Towards a continuous Demand and Capacity Balancing process for U-space

Innovative approach to implement dynamic separation criteria in Tactical Conflict Resolution and Dynamic Capacity management services as part of the U-space ecosystem

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Abstract— **The paper proposes an innovative approach to implement performance-based separation for tactical conflict resolution purposes by integrating multi-parametric and dynamic criteria into an algorithm that is based on the principles of the Field Theory. A laboratory-based experiment allowed testing this Tactical Conflict Resolution service embedded in a digital environment, which was equivalent to the principles of the U-Space framework and resembled the other interconnected services. The results indicated that a procedure that adapts separation individually is effective to handle multiple drone operations in the same airspace, but at the prize of reducing the overall efficiency of the drone missions.**

Finally, the paper details how the performances of the Tactical Conflict Resolution service will impact on the envisioned U-space Demand & Capacity Balancing (DCB) process that will integrate in a consistent solution the relevant demand and capacity influence factors, boundary conditions such as airspace structures or regulatory framework, and other U-space services which are involved in this process from the strategic to the tactical phase.

This research was conducted under the IMPETUS project (Grant 763807) supported by SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme. IMPETUS aims at investigating the information management needs of U-space and design and validate solutions based on the microservices paradigm. The IMPETUS consortium is formed by CRIDA, ALTITUDE ANGEL, INECO, JEPPESEN, TU Darmstadt, C-ASTRAL and Boeing Research and Technology Europe. The project has finished in 2020.

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Keywords-component; Demand and Capacity; drone; U-space; Architecture; Services.

NOMENCLATURE

U_{att}	The attractive potential
U_{rep}	The repuslive potential
F_{att}	The attractive force
F_{rep}	The repulsive force
F_{total}	The resultant force of the attractive and repulsive force
ξ	The scaling factors of the attractive potential, $\xi > 0$
η	The scaling factors of the attractive potential, $\eta > 0$
ρ_0	The scope of the repulsive potential, $\rho_0 > 0$
P	The UAV Position
P_{dest}	The destinations position
P_{opp}	The opposing object's position
$\rho(P, P_{opp})$	ρ(Pa, Pb) = ||Pa–Pb||, the distance between Pa and Pb

I. INTRODUCTION

Services rendered with drones are expected to have a huge economic impact in the coming years. Possible commercial applications range from rural operations in agriculture, to last-mile parcel services and support of governmental tasks in public safety and security. But, despite great administrative and technical advances, the industry is yet to reach its full potential [1, 2]. Besides regulatory challenges, one of the key enablers necessary for a successful integration of high number of drones into low-level airspace is the provision of an effective European Union-wide drone ecosystem [3]. Therefore, the SESAR Joint Undertaking (SJU) has defined a framework, which is designed to support the development of the European drone industry and guarantee safe and efficient operations in all environments: the U-Space [4].

SJU defines it's Blueprint as "a set of new services relying on a high level of digitalisation and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones" [4]. U-space is not a fully defined end-to-end solution but rather a framework for the continuous development of new services. The Blueprint and the European ATM Masterplan [5] foresee up to four steps for the progressive deployment of the U-space services with gradually increased capabilities, ranging from U1 to U4 services. The so-called U-space advanced services – U3 – will support complex drone operations in dense areas thanks to the implementation of three relevant services: Collaborative Interface with Air Traffic Control (ATC), Dynamic Capacity Management and Tactical Conflict Resolution. This paper addresses this last service and the relation with the previous one to design a continuous Demand and Capacity Balancing (DCB) process for U-space.

Tactical Conflict Resolution by definition refers to the airborne vehicles whereas Dynamic Capacity Management starts in the flight planning and preparation phase before takeoff [6, 7].Thus, Dynamic Capacity Management interacts with the Tactical Conflict Resolution and with the Strategic Conflict Resolution service also. Complemented with on-board conflict avoidance mechanisms such as detect-and-avoid, these services are essential for ensuring a permanent separation of aircrafts [8] and therefore decreasing air and ground risk [9] during operation.

However, a number of challenges arise from highly automated Unmanned Aircraft System Traffic Management (UTM) frameworks in general and the provision of the described services in particular. As Vacik and Hansman [10] identified in their research, traffic management systems for drones need to be scalable to handle different volumes of traffic, provide a demand-based availability of infrastructure and take into account measures that encourage the community acceptance of Urban Air Mobility (UAM). Furthermore McCarty et al. [9] highlighted that it remains unclear "how the proposed data and information services are integrated and implemented in order to: address risk, model airspace and manage high volumes of drone movements." Especially in terms of detailing the strategic and tactical deconfliction scenarios, they still see the need for further investigations. And again, Vacik and Hansman [10] emphasize on the operational problems that arise from a mismatch of demand and capacity of the system.

