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IMPETUS

INFORMATION MANAGEMENT PORTAL TO ENABLE THE INTEGRATION OF UNMANNED SYSTEMS

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Abstract

IMPETUS D6.3 is the final report of the project. It details the work performed in the project as a whole, its technical deliverables and summarizes key results that were obtained in relation to information management 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 IMPETUS was to investigate and test information management solutions for U-space. The project identified the information needs of drone users by defining a drone information lifecycle that best supports the flight lifecycle of a drone. These then flowed into the development of a reduced set of U-space services in support of drone operations. The implementation of these services was based on the 'micro-services' paradigm, aiming at exploring lightweight decoupled services, with a clearly defined functionality and simple interactions. The services were tested in a series of experiments that reflected the nature of future drone missions and simulated expected quantities of service users. The experiments were elaborated in such a way as to obtain results on individual service functionalities, beyond the current state-of-the-art, as well as transversal results on safety, failure modes, scalability, flexibility, data management and economic feasibility, in order to draw conclusions on the U-space architecture as a whole.

IMPETUS project results showed that many of the 'apparently' big differences between air traffic management (ATM) and U-space have to do mainly with scale aspects –such as geospatial scales, scale of operational timeframes, scale of heterogeneity in vehicle types, performances, etc. – and not so much with the nature of the functions and services involved in the operational picture, which are in essence the same.

Concerning the U-space architecture, the project was able to elicit key features which would need to be implemented, such as a common infrastructure to interface with clients and exchange information across the ecosystem, a service discovery module to detect new services as they become available as well as authentication layers (for registering services, clients and data sources) and configuration layers (in which the rules of the architecture are defined). Results of tests on the micro-service architecture showed clear advantages over monolithic implementations, such as architecture robustness by design, resistance to failures due to continuous status monitoring as well as automated service failure mitigation actions.

Results of tests on individual U-space services showed many promising benefits of the concepts that were tested. For instance, the use of probabilistic micro-weather services for drones showed significant improvements over current, static weather forecast accuracy at 3h look-ahead time. Results on mission management showed clear benefits on mission trajectory optimisation using cost functions to help refine four-dimensional trajectories of drones. Concerning the management of drone flight plans a conflict-resolution scheme was tested and validated which would mitigate the need for centralised flight plan de-confliction. Finally, de-confliction of drones at a tactical level was tested and showed that a concept in which virtual "weights" are added to each drone, which in turn defined the separation criteria, was an efficient way to provide dynamic separation.

Results of the exercises were then translated into a series of conclusions on the service concepts and their technical feasibility as well as on service performance and maturity. Service concepts were mapped onto the architecture proposed in the U-space ConOps to highlight the conceptual processes for information management that IMPETUS devised for the services. Subsequent chapters identify discrepancies with the guiding master documents and suggest updates to the corresponding sections. Maturity assessments of the services summarize the current state of the service and provide a list of gaps that IMPETUS has identified. These gaps include the need to perform further tests in dense urban environments to improve weather prediction in these areas, additional tests on the effects of trajectory uncertainty in mission and flight planning and the requirement to perform additional safety performance, security and environmental assessments on the provision of dynamic capacity management services.

Finally, recommendations are provided concerning initiatives for standardisation and regulation on a service-by-service basis. Recommendations cover needs for standards on minimum service performance, level of safety, interoperability with other services and security as well as additional requirements for regulations. One of the most important findings is that current standards are sufficient for building up the U-space service architecture, which should rely on the use of existing SWIM data formats and common, open source communication protocols. However, it is important to define which standards should be used for inter-service communication and how these services should communicate. Therefore, we recommend the development of regulated interfaces with the core elements of the U-space architecture, which can be accessed through agreed data exchange protocols, as well as the provision of a regulated service discovery mechanism, through which approved U-space services can be identified.

1.1 Acronyms and terminology

The following acronyms are used in this document:

Table 1: List of acronyms

Abbreviation	Description
AMQP	Advanced Message Queuing Protocol
API	Application programming interface
ATM	Air traffic management
BADA	Base of Aircraft Data
BVLOS	Beyond visual line-of-sight
CFD	Computational fluid dynamics
CNS	Communication, navigation and surveillance
CPU	Central processing unit
DTM	Drone traffic management
GFS	Global Forecasting System
HMI	Human-machine interface
IoT	Internet of things
JMS	Java Message Service
KPA	Key performance area

