.SOCI.0010	DCM performances	DCM service shall be able to identify hotspots in less than one minute	<in progress>	This is required to be able to propose UAS flight plan changes in acceptable delays.	X					<DACUS-15>					X
REQ-DACUS-D32.SOCI.0011	DCM hotspot identification	DCM service shall identify a hotspot a soon as one of the defined thresholds (set for Noise Annoyance, noise exposure, visual annoyance and visual exposure) is reached.	<in progress>	This allows to only affect one operation.	X					<DACUS-16>					X
REQ-DACUS-D32.SOCI.0012	DCM DCB measure proposal	DCM shall propose a DCB measure to the operator of the UAS operation which has triggered the hotspot, unless this operation has a priority status	<in progress>	UAS operator needs to receive a DCB measure proposal to speed up the process of his UAS flight authorisation.	X					<DACUS-17>					X
REQ-DACUS-D32.SOCI.0013	DCM hotspot localisation	DCM should localise social impact hotspot in cells of 1 km square	<in progress>	1 km square is a good compromise between the precision of hotspot localisation and hotspot calculation time.	X					<DACUS-18>					X

Table 5. Conclusions on requirements.

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3.2 Recommendations

3.2.1 Recommendations for concept clarification

3.2.1.1 Recommendations for updating U-space services and capability definitions

DACUS project proposes the following definition and process for the Dynamic Capacity Management service:

The Dynamic Capacity Management service is constantly monitoring the demand in the U-space airspace ***along the different planning phases****, detecting the hotspots associated to the collision risk distribution in the U-space airspace, the hotspots related to the environmental and social impact over the population, and solving those hotspots by means of pre-defined DCB measures. The Dynamic Capacity Management service will use as an input the Separation Minima, metrics objectives and airspace structures provided by the Separation Management service.*

Additional text for a better understanding of the scope and requirements of the Dynamic Capacity Management service is provided in the following paragraphs:

The submission of the first operation plans will determine the ***start of the strategic phase****. The service will integrate the submitted operation plans together with historical data of demand based on previous representative days. As soon as UAS flight plans are available, the Dynamic Capacity Management service will continuously evaluate local imbalances integrating these new plans with the initial demand estimations. This will be done through the* ***continuous calculation of the collision risk in the U-space****, considering the separation minima standards as an input, together with the real distribution of drone types, relative trajectories and CNS status or weather conditions.*

Given that most of the UAs flight plans will be unknown in this strategic phase, two processes will be performed by the service:

- *Comparison of estimated demand with the reference capacity objectives in the entire U-space airspace provided by the Separation Management service. DCB measures can be identified and implemented if demand is highly exceeding the capacity. These are measures that will be affecting to a wide area or the entire U-space airspace such as the organization of the overall traffic per flight layers or the introduction of route structures. These global DCB measures may imply changes in the already approved or pre-authorized flight plans.*
- *Analysis of the geographical distribution of the collision risk in the U-space airspace. Although hotspots are not consolidated at this stage, this process will determine areas where collision risk could be higher than the acceptable TLS. Lower "Probabilistic" authorizations or pre-authorisations will be given to those new UAS flight plans requesting to operate in those areas. In FIFO approach is fully implemented, those operation plans will be first candidates for a change if those areas are still identified as hotspots when starting the pre-tactical phase*

In the transition between the strategic to the pre-tactical phase*, most of the operation plans are already known. Then, the service will consolidate the areas of the U-space airspace where the collision risk is above the acceptable safety targets, i.e., the hotspots. Collisions between UAVs will be calculated as a factor of the number of vehicles, their performance limitations, the time to react in case of conflict, the capability of detecting a conflict as well as CNS performances. Potential catastrophic failures of the UAVs while flying will be measured via its "Mean Time Between Failures" (MTBF), and, consequently, it will be proportional to the flight time. Once the collisions and failures are calculated, the probability* *of fatal injuries to third parties on the ground will be determined taking into consideration the distribution of population density as well as how protected people are in the impacted area, i.e., "sheltering factor" in the area.*

***Capacity may be limited for reasons other than safety**, such as environmental and social impact, i.e., perceived noise at ground and visual impact. The service will provide noise and visual annoyance as well as exposure indicators. This will allow distinguishing between noise and visual impact, and also between the level of exposure and how this level is disturbing the citizens in the area*