Actually, most of the proposed UTM concepts of operations around the world recognize the challenge of implementing a continuous DCB process to support operations as the number of drone operations increases. This process will have major differences with respect to the DCB in the current Air Traffic Management (ATM) systems due to the wider diversity of business models, aircraft types and the envisioned Communication, Navigation and Surveillance (CNS) technologies in the drone market among other reasons. Future UTM concepts of operations visualize the need of re-designing this process taking into account these particularities. Thus, Federal Aviation Administration (FAA) UAM concept [11] reserves the right to increase individual aircraft operational performance requirements in order to optimize the capacity utilization of the airspace structure. FAA and Swiss U-space Implementation (SUSI) UTM concepts [12, 13] suggest the design of equitable airspace configuration solutions to optimize airspace equity and access and resolve demand and capacity imbalances. The U-space concept proposed by the CORUS consortium provides further details on the envisioned DCB process and the increase in flexibility of the process in comparison with ATM. Thus, CORUS [14] states that hotspots - areas with imbalances between demand and capacity - may trigger a revision of traffic organization schemes at short notice; for example, implementing speed-controlled zones. CORUS also proposes that longer-term demand trends might lead to changes in the technical requirements for the airspace concerned; for example, higher precision tracking and navigation performances may allow closer spacing between aircraft and may be mandated for a volume that is frequently subject to demand regulation measures. In addition, CORUS also identifies the U-space services which should be part of the DCB process and the interactions among them, with special emphasis on the close relation between the Tactical Conflict Resolution and the Dynamic Capacity Management services. CORUS explains that the level of confidence in how well the Tactical Conflict Resolution service will work can match to the difficulty of the task the service faces by limiting the number of flights in a particular volume of air, which is the job of the Dynamic Capacity Management service.

In this paper, we present a technical solution, developed by the IMPETUS project, for the design and implementation of the Tactical Conflict Resolution service and how this service may impact the overall DCB process. In addition, we explore how this U3 service will be interconnected and interact with the rest of U-space services. To design the technical solution, we implemented algorithms that integrate dynamic separation criteria with the field theory. To address the interactions between services, we designed a services-orientated architecture based on a microservices implementation approach. Simulation experiments allowed assessing the applicability of the solution and the proposed architecture. Moreover, we raised conclusions that are relevant for the improvement of this service as a relevant component of the DCB process and the supporting architecture. Finally, taking into consideration these conclusions, we detail the next steps towards the development of a continuous DCB process from the strategic to the tactical phase. This research will be performed by the recently started DACUS project.

II. STATE-OF-THE-ART

Today, all drones operate under the same operating conditions defined by their level of certification, regardless of their actual mission [15]. This operating method hinders the growth of drone operations. Mission-adaptive traffic management services need to be in place in order to facilitate drone operations in the future. The proposed services should use information stored in a registration system to influence the flight plan approval process through performance & permission-based airspace access and dynamic separation criteria. Drone capabilities, equipment levels and exemptions should determine access to the airspace. Separation criteria should be based on maneuvering capability and mission constraints. This way, drone operators should only need to equip their drones for the operating areas and missions they attempt to fly.

Among the plethora of possible methodologies to address previous ideas, Geister et Korn propose in a recent study to model each airspace user by an ellipsoid considering drones design, performance and capability aspects [16]. They foresee potential benefits to safely and efficiently organize the U-space airspace; however, they are not quantified thought experiments. To this respect, we have found that the utilization of field theory for distributed control in conflict scenarios has been treated in previous research. Sigurd et How investigated the feasibility of a total field sensing approach of magnetic nature as an alternative to approaches where each vehicle needs to know the positions of the other vehicles [17]. While they assess the developed algorithm in a series of simulations, it remains unclear how the technique can be applied to real drone systems with different navigation performances.