Abbreviation	Description
METAR	Meteorological terminal aviation routine weather report
MOPS	Minimum operational performance standards
MQTT	Message Queueing Telemetry Transport
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to airmen
RAM	Random access memory
RMSTE	Region Management Simulation Test Environment
RTTA	Reasonable time to act
SESAR	Single European Sky ATM Research
SORA	Specific Operations Safety Assessment
SWIM	System-wide information management
TAF	Terminal aerodrome forecast
TDCF	Table driven code form
TFR	Temporary flight restriction
TLOS	Target level of safety
TRL	Technology readiness level
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
USSP	U-space Service Provider
UTM	Unmanned traffic management
VLL	Very low-level
VLD	Very large demonstration

2 Project Overview

This section provides a high-level overview of the IMPETUS 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

IMPETUS takes into consideration drone market needs and emerging information technology solutions to propose a cloud-based server-less environment based on the application of **the 'micro-services' paradigm to deliver a solution** which should be cost-effective, scalable and capable of enabling both market-based mechanisms for information provision as well as public governance and oversight required for safety and regulatory compliance.

Micro-services are characterised by being small, self-contained units of execution with well-defined application programming interfaces (API). Each micro-service is decoupled from the rest and deployed individually, having a reduced operational complexity. Micro-services have a fully automated lifecycle, allowing the scalability of the overall system to meet demand. They are designed to ensure that micro-service developers do not need to care about service placement or infrastructure specifics, ensuring security requirements. Developers are also free to choose whatever technologies make sense for the micro-service and there is no need of defining common standards for micro-services design and development.

SESAR defines U-space in the Blueprint [20] 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*". By this definition, and indeed all other proposed UTM implementations around the world, U-space is not a fully defined end-to-end solution but rather a starting point for continuous development. It is very clear that under the current roadmap**,** U-space will be a highly complex system of systems and is only going to become more so as research continues. Consequently, **the notion of breaking this down into simpler service is un-questionably the right approach**. Initially, a basic set of U-space services are likely to be built, however over time as the technology and capabilities develop, new services will be added, and existing services will either be upgraded or swapped out. For this reason, the ability for services to be independently deployed, will provide the flexibility required for rapid and agile increments of the overall U-space capability.

On the contrary, a micro-service architecture is also more complex to maintain, requires more effort on service management and raises unique challenges which do not apply to monolithic ones. This architecture needs **proper mechanisms for the micro-services orchestration**, including real-time service-discovery instruments to identify available micro-services and their locations. Additionally, it is necessary to maintain the **data consistency across multiple services** as this architecture is characterized by a decentralised data management in which they have their own private database and do not necessarily have access the database owned by the other micro-services. Also **failure modes which are impacting safety-critical services** and thus, safe drones' operations, need to be managed properly.

IMPETUS has tested the benefits and constraints of the micro-service architectures through four different laboratory-based experiments which addressed the U-space services defined in the following table.

In particular, the IMPETUS project contributed to the elaboration of the following U-space services:

Mapping Service ConOps Baseline 3	U-block	Coverage	Type of flight		Density of drones			Airspace	
		- Fully Covered - Partially Covered - Not covered	Altitude - VLL - Above (VLL) - All N/A	- Simulation - Flight Trials - Mix - N/A (none, ...)	Number of drones	Max. number of simultaneous flights	Type of drones: - Rotorcraft - Fixed wing or hybrid - Mixed traffic - N/A	- X - Y - Z - Mix - N/A	comments
Tactical Conflict Resolution	U3	Partially covered	VLL	Simulation	1000	1000	Mixed	Z	IMPETUS tested the applicability in dense areas of dynamic separation criteria based on drone performances which adapt the size and shapes of the safety buffers around drones, 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.
Monitoring	U2	Partially covered	All	Simulation	250	250	Rotorcraft	Z	Traffic Monitoring and Traffic Information services were tested together in a congested airspace in which most of the drone flight plans interacted with each other. Performance characteristics of these services within a microservice-based architecture were gathered from stress-tests on the data exchange processes between both services.
Traffic Information	U2	Partially covered	All	Simulation	250	250	Rotorcraft	Z	Traffic Monitoring and Traffic Information services were tested together in a congested airspace in which most of the drone flight plans interacted with each other. Performance characteristics of these services within a microservice-based architecture were gathered from stress-tests on the data exchange processes between both services.
Weather information	U2	Partially covered	All	Simulation	1000	1000	N/A	Mix	IMPETUS has performed two different kind of tests regarding a hyper localized weather service for drone operations. One kind was for stress testing the service with up to 1000 clients connected concurrently and the other was with a single client using fixed wing UAVs for testing operational benefits of the propoused approach. In the second case this service was used to provide probabilistic weather predictions for areas with size of only a few square kilometres. The benefits of this service to provide more robust mission, flight and traffic planning was showcased in a rural environment with moderate terrain elevation.
Operation Plan Processing	U2	Partially covered	VLL	Simulation	500	15/km²	N/A	Z, Y	Interaction of Operations Management and flight planning management in suburban areas integrating drone-specific aeronautical information, local-scale meteorological models and local meteorological measurements. Processes to ensure consistency between mission plan and flight planning was explored.
Operation Plan Preparation Assistance	U2	Partially covered	VLL	Simulation	500	15/km²	N/A	Z, Y	Interaction of Operations Management and flight planning management in suburban areas integrating drone-specific aeronautical information, local-scale meteorological models and local meteorological measurements. Processes to ensure consistency between mission plan and flight planning was explored.
Dynamic Capacity Management	U3	Partially covered	VLL	Simulation	1000	1000	Mixed	Z	IMPETUS tested the applicability in dense areas of dynamic separation criteria based on drone performances which adapt the size and shapes of the safety buffers around drones, 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.