***U-space DCB measures will be categorized according to their impact on the fulfilment of the mission objectives** as one of the main classification criteria, assuming that not all requirements included in the operation plan are necessary to guarantee the success of the mission. U-space DCB measures can impose constraints on the drone operation plans, such as flying in a certain flight level, which are not necessarily impacting on the requirements of the drone operators to fulfil their missions. The more restrictive measures such as imposing to fly in a certain flight level in the whole area will be applied in the strategic phase.*

Once hotspots are consolidated, a set of pre-defined solutions may be applied in the transition to the pre-tactical phase. Drone operations that were submitted earlier will be prioritized – if applying FIFO strategy -, or similar predefined rules also incorporated to the strategic conflict resolution function. The most common measures will imply adjustments of the departure time, rerouting to non-congested areas, adjustments of the speed or flight level among others. They will be commonly applied to individual flights.

Drone operators with UAs flight plans that are affected by the DCB measures will be informed. It is remarkable that the diversity of drone operators makes it necessary to consider that some of them will have wide technological capabilities to have full access to U-space and others will not be able to dynamically react to continuous changes.

3.2.1.2 Recommendations for updating the U-space architecture

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

3.2.1.3 Recommendations for elaboration of the U-space concept

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

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

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

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

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

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

3.2.2 Recommendations for standardisation and regulation

The DACUS DCB process has been built upon the drone operation plan as the fundamental source of information on which to take decisions concerning DCB. As part of the experiments performed in the project, several criteria were tested which would need to be reflected as part of the operator's mission plan submission to the U-space system.

The drone operation plan is an angular element of the flight plan processing processes and the intended capacity and demand analysis. Throughout the project, the DACUS consortium developed an extended data model for DOP to incorporate information related to operational uncertainty, contingency planning and weather limitations of the vehicle. All DOP elements are formalized using the *JSON* standard to ensure interoperability. The relevant elements of the DOP that have been used in the DACUS experiments and are recommended for standardisation and regulation are the following:

DOP aspect	Field name	Data representation
Drone	Weight	[kg]
	drone class	Name of class

DOP aspect	Field name	Data representation
	drone type	Name of type
	Wind speed restriction	[m/s]
Operation	Expected start	[datetime]
	Expected end	[datetime]
	Operation type	Name of type
	Operation domain	Name of domain
Geospatial occupancy	Crossing datetime	[datetime]
	Point 3D	[lon,lat,height]
	Uncertainty	[meters,seconds]
Contingency plan	Phase	[initial coord., end coord.]
	Contingency type	Name of type
	Contingency strategy	Array of procedures and measures

Table 6: DOP information relevant for performing DCB in U-space

Finally, with regards to the regulation, one of the changes identified is that DACUS does not applied the FIFO principle identified in 2021/664 regulation to ensure fairness and equity in decision-making when implementing DCB measures.

3.3 Plan for next R&D phase (Next steps)

In addition to the recommendations for further research already mentioned along the document, the next step should address the short-term implementation of the Dynamic Capacity Management service. For that, two approaches could be followed:

- Identification of a set of areas of the U-space airspace or components of the U-space network that should be monitored to search for imbalances. Some examples could be high-speed tubes, highly populated areas or vertiports. DCB measures associated to each element could be pre-defined and implemented in case of imbalances.
- Divide the entire U-space airspace into cells of a grid, without the need of previously identifying the areas or components where imbalances could exist. It prevents the risk that future drone demand could be highly dynamic, but at the same time, it is more complex to implement.

Additionally, some aspects need to be consolidated, such as:

- The criteria to determine when a collision or a social impact hotspot exists.
- The acceptable threshold for the social impact model.
- The size of the cells in a grid covering the entire U-space airspace.

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[4] DACUS, Trajectory Management Framework, D2.2, 00.01.01, 09/07/2021.

[5] DACUS, Support to operations, D2.3, 00.01.01, 09/07/2021.

[6] DACUS, AI demand prediction models, D3.1, 00.01.00, 18/05/2021.

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4.2 Project Publications

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[23] DACUS' Twitter: https://twitter.com/dacus_research

[24] Publication of paper “Towards a continuous Demand and Capacity Balancing process for U-space". SESAR Innovation Days (SIDs) 2020.

[25] Publication of paper “UAV collision risk as part of U-space DCB”. SESAR Innovation Days (SIDs) 2021.

[26] Publication of paper “A Drone Operation Plan model to support the effect of uncertainty in advanced U-Space Capacity Planning Process”. EASN Conference 2022.