A. Potential Field Theory

Among the plethora of possible methodologies to address previous ideas, Geister et Korn propose in a recent study to model each airspace user by an ellipsoid considering drones design, performance and capability aspects [16]. They foresee potential benefits to safely and efficiently organize the U-space airspace; however, they are not quantified thought experiments. To this respect, we have found that the utilization of field theory for distributed control in conflict scenarios has been treated in previous research. Sigurd et How investigated the feasibility of a total field sensing approach of magnetic nature as an alternative to approaches where each vehicle needs to know the positions of the other vehicles [17]. While they assess the developed algorithm in a series of simulations, it remains unclear how the technique can be applied to real drone systems with different navigation performances.

The underlying and comparable principle that has been utilized for the solution discussed in this paper is known in robotics by the name of Artificial Potential Field theory (APF) [18, 19]. In analogy to the mathematical description of potential fields in electrostatics, it uses the fact that fields bearing the same electric charge repel each other whereas dissimilar charges are resulting in an attractive force instead. The main equations needed for this approach can be summarized as follows (1)-(5):

$$\boldsymbol{U}_{att}(P) = \frac{1}{2}\xi\rho^2\,(P, P_{dest}) \tag{1}$$

$$\boldsymbol{U}_{rep}(P) = \begin{cases} \frac{1}{2}\,\eta\left[\frac{1}{\rho(P,P_{opp})} - \frac{1}{\rho_0}\right]^2 & \rho\big(P,P_{opp}\big) \le \rho_0 \\ 0 & \rho(P,P_{opp}) > \rho_0 \end{cases} \tag{2}$$

$$\boldsymbol{F}_{att}(P) = \xi\rho(P, P_{dest}) \tag{3}$$

$$\boldsymbol{F}_{rep}(P) = \begin{cases} \eta\left[\frac{1}{\rho(P,P_{opp})} - \frac{1}{\rho_0}\right]\frac{1}{\rho^2(P,P_{opp})} & \rho\big(P,P_{opp}\big) \le \rho_0 \\ 0 & \rho(P,P_{opp} > \rho_0 \end{cases} \tag{4}$$

$$\boldsymbol{F}_{total} = \boldsymbol{F}_{att} + \boldsymbol{F}_{rep} \tag{5}$$

The forces $\boldsymbol{F}$ resulting from the equations are then used to navigate the drone by attempting to minimize the potential $\boldsymbol{U}$ over time, taking into account the position $\boldsymbol{P}_{opp}$ of opposing drones or obstacles (6):

$$\text{minimise} \int \boldsymbol{F}_{rep}\,(P)\,dt \qquad for\ all\ P \,\epsilon\, P(t) \tag{6}$$

For the navigation to be successful the potential field needs to follow the two constraints:

- It needs to decrease smoothly with distance to the target position $\boldsymbol{P}_{dest,}$ i.e. the closer the drone is to the destination, the lower its potential.
- It needs to rapidly increase with distance to the opposing obstacle at $\boldsymbol{P}_{opp}$, such as other drones or restricted areas, i.e. the closer the drone is to either another drone, manned aviation or no-fly zone, the higher its potential.

This leads to the desired effect that drones are approaching their destination with a continuous attractive force, being repelled strongly by other drones nearby while drones that are far away have no effect on each other. The implementation presented in the following sections advances these concepts to tailor a solution for conflict resolution in the tactical phase.

B. Microservice-based architecture

Furthermore, another relevant aspect to consider in the implementation and deployment of interconnected services is the underlying architecture. U-space can be seen as a highly complex system of systems, which will need to be agile and readily available. Microservice-based architectures provide the flexibility required for rapid and agile increments of the systems [20]. Microservices are characterised by being small, self-contained units of execution with well-defined Application Programming Interfaces (API). Each microservice is decoupled from the rest, deployed individually and has a fully automated lifecycle [21]. This allows for a rapid scaling of the overall system to meet demand. This type of architectures for distributed systems has been widely use in other fields.

III. SOLUTION

As core of the Tactical Conflict Resolution service, IMPETUS proposes to manage interactions between dynamic volumes around individual drones through the definition of separation criteria that adapt the safety buffers around drones. Therefore, the drone performance, degree of autonomy, local CNS parameters and environmental factors, such as weather and airspace characterization, are factors to determine the size and shape of those buffers. Such multi-parametric dynamicity would greatly improve airspace utilization, however at the price of higher complexity in air traffic management solutions and, in some cases, higher capabilities of vehicles operating in the airspace.