2.2 Project Scope and Objectives

IMPETUS analyses the information management needs of drone operations in very low-level (VLL) airspace and it also propose a technologically and commercially feasible solution, which is based on the 'micro-service' paradigm, to address those needs.

The project's objectives can be summarized into two main areas:

1. The definition of a drone information lifecycle that best supports the flight lifecycle, to provide the users with knowledge and wisdom, which will ultimately lead to safe and efficient operations, with a view to defining a set of U-space[1] services that leverage the data.

2. The design and test of a technological solution to deliver these U-space services, addressing some of the challenges of the envisioned drones market: scalability to respond to multiple users with diverse business models, mechanisms to assure the data quality and integrity, and flexibility to progressive integration of new U-space services. IMPETUS proposed a cloud-based server-less environment based on the application of the 'micro-services' paradigm to deliver this solution.

2.3 Work Performed

The overall work performed by the IMPETUS consortium (and its results and conclusions) can be divided into three distinct phases: A drone information need identification and service concept elaboration phase, the elaboration of a logical and system architecture based on micro-services and the testing of specific U-space services through experiments. This is in line with the project scope and objectives defined in the grant agreement and covers some additional work which was necessary in the early phase of the project as some of the necessary U-space guidelines were being elaborated in parallel. The contents of this chapter, as well as the following, are divided accordingly.

2.3.1 Drone information needs and service concepts

In order to better understand the scope of requirements for drone information management, a bottom-up domain analysis was performed. The analysis was conducted through a stakeholders' survey, the evaluation of outlook studies, a description of existing UTM concepts and current information services for manned as well as unmanned aviation. Furthermore, we detailed **six use cases, which cover the most relevant operation types in rural and urban environment**: inspection, surveying and light load movement, with a focus on information exchange. The entire set of information was finally used to perform an initial gap analysis. **The types of information which are generally needed for drone operations were identified** and compared with the existing data services in manned aviation, the identified services of unmanned aviation that are currently available, the description of U-space services taken from the ATM Master Plan [21] and the particular users demand identified in the survey. Results of the overall process were detailed in D2.1 [2].

[1] Note that U-space services had not been defined when IMPETUS was granted.

Complementarily to the domain analysis conducted in D2.1, the methodological top-down approach adopted in D2.2 [3] was aimed at organizing all the information previously compiled into a coherent operating picture that reveals how drones are envisioned to be operated in U-space, what information is needed to support drone operations (and why), and how such information might be produced. To achieve these objectives, D2.2 performed the abstraction from the information collected in D2.1 of a 'generic drone operation lifecycle' that aimed at facilitating the harmonization of concepts and terminology, as well as the identification of the main actors, systems and functions playing a role in drone operations and, ultimately, of the **elements of information almost invariably needed/involved in drone operations**. As a second step, we addressed the elucidation of `conceptual drone information services' that could potentially become part of U-space to satisfy the information needs identified. In line with the objective of IMPETUS to contribute a long-term perspective to U-space, we have focused on **U3 and, to some extent, U4 services** –i.e. UAV of any type operating in a 'business as usual' mode, including air taxi in city environments and large UAV (e.g. autonomous air cargo) having to operate in manned airspaces. Thus this document provides reasonable answers to the questions above to a considerable extent of detail and completeness, and could allow designing those U3 and U4 services which were not fully addressed by the 'Concept of Operations for U-space' [22].

It is relevant to mention that **a list of requirements was extracted from D2.2** and included as an appendix of D3.1 [4]. These requirements are covering all envisioned U-space services and not only those selected for testing (described in the following section). IMPETUS also included the traceability of each requirement with the relevant section in D2.2.