4.3 Other

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

Appendix A

A.1 Glossary of terms

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

Table 7: Glossary

A.2 Acronyms and Terminology

Acronym	Definition
ADS-B	Automatic Dependent Surveillance–Broadcast
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management

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Acronym	Definition
BVLOS	Beyond Visual Line-Of-Sight
CIS	Common Information Service
CNS	Communication, Navigation and Surveillance
CONOPS	Concept of Operations
DACUS	Demand and Capacity Optimisation in U-space
DCB	Demand and Capacity Balancing
DCM	Dynamic Capacity Management
DOP	Drone Operation Plan
DTM	Drone Traffic Management
EGNOS	European Geostationary Navigation Overlay Service
ER	Exploratory Research
EVLOS	Extended Visual Line-Of-Sight
FIFO	First In First Out
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
KPA	Key Performance Area
KPI	Key Performance Indicator
MTBF	Mean Time Between Failures
PU	Public
RAIM	Receiver Autonomous Integrity Monitoring
RTTA	Reasonable Time To Act
SBAS	Satellite-Based Augmentation Systems
SESAR	Single European Sky ATM Research
SORA	Specific Operation Risk Assessment
TLS	Target Level of Safety
TRL	Technology Readiness Level
TOLA	Take-off and Landing Area
UA	Unmanned Aircraft
UAM	Urban Air Mobility
UAS	Unmanned Aerial System

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Acronym	Definition
UAV	Unmanned Aerial Vehicle
USSP	U-space Service Provider
UTM	UAV Traffic Management, Unmanned Traffic Management
VALR	Validation Report
VLL	Very Low-Level
VLOS	Visual Line-Of-Sight
VTOL	Vertical Take-off and Landing
WP	Work Package

Table 8: Acronyms and technology

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Appendix B U-space DCB processes