IMPETUS goes a step further by integrating principles of field theory and the dynamic separation criteria into a joint algorithm (in the following referred to as Field Theory Algorithm) to establish a standard size and shape of a field around individual drones. The size and shapes of the fields change to mimic differing types of operations, such as emergency operations. This concept consists of adding virtual “weights” to each drone depending on a series of characteristics, which in turn define the separation criteria.

Conflict resolution was achieved by having the drones’ vector away from the drone they conflict with. The amount they rotate/turn rate was determined by a "time to impact", where the sooner the objects will collide, the more they will turn. These instructions were only sent for drones that are "approaching" others, for instance at an angle or head on. If they are not determined to be approaching the drone they conflict with, then they will take no action. For example, two drones in a line travelling in the same direction will conflict with each other, but only the one behind will receive instructions, since the one ahead has no conflict in front. Where a drone conflicts with many other drones, the Field Theory algorithm determines which other drone (that it was approaching) was furthest to its right, and then turns right around it to avoid it.

To address the interactions between services, IMPETUS implements the U-space ecosystem through a microservice-based architecture. In particular, we developed and tested mechanisms for service orchestration, including real-time service-discovery instruments to identify available services and their locations. We designed a Discovery Service, which essentially provides a look-up for available U-Space Services and keeps a categorisation of data providers.

On the other hand, it was important to consider geographic separation of the services provision and the effects that this will have on replication needs, disaster recoveries and latency during failover. We designed our service architecture through a cluster of nodes. Each node is a server or service instance. The cluster, through its nodes, will service incoming requests to manage load and support high availability. This design allows managing failures of individual nodes in a deterministic manner.

IV. METHODOLOGY

The IMPETUS experiment tested the applicability of the previously described solution for the Tactical Conflict Resolution service and how this service is impacting the DCB process in the tactical phase. In particular, we tested the

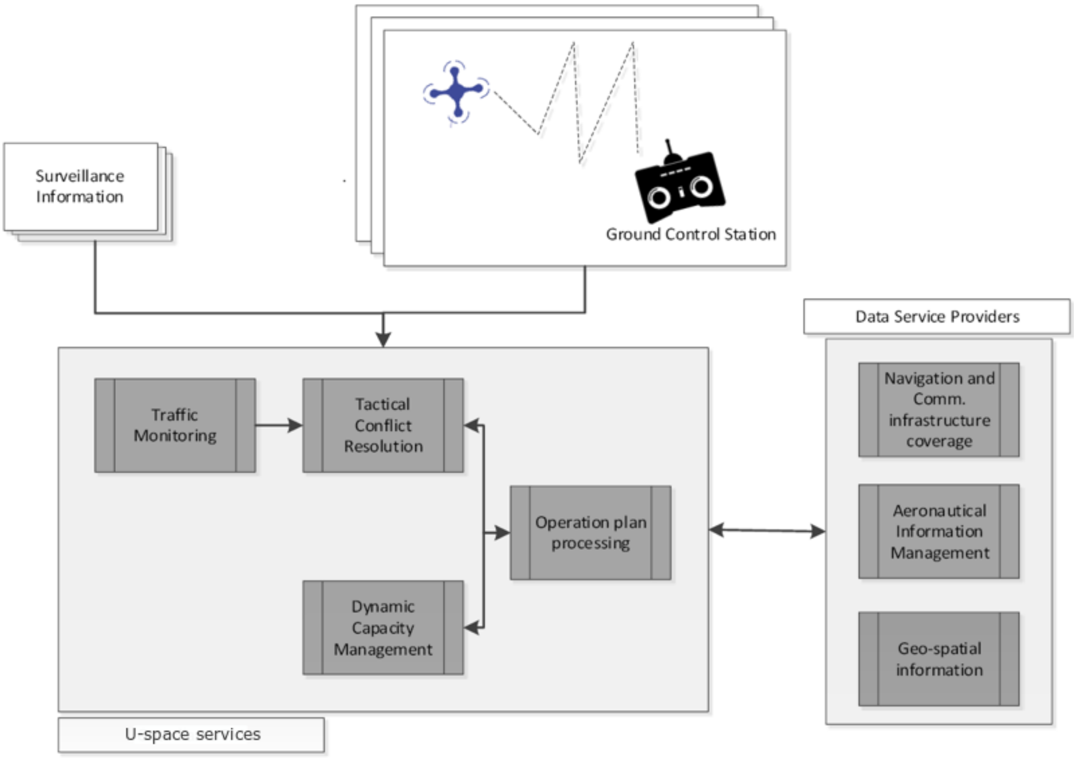

Figure 1. Scheme of the services involved in the experiment

applicability in dense areas of dynamic separation criteria based on drone performances and how to deal with diverse and multiple changes that can be received during the execution phase and are affecting the approved flight plans and the capacity limits in a certain area. Additionally, we also explore how this service interacts with the other U-space services.