2.3.2 Logical and system micro-service-based architecture

Based on the use cases previously identified in D2.1 [2] and the invariant information needs in drone operations from D2.2 [3], IMPETUS identified, described and characterized the **functional requirements of those U-space services selected for testing**. Detailed sequence diagrams were used to support the elicitation process. The selected services were:

- *Weather information* service, with focus on how a better knowledge of the uncertainty in the meteorological prediction will improve the robustness of trajectory-based decision making process;
- *Drone operational plan preparation assistance* and *drone operation plan processing* services, which guarantee the successful and safe adaptation of the initial submitted flight plan complying with the traffic management needs together with the mission targets;
- *Monitoring* and *traffic information* services, which are considered as automated services to process traffic information and show to the drone operators ensuring data quality and integrity;
- *Dynamic capacity management* service (and interdependencies with *tactical de-confliction* for drones), exploring the services which are needed to dynamically manage the airspace and the impact on the drones' trajectories in execution phase.

D3.1 [4] has also elaborated a logical architecture of U-space, identifying the **roles and responsibilities, the services involved[2] and the dependencies between services in the whole drone operations**

[2] Not only the ones proposed initially by the U-space Blueprint [20], but other services identified by IMPETUS consortium in D2.2 [3].

lifecycle. This IMPETUS logical architecture is based on a federated scheme, built around the idea of a layered distribution of responsibilities with a central actor which has a global view and the single point of truth of the airspace situation.

Additionally, D3.1 [4] proposed a technical architecture (using micro-service architecture as reference) capable of providing a solution not only to current needs, but also to future ones (scalability, cost-effectiveness, efficiency and security). The core modules, the mechanisms for the transmission of information between micro-services and the generic **requirements of such micro-service-based architecture** were described.

2.3.3 Experiments to test specific U-space services in a micro-service-based architecture

Individual U-space services were explored through several experiments by balancing the interests of the consortium members and the relevance of information management challenges that were previously identified. The services which were addressed are: weather information service, drone operational plan preparation assistance and drone operation plan processing services, monitoring and traffic information services and dynamic capacity management service in combination with a tactical de-confliction service.

The experiments addressed the requirements and challenges of the previously detailed U-space services and also transversally explored the benefits of a U-space implementation based on micro-services. All exercises provided inputs to better quantify the benefits of this implementation by **analysing whether the micro-service solution is scalable, secure, flexible and cost-effective enough to meet the U-space operational requirements**, whilst meeting all the safety requirements from an ATM perspective.

D5.1 [6] describes the experiments which the consortium intended to perform. Following the experimental plan defined in D5.1 [6] and considering the functional requirements so as the architecture framework from D3.1 [4], D5.2 [7] detailed to what extent the defined validation objectives and success criteria were fulfilled. This deliverable concluded with the technical and economic feasibility assessment of the simulated services and provided a series of recommendations.

2.4 Key Project Results

2.4.1 Drone information needs and service concepts

The bottom-up domain analysis performed in D2.1 [2] was focused on capturing users' needs and the characterization of data requirements through specific use cases. One initial conclusion from this study was that, although many UTM service providers already compete on the market, **they would benefit from a central U-space authority and harmonised structures throughout all of Europe**. Analysing the requirements more precisely by dividing them among the different types of generalized operations (surveying, inspections and point-to-point) indicated that differences in information demand are existing and capable of being differentiated.

Additionally, the gap analysis revealed that in **manned aviation similar information is available, but not always sufficient for a direct usage in drone operations**. Apart from the aeronautical data, most other information services would require higher fidelity information and/or additional service functions. Several gaps were also identified concerning some drone specific information categories, which neither existing data services in manned aviation, nor currently available UTM service providers covered.

D2.2 [3] was the result of bringing together all the information compiled bottom-up in D2.1 [2] with an analytical effort conducted top-down following the so-called 'domain invariant analysis' methodology. One major conclusion of the effort conducted was that many of the **'apparently' big differences between ATM and U-space have to do mainly with scale aspects** –such as geospatial scales, scale of operational timeframes, scale of heterogeneity in vehicle types, performances, capabilities and limitations, scale of affordability, scale of weather effects, scale of traffic volumes, scale of diversity of operations, scale of automation, etc. – not so much with the nature of the functions and services involved in the operational picture, which are in essence the same. This allowed for the elaboration of a paradigmatic 'drone operation life cycle' that largely resembles that of a manned aerial operation except for some specificities inherent to UAS.

One key of such specificities is the fact that the pilot, being remotely located, is deemed not to be able to safely handle safety-critical in-flight contingencies, which drives another major conclusion, that is the **inescapable need for autonomy**; however, any autonomous drone behaviour should be deterministic and predictable. It should not come with surprise that flight management autonomy is required for at least contingency management in an environment like U-space, where fully autonomous traffic management is advocated for capacity and affordability reasons.