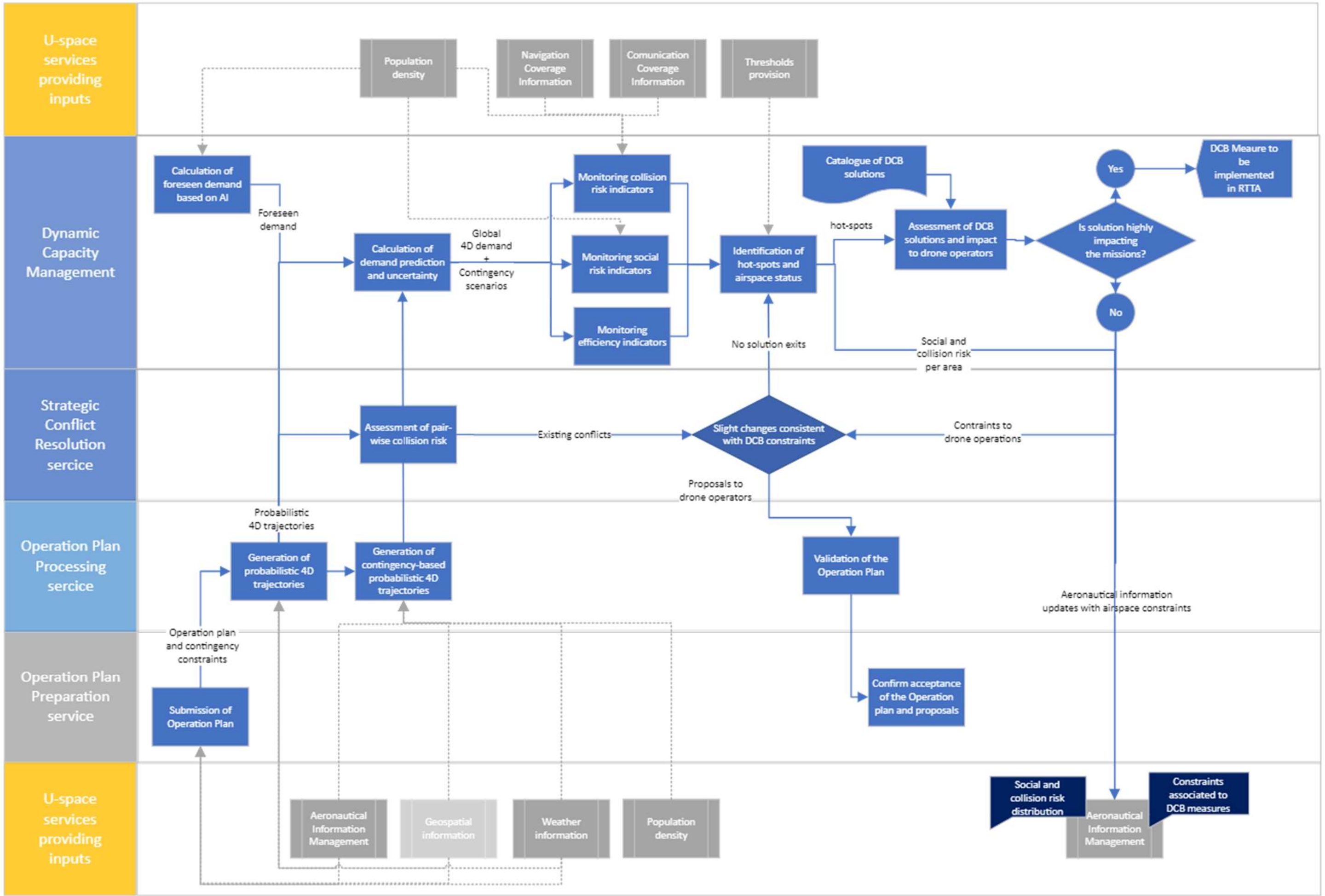

Figure 7: Detailed DCB processes in the strategic phase

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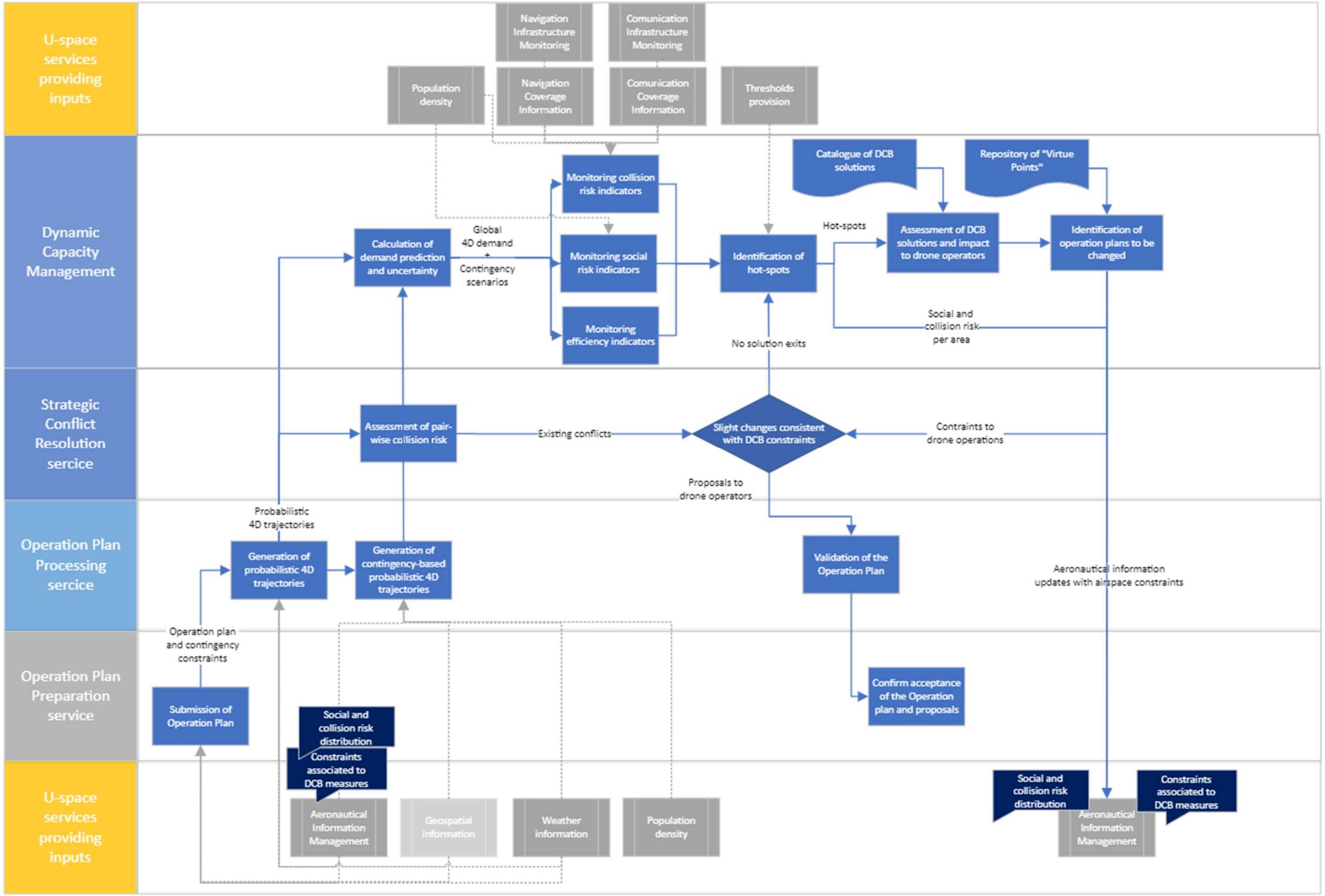