A. *Description of the Experiments*

Figure 1 shows the interactions between U-space services. A safety-critical service such as Tactical Conflict Resolution service requests information to diverse data service providers – Navigation and Communication Infrastructure Coverage, Aeronautical Information Management and Geospatial Information.

Field Theory algorithm provided navigation assistance to simulated vehicles to dynamically adjust their flight paths. For the sake of the experiments, initial flight plans were designed to conflict in order to test the performances of the Tactical Conflict Resolution service. The algorithm generated one instruction per second (configurable) to each vehicle in conflict. Instructions were commanded repeatedly until a change in the course was observed and then refreshed until the conflict was resolved or a loss of separation event occurred.

A field with a baseline size and shape was assigned to each of the drones within the simulation environment. Individual fields were then adjusted to mimic the characteristics of differing types of operations and associated separation requirements through the use of weighted metrics. Figure 2 depicts the factors which are considered in determining the weights. The higher the weight of the metric, the stronger the positive field of the drone, and thus the larger the separation minima.

Figure 2. Scheme of the factors which are considered in the Field Theory algorithm

The model functions in 3-dimensions however for the purposes of the experiments, the visualizer is shown in 2-dimensions,

Apart from testing the applying of the Field Theory algorithm to dynamically de-conflict drones, the aim of the experiment was also to identify how the solution would fare from an architecture design standpoint. Given that Tactical Conflict Resolution service is safety-critical, we tested its tolerance to diverse types of failures. In particular, we tested the failure of a node and the failure of a cluster of nodes. Finally, we tested if the architecture was able to adapt to the failure of other services that Tactical Conflict Resolution is dependent on, by switching service providers or increasing drones' separation to the maximum level, while it recovers.

B. *Objectives of the Experiments*

Two high-level objectives were addressed by the experiments:

1) *Objective 1:* Assess the impact of conflict detection and resolution based on the Field Theory algorithm on the efficiency of drone missions. Drone operations will be affected by conflicts with other drones and by new airspace restrictions during the execution phase.

2) *Objective 2:* Assess the impact of failures of dependent data service providers on the performance of the Tactical Conflict Resolution service. We tested the ability of the system to switch data providers and the recovery time.

C. *Validation Scenarios*

The area covered by the experiment is a rectangular bounding box with the North West coordinate 51.46353 degrees North, -1.07561 degrees West and 51.40382 South, -0.94549 East respectively. The service was able to manage up to a maximum of 1,000 concurrent operations within this fixed area of approximately $60km^2$, i.e. 16 drones per km^2, and with at least one conflict per drone flight plan.

Tactical Conflict Resolution service was designed with automatic monitoring by an independent set of software components (on independent cloud infrastructure). This separation between production systems and monitoring systems provides a more robust monitoring and alerting solution.

For the purposes of these tests, we introduced various cylindrical airspace restrictions from $2km^2$ to $10km^2$, and studied how the traffic reacted.

During execution, each simulated drone was given a pre-determined origin and destination coordinate within the boundary. Also, each drone had its characteristics configured in accordance with the 'weights'. Drone missions were set semi-randomly, in a manner that they would cause conflict with another drone at some point, in order to stress the system. The numbers of drones were progressively increased.

Altitude Angel's existing GuardianUTM technology was used to perform these experiments. This platform was the state of the art at the time of the execution of the exercises. From this, Altitude Angel built a technical proof of concept to test performance-based separation based on Field Theory algorithms. This was one of the four experiments performed by the IMPETUS consortium which tested the deployment of U-space services with microservice-based architectures. [22, 23]

V. RESULTS

A. Objective 1: Conflict detection and resolution based on the Field Theory algorithm

We have observed that the Tactical Conflict Resolution service managed the simulation area using the dynamic separation criteria without having any loss of separation incident. In 100% of the simulated cases, drones were able to arrive at their destination with a 0% rate of separation losses. This was the case even for the highest number of concurrent drone operations, around 1,000 vehicles at the same time.