Another specificity of drone operations is the concern about **security, privacy and insurance issues in addition to safety**, which drives the need for U-space to consider mission-specific aspects of drone operations to the extent needed to cope with such new concerns.

Diverse scale effects make it impossible in general that drones rely on the standard communications, navigation and surveillance (CNS) solutions that manned aircraft use, which drives the need to resort to non-conventional **CNS solutions whose performances will play a central role in any capability-based schema** that articulates drone access to airspace analogously to the performance-based CNS schema being adopted in manned aviation. Besides CNS, further elements of the capability-based schema are identified and discussed, an important one being contingency management.

Scale effects also require that the aeronautical, geospatial and weather information be significantly more detailed and diverse than the analogous information in use in manned aviation.

2.4.2 Logical and system micro-service-based architecture

D3.1 [4] showed the alignment between the needs of U-space (from both services and the different roles participating) and the objectives that an architecture built on micro-services aims to achieve (and that, using the proper configuration, can be implemented). The information processing capabilities, the high performance and the multiple connections between the consumers and data providers can be supported with an architecture based on micro-services in which each functionality can be atomized as estimated.

A key output of the project regarding micro-services was the **elaboration of a list of requirements for the U-space architecture and the elicitation of its key features**, which include:

- The capability of offering a common interface for clients and data sources based on a defined standard;
- The existence of a *common information exchange layer* which receives the information and, based on a set of predefined rules, redirected it to the proper consumer of information;
- The *service discovery module* in constant communication with the API gateway as a support to detect the new services available;
- A *service layer* in which containers are deployed, offering a certain functionality (or set of capabilities) in each module;
- The prerequisite that services' internal structures can be implemented using different business approaches, depending on the interests of the U-space service provider
- *Storage units* should be divided into a temporal cache for real-time processing, ensuring the availability of information and low latencies for crucial U-space services;
- An *authentication layer* must be provided, acting as a registration module in which the services, clients and data sources must be validated to be part of the ecosystem; and
- A *configuration layer*, in which the rules of the architecture are defined and the configuration parameters are set, so the system is capable of self-managing its own operation.

2.4.3 Experiments to test specific U-space services in a micro-service-based architecture

D5.2 [7] presents the results of four experiments performed to validate specific U-space services, exploring if the micro-service technology can be employed to cope with the key challenges of U-space. To validate the technical and economic feasibility of this solution, IMPETUS focused on specific research areas:

- Research on how to deal with the possibility of failure modes, which are affecting safety-critical services and thus, safe drone operations;
- Analysis of the impact on data management of an ecosystem of micro-services having their own private database in safe drone operations, and in particular the challenges of dealing with data quality and integrity;
- Research on the scalability of the solution based on micro-services taking into account the expected growth of drone operations;
- Research on the flexibility of the solution to assign computing resources as needed optimising the cost implications to the final U-space users;
- Analyse the commercial feasibility of a U-space micro-service architecture, with special focus on the business model and how to proportionally bill the services provided.

The following table shows how the exercises relate to the services defined in the current U-space ConOps [22]. Moreover, the level of relation is detailed as the exercises addressed services and capabilities to a different extent.

U-space services and capabilities		Exercise 1	Exercise 2	Exercise 3	Exercise 3
U1 services	Registration				Dependency
	E-identification				Dependency
U1 capabilities	E-identification			Dependency	Dependency
	Security				Dependency
	Telemetry				Dependency
	Tracking			Dependency	Dependency
	Command & control				Dependency
	Communication, navigation and surveillance			Dependency	Dependency
U2 services	Strategic Conflict Resolution		Moderate		Dependency
	Weather information	**Strong**	Moderate		Dependency
	Tracking			Dependency	Dependency
	Operation Plan Assistance	Moderate	**Strong**		
	Operation Plan Preparation	Moderate	**Strong**		
	Surveillance Data Exchange			Dependency	Dependency
	Monitoring			**Strong**	Dependency
	Traffic information			**Strong**	Dependency
	Drone Aeronautical Information Management		Moderate		Dependency
	Geospatial information service		Moderate		Dependency
	Legal Recording				Moderate
U2 capabilities	Tracking			Dependency	Dependency

U-space services and capabilities		Exercise 1	Exercise 2	Exercise 3	Exercise 3
U3 services	Tactical Conflict Resolution				**Strong**
	Dynamic capacity management				Moderate

Table 2: Relation of exercises with U-space service and capabilities

In the other hand, the following table shows how the exercises address research questions relevant to conclude on the benefits of the micro-service architecture implementation.