Figure 8: DCB processes in the pre-tactical phase

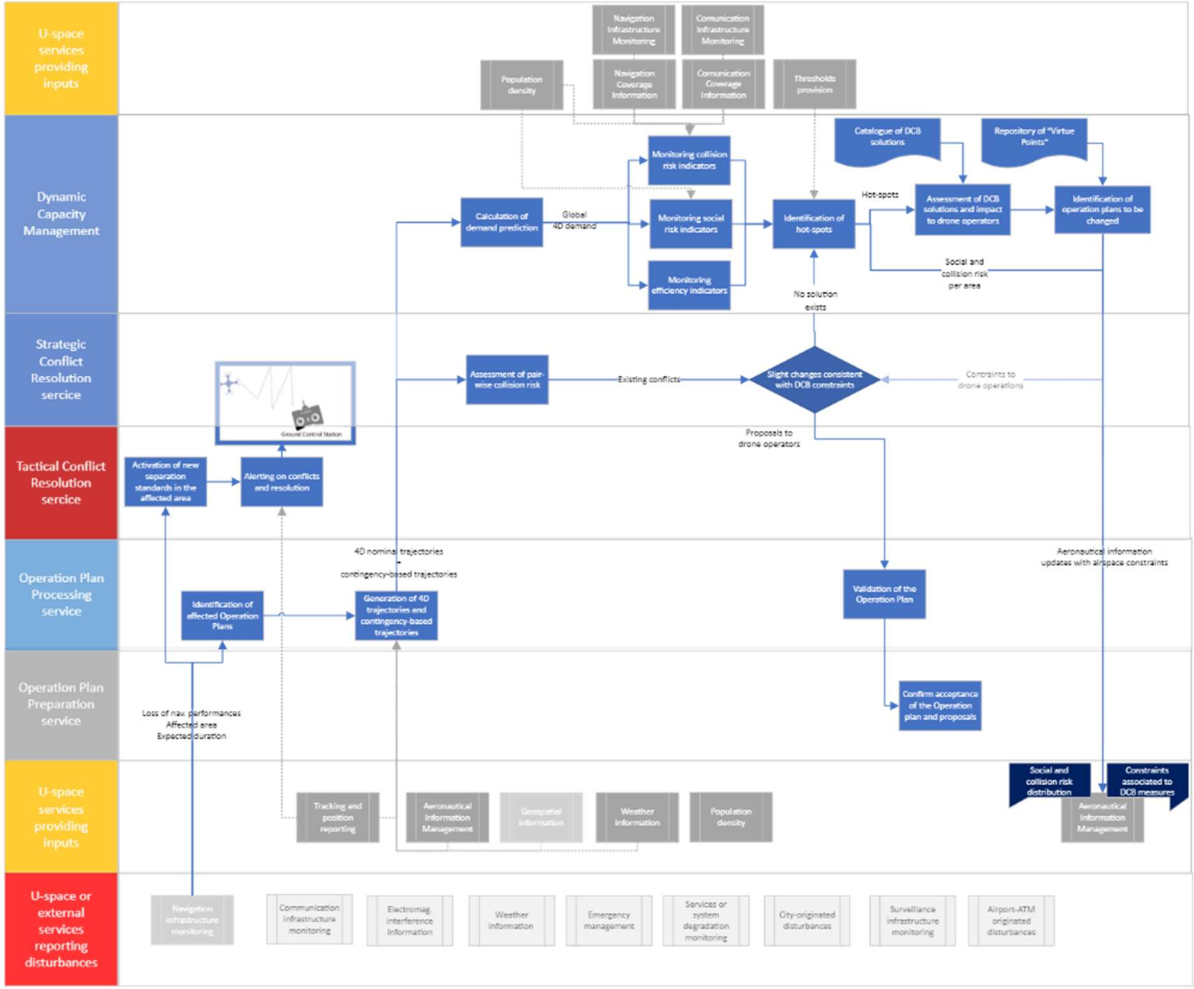

Figure 9: DCB processes in the tactical phase activated by the Navigation Infrastructure Monitoring