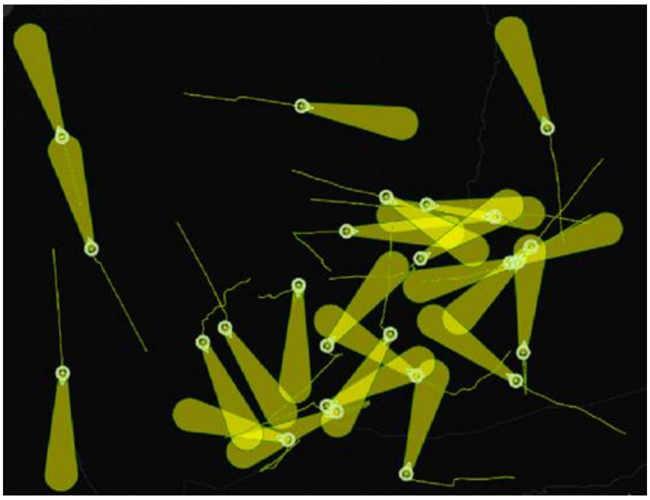

Figure 3. Simulation environment with conflict resolution areas per drone operation

Tactical Conflict Resolution service did not instruct any maneuver that the drone was not able to perform safely, both in the case of rotor-based drones and in the case of fixed-wing drones. In the experiment, we assumed a split of 75% rotor-based and 25% fixed-wing drones, accelerating gradually over a period of 15 seconds up to a maximum speed of 25 m/s for fixed wings, and 20 m/s for rotor-based. This remained constant until the drone decelerated in the final 50 m of its approach to its waypoint, where it decreased linearly to 0 m/s.

Whilst it is noted that this number of drones could be increased further before having unmanageable number of conflicts, the efficiency of each of the affected drone missions decreased when the conflict number increases. The following graph shows the decrease of the mission efficiency with the number of operations. Mission efficiency did not drop below 72%, yielding a maximum route deviation average of 22% for the previously described traffic density. We observed that it would be counter-productive for the mission efficiency to allow more traffic even with the ability to ensure separation.

On the other hand, when new airspace restrictions of different sizes were added progressively, the Tactical Conflict Resolution service was able to identify every drone to which new airspace restrictions applied during the execution of the mission and re-route.

As an example, Figure 5 shows four drones which were affected by a dynamic temporary flight restriction (only known after the commencement of each mission). All four drones took actions to exit the restricted area. Based on the rules assigned, two drones were able to quickly exit the area. This deconfliction did not significantly disrupt their missions due to their locations. On the contrary, the other two drones had to exit through a non-efficient path although they were able to find alternative trajectories to their destination in the simulation.

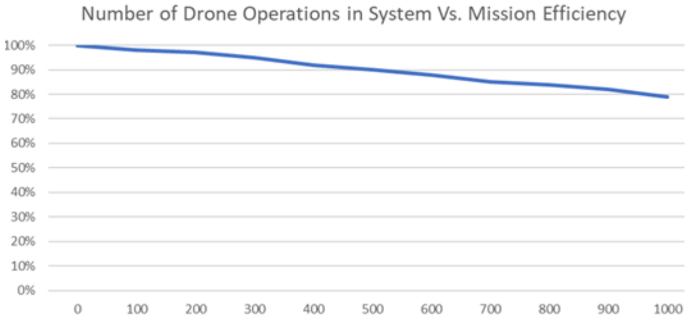

Figure 4. Graph shows average drone operations efficiency as number of drones managed increases

In general, whilst in all cases the Tactical Conflict Resolution service was able to re-route the drones to comply with new airspace restrictions during the flight execution, there will be examples in the real world where the efficiency or even the mission feasibility can be questioned.

- Obviously, when the mission destination or compulsory waypoint was within the temporary restriction, the mission became unfeasible until the lifting of such a restriction.
- As a result of a re-routing, based on the real world circumstances, which were not simulated e.g. drone endurance

Figure 5. Visualization of a new flight airspace restriction and all airborne drones within this region exiting the restricted zone

B. Objectives Failures of Dependent Data Service Providers

In our cluster of nodes, several types of failures were initiated, in order to test the different automated mitigation actions facilitated by the IMPETUS architecture solution for U-space.

In our first experiment, we observed that it was possible to automatically de-provision and provision of a new node member in the same cluster in case of failure of a node or an individual subsystem upon which a node is reliant. For example, Tactical Conflict Resolution service was deployed in a four-node cluster and no capability was lost with removal of 25% of the nodes in a state of 70% total load.