Research area	Exercise 1	Exercise 2	Exercise 3	Exercise 3
Safety & Failure modes	X		X	X
Data management		X	X	X
Scalability	X		X	X
Flexibility			X	
Commercial implications	X	X	X	

Table 3: Relation of the exercises with the considered research areas

The main conclusions from these experiments can be summarized as follows:

Concerning the use of probabilistic micro-weather services (Exercise 1), results showed significant improvements over current, static weather forecast accuracy at 3h look-ahead time. This has substantial benefits on mission planning accuracy, reducing trajectory uncertainty as well as drone contingency planning and traffic planning.

Results on *mission management* (Exercise 2) showed clear benefits on mission trajectory optimisation using cost functions to help refine four-dimensional trajectories of drones.

Concerning the use drone flight plans, a minimum set of flight plan data fields was established which would be required for conflict detection at strategic level. Furthermore, a conflict resolution scheme was tested and validated which would mitigate the need for centralised flight plan de-confliction. In this scheme, the flight planning management service provides the minimum information on where a flight plan is in conflict with another, without the need to provide potentially business-sensitive data, all the while leaving the final decision on how to update the flight plan with the affected operator. Finally, separation margins guidelines and prioritization criteria were developed for strategic conflict detection among flight plans, adverse weather and airspace restrictions.

Concerning de-confliction of drones at a tactical level (Exercise 4), the experiments performed by IMPETUS provide some examples of how *tactical de-confliction* could be achieved for 'Zu'-airspace. IMPETUS proposed a dynamic de-confliction which is based on the *positive field theory* concept. This concept consists of adding virtual "weights" to each drone depending on a series of characteristics, which in turn define the separation criteria. Although other algorithms could be used to implement dynamic separation, IMPETUS experiments allow detailing the key parameters which should be considered for the definition of separation standards.

Finally, IMPETUS performed several transversal analyses (Exercises 1 to 4) concerning the technical feasibility of the individual services and the proposed architecture based on the micro-service-paradigm. These analyses were integrated into the U-space service experiments and divided into individual research areas – safety, failure modes, scalability, flexibility, data management and economic feasibility – in order to draw conclusions on the U-space architecture as a whole.

2.5 Technical Deliverables

Reference	Title	Delivery Date[3]	Dissemination Level
Description			
D2.1	Drone Information Users' Requirements	08/04/2018	PUBLIC
IMPETUS D2.1 performs a domain analysis dealing with the information management of the future U-space system. The analysis is focused on capturing users' needs and the characterization of data requirements through specific use cases. This task was performed by following a bottom-up approach, including an extensive literature review and a stakeholders' survey designed by the IMPETUS Consortium.			
D2.2	Drone Information Services	17/07/2018	PUBLIC
IMPETUS D2.2 focuses on the elucidation of the information services that will be needed to realize U-space. The document yields a coherent framework identifying key information needs that U-space services – as of U1, U2, U3 and, to some extent, U4, will have to fulfil. Moreover, up to 35 U-space service concepts have been elucidated and numerous of their key aspects have been thoroughly discussed.			
D3.1	IMPETUS architecture and functional requirements	01/03/2019	PUBLIC
IMPETUS D3.1 describes a set of requirements that the consortium has identified related to a certain set of services of interest and the complete architecture to support them. The approach to this definition has been performed using the use cases defined in previous deliverables as real scenarios to be analysed in terms of information management and the role of the different actors that are active and passive participants in a set of operations. The analysis reveals the necessity of a scalable and highly-efficient architecture that can be supported by the micro-service paradigm.			
D4.1	IMPETUS platform and micro-services model	09/09/2019	PUBLIC

[3] Delivery data of latest edition

IMPETUS D4.01 is not a textual deliverable, it is simply the confirmation that the technical specifications, development, testing and deployment of the individual, micro-service based, platforms for each of the scenarios tested by the partners has been completed.			
D5.1	Experimental plan	17/12/2018	PUBLIC
IMPETUS D5.1 describes a set of experiments which the consortium aims to perform in order to flesh out key services for U-space. All experiments are defined based on a federated, micro-service-based architecture. This will serve to identify the benefits and drawbacks of using a federated service provision approach as well as to test whether the micro-service solution is scalable, efficient, secure and cost-effective enough to meet U-space operational requirements.			
D5.2	Technological and economic feasibility report	13/01/2020	PUBLIC
IMPETUS D5.2 presents the results of the experimental testing performed by the consortium. The experiments deal with a set of crucial U-space services and are addressing the previously defined use cases. All services have been prototyped and implemented based on a micro-service-based architecture. The analysis reveals that, although there are challenges in designing a technical architecture for U-space, the micro-service implementation approach is able to provide useful mechanisms and tools to address these challenges.			

Table 4: Project Technical Deliverables

3 Conclusions and recommendations

3.1 Conclusions

This section describes the conclusions that IMPETUS has obtained that are of relevance to the overall U-space concept and its technical feasibility, the relation of results to the proposed architecture as well as a summary of performance assessments and service maturity.

3.1.1 Conclusions on concept clarification

This section summarizes the discrepancies in the U-space services that were tested by IMPETUS with respect to their description in the U-space ConOps [22]. Each section lists the main aspects of the service that have been tested in reference to the definitions in the ConOps in a tabular form. The structure of the table is explained below. Two relevant IMPETUS deliverables are used as reference to identify these discrepancies, D2.2 Drone Information Services [3], and D5.2 Technological and Economic Feasibility Report [7].

ID	*Identifier of the table. The structure of the identifier is as follows:* *[SERVICE]-discrepancy.01*
Service aspect	*Aspect of the service that has been refined.*
Corresponding section in U-space ConOps	*Reference and title of the corresponding section in the U-space ConOps main document.*
IMPETUS Reference	*Reference to the corresponding IMPETUS deliverable and section from which the discrepancy was obtained.* *Furthermore, an additional level of confidence in the results is indicated to distinguish whether this discrepancy came from an observation that was:* • *Theoretical (mainly coming from D2.2 [3]), or;* • *Tested (mainly from D5.2 [7]).*
Observation	*Definition of how the discrepancy affects the description of the service in the U-space ConOps. Titles are limited to one of the following:* • *Refinement;* • *Amendment; or* • *Contradiction.*
Description	*Technical summary of the discrepancy.*

Table 5: Overview of the tabular structure used to describe discrepancies between the service definitions in IMPETUS and those provided within the U-space ConOps

3.1.1.1 Weather information

The tests related to the provision of a **weather information service** highlighted the need to update the description of the service in the U-space ConOps, as the amount of requirements imposed to the future weather services is limited and vague. We propose the following concept clarification for this service.

ID	Weather information-discrepancy.01
Service aspect	Service enablers
Corresponding section in U-space ConOps	5.1.7.1 Weather information
IMPETUS Reference	D5.2 Section 3.3 Detailed analysis of results per research area of the micro-service-based architecture; and D5.2 Section 4.1.1 Technological Feasibility Confidence level: Tested
Observation	Refinement
Description	The weather information service, as most services in a service cluster environment, belongs to a group of services called primaries, meaning that they offer basic functionalities to other services (such as mission planning or traffic separation control for example) without consuming from services – just data from sensors. This means that the *weather information* service should not only aim to meet its direct requirements, but also enable its client services to meet them. So, going further than what U-space ConOps imposes in the requirements for the weather service, we identified some **enablers that should be offered to the clients**: • **Maximise automation**: In order to achieve the desired U-space high capacity and low cost per actor. • **Uncertainty measurement**: As required by the drone operation plan processing service to predict a construction of a probabilistic 4D model of the flight's likely airspace occupancies. • **Service robustness**: As the weather service is a primary service its failure would lead to a cascade of services that can't perform their tasks or at most do it sub optimally

3.1.1.2 Monitoring and traffic management

The tests on the **monitoring service** and the **traffic management service** interactions have provided some results which would require refinements in the description of the architecture principles and the description of the monitoring service.

ID	Monitor and Traffic Management -discrepancy.01
Service aspect	Redundancy of the services
Corresponding section in U-space ConOps	5.2.1 Architecture principles
IMPETUS Reference	D5.2 Section D3.3.1 Safety and Failure Modes Confidence level: Tested
Observation	Refinement
Description	In addition to the definition provided by CORUS, we propose to emphasise further aspects of the architecture principles. To guarantee system response performance, it would be necessary to **provide redundant services** or the ability to reinstate the most critical services. This would improve the performance of the whole system. Therefore we recommend that the architecture provides mechanisms to create new instances when an overload or a fault of a service occurs.