We also tested a situation in which the entire cluster fails. Consequently, the re-instantiation of a new cluster was required. We concluded that cluster failures were harder to recover in case of safety-critical services such as Tactical Conflict Resolution service because the time to recover was between one to two minutes. This should be mitigated by deploying multiple clusters for the same service.

Finally, we also tested the failure of a dependent data service, To solve this failure mode, we had a categorization system of data providers. For example, weather data is regarded as a lower priority to connections to ADS-B data feeds or the NOTAM system. During the degradation period, the Tactical Conflict Resolution service itself was able to fall back into a pre-defined degraded state, which increased dynamic separation to an acceptable level based on a worst-case scenario. Through the Discovery Service, it was possible to 'call-out' to see if any alternative data source exists at regular intervals during this degraded performance scenario, and switch to them automatically.

VI. CONCLUSIONS

We proved the applicability of a solution to implement **dynamic separation criteria as an essential elemen**t of the U-space Tactical Deconfliction Service in high density environments. These dynamic criteria allowed quantifying the 'weight' of each single drone operation taking into consideration multiple factors such as CNS performances, mission types or drone characteristics, among others. In contrast to other time-based solutions that rely on the drone capabilities to maintain the separation, this performance-based separation solution is based on the provision of U-space services on the ground. The 'weights' used in the experiment were conservative, assuming that safety is the key driver of the separation provision. **These 'weights' could be decreased** as higher degrees of certainty and confidence is built in the data feeding the U-space ecosystem, as well as those to services used to communicate with drone operators or the drones themselves.

The diverse factors that are impacting that dynamic management of separation provision through a capability-based schema such as drone speed, mission priority, electronic conspicuity or weather data quality among others make no possible to provide separation with the human as the central actor in the process. Thus, a system of a very high level of **automatization is unquestionably the right approach** to implement the future U-space in high density environments.

The Field Theory algorithm required some adaptation due to edge cases where drones were taking unexpected deviations as part of their tactical conflict resolution actions. These adaptations primarily focused on **adding additional strategic de-confliction recalculations** where tactical resolution was required in order to provide solutions that smooth the trajectories deviations.

There was a threshold in which the average mission efficiency started to decrease as the number of drone flights are increased within a defined area, Thus, there is a point where the airspace manager will need to decide on the capacity limit because some drone operations would no longer be feasible based on this drop in efficiency. Surprisingly, and contrary to ATM, the experiments showed that the maximum number of drones in high-density environments are **limited by the loss in mission efficiency and not by the increase in the number of potential encounters** to be solved. It is anticipated that the maximum number of drone operations in an area will be dynamic based on the factors highlighted throughout the experiments, and that the performance requirements for drones entering that area may also be dynamic for a given period in order to be able to increase the maximum number of manageable operations.

The **microservice-based architecture allowed detecting and absorbing failures in the system**, and also incorporating countermeasures able to react in real-time. We recommend using this architecture to implement a deterministic management of failure modes, which is beneficial for distributed systems such as the one conforming U-space services. This management is facilitated through the **Discovery Service** which allows treating differently and deterministically the failure of each service. Back-up services must be previously configured, especially for complex external services. In our case, if Tactical Conflict Resolution Service wishes to utilize Strategic Conflict Resolution service, the maturity of the standards and the variety of capabilities offered in such services make the integration more complex.

VII. NEXT STEPS

Our experiment explored the main principles that will guide the implementation of the Tactical Conflict Resolution. This service should be part of a continuous DCB process that will integrate in a consistent solution the relevant demand and capacity influence factors, boundary conditions such as airspace structures or regulatory framework, processes such as separation management and other U-space services which are involved in this process from the strategic to the tactical phase.

Figure 6 depicts a possible approach to the U-space DCB, highlighting the demand and capacity related processes and services. Also, we propose the integration of models that will allow improving the performance of some of these services through the use of Artificial Intelligence (AI).

DCB is performed iteratively beginning in a certain time before the start of the period of interest.

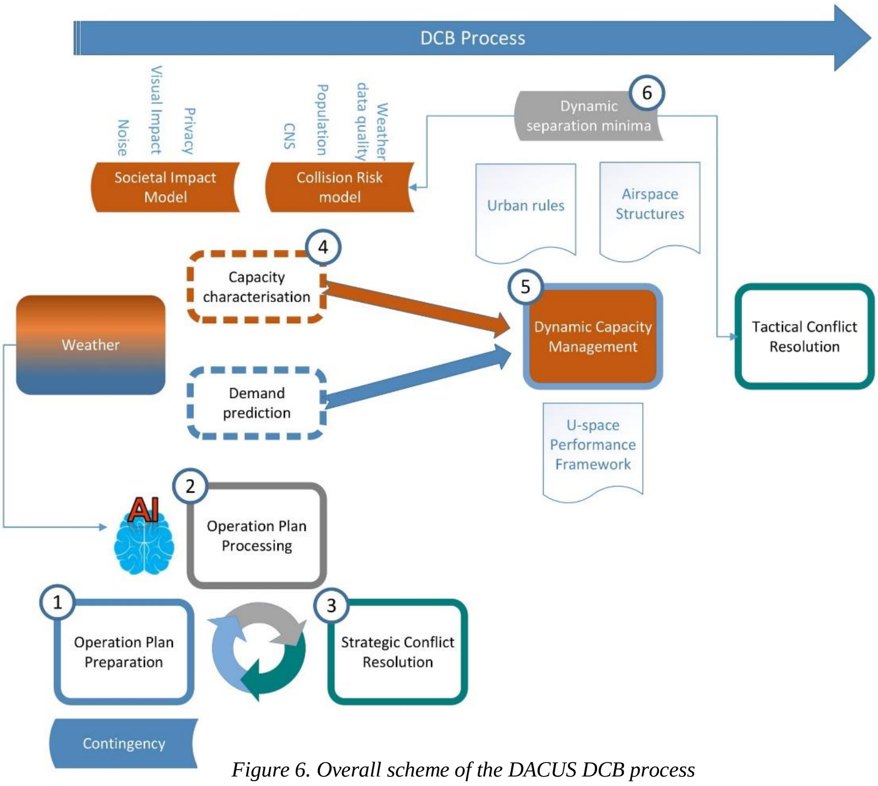

Figure 6. Overall scheme of the DACUS DCB process

(1) Initial demand prediction is based on the declared demand at the time of analysis. Operation Plan Preparation service integrates drone mission plans which account for a plan of one or a series of flights to achieve one business objective. Mission plans, which are closely linked to the business needs of the drone operators, include contingency considerations for the declared flights.

(2) Mission plans must be conciliated with the whole demand picture and particular restrictions / regulations known by the Operation Plan Processing service. A Demand Prediction model can be envisioned to take into account factors that might impact the declared demand, such as weather forecast. This AI should be able to learn from historical datasets with the response of diverse types of demand to certain scenarios.

(3) Strategic Conflict Resolution enters in play when the demand raises over a level that leads to conflicts between flight plans. This will allow strategically de-conflicting the drone flight plans in order to reduce the amount of tactical deconfliction actions, and therefore decrease the number of in-flight conflict resolutions.

(4) Capacity characterization does not necessarily mean to predict the number of operations allowed for a certain time period only, but rather to characterize the factors that will be the input of the capacity calculations of the Dynamic Capacity Management service. Some of these factors match with those which were studied in previous experiments. This is due to the fact that, as stated also by CORUS [14], the process to predict times in the future when an airspace will be full is related to the probability that flights lose safe separation, and thus, to how well Tactical Deconfliction service works. As an example, the provision of better CNS performances would allow reducing the ‘weight’ of some drones in the Field Theory Algorithm, and consequently, the number of drones could be increased in that area.

Two specific models can be envisioned to quantify the impact of these factors: A Collision Risk model and a Societal Impact model. The Collision Risk model will take into account all factors influencing the mid-air collision probability and severity, including contingency measures associated with the declared demand at the time, as well as other influence factors impacting the capacity such as the population density in real time. The Societal Impact model will also input in the picture environmental biases and social concerns related to noise, visual impact or perceived safety, among others.

(5) With inputs from the previous models and the airspace framework (applicable airspace structure and urban rules), the Dynamic Capacity Management service will evaluate if demand and capacity figures can be executed safely and efficiently. An estimation of the performance results of this process should also be considered, guided by a Performance Framework adapted to U-space.

(6) Dynamic separation minima criteria of the Tactical Conflict Resolution service interplay with the risk model, since they refer to pair-wise separation required between drones depending on drone capabilities, the expected CNS infrastructure performances and weather forecast.

DACUS project will design and validate this continuous U-space DCB process in diverse scenarios and conditions that will be foreseen in dense urban environments.

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