ID	Monitor and Traffic Management -discrepancy.02
Service aspect	Status of the drone.
Corresponding section in U-space ConOps	5.1.6.1 Monitoring service Confidence level: Tested
IMPETUS Reference	D5.2 Section 2.4.3 Traffic Information and Monitoring Services
Observation	Refinement
Description	In addition to the definition provided by CORUS, we propose to emphasise the necessity of providing information about the status of the drone, specially the capacity of the battery. IMPETUS experiments found that the minimum dataset for *monitoring* purposes to be sent from the drone to the system should include: • Drone identification • Position • Battery status

3.1.1.3 Mission management

U-space ConOps considers that all requirements dealing with mission management are covered through several services and not only one as IMPETUS initially proposed. These services are **risk analysis assistance, operation plan preparation assistance** and **drone operation plan processing**. IMPETUS has provided some updates to the scope of the mission management services and gathered useful information on how planning can be improved utilizing probabilistic weather information.

ID	Mission management-discrepancy.01
Service aspect	Mission planning capabilities
Corresponding section in U-space ConOps	5.1.3.1 Drone operational plan preparation assistance
IMPETUS Reference	D2.2 section 4.10.1 Mission planning Confidence level: Theoretical
Observation	Refinement
Description	In addition to the definition provided by CORUS, we propose to emphasise further aspects of mission planning as we understand that a paramount difference with current ATM is the need of considering mission-specific aspects as part of the overall U-space system. To ensure mission feasibility and other *Quality of Service* aspects, modern mission management shall **consider the performance characteristics of the UAV platforms** and **payloads** to be allocated to the mission, as well as all **context information** relevant to the mission. For single UAV missions, the drone *operational plan preparation assistance* service shall output a plan that includes the flight plan along with the specific tasks to be performed by the on-board and ground mission execution resources in coordination with the trajectory execution resources. For multiple UAV missions, it shall output a consolidated plan that breaks down into the specific mission plan for each single UAV; when dynamic mission re-planning is required upon mission, flight or traffic execution events, *drone operational plan preparation assistance* shall interact with a *drone operational plan processing* service to safely accommodate mission plan changes that involve trajectory changes.[4]

[4] Please take in to consideration that IMPETUS deliverables refer to "mission planning management" and "flight planning management" instead of "drone operational plan preparation assistance" and "drone operation plan

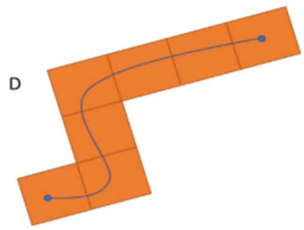
ID	Mission management-discrepancy.02
Service aspect	Operational plan optimisation
Corresponding section in U-space ConOps	5.1.3.1 Drone operational plan preparation assistance 5.1.3.2 Risk analysis assistance
IMPETUS Reference	D05.02 section 3.2.2.1 FPM-1 Confidence level: Tested
Observation	Amendment
Description	The utilization of optimization techniques for **refining 4D trajectories** based on the minimization of a **cost function** (where the variables acting as weighting parameters are provided below) is a viable solution for an advanced tool that allows mission trajectory optimisation and increases operational safety. $$\min_M J(M) = \min_M J(P, D, R, G, A)$$ J is a function of the power consumption (P), the overall distance (D), the flight time over safety-critical areas (R), clearance from the ground surface (G) and further restricted airspace volumes (A). Some of the previous parameters are closely linked to the SORA processes. IMPETUS proposes to integrate the service *risk analysis assistance* as part of *drone operational plan preparation assistance*. In this way, the service will generate an initial drone operational plan which will comply with SORA requirements. This will imply to extend the proposed cost function with other parameters which are relevant in the SORA processes.

ID	Mission management-discrepancy.03
Service aspect	Probabilistic weather factors affecting mission planning
Corresponding section in U-space ConOps	5.1.3.3 Drone operation plan processing service

processing” service respectively. To our understanding, both services are equivalent but we think that mission-specific aspects need to be emphasized.

	5.1.7.1 Weather information
IMPETUS Reference	D05.02 section 3.2.1.5 Other probabilistic weather factors affecting mission planning D05.02 section 3.2.1 Drone-specific weather service Confidence level: Tested
Observation	Refinement
Description	U-space ConOps states the need of providing hyperlocal weather information and the need of using the *weather information* service to construct a probabilistic 4D model through the drone operation plan processing service. We propose to further detail the weather factors that were proved by IMPETUS to be relevant in the process of obtaining the probabilistic 4D trajectory, that is **pressure, temperature and wind**. The uncertainty associated with the forecast of these atmospheric factors can be translated into trajectory prediction uncertainty in terms of 3D position and timing. **Probabilistic micro-weather predictions** of additional meteorological variables that can be relevant to the mission, such as **visibility, precipitation and turbulence**, need to be considered to assess whether the mission is feasible, safe to execute or economically viable before actually planning the flight trajectory. Initial testing was done in IMPETUS to assess the impact of these three variables. Having a reliable probabilistic forecast of all previous variables will be of great value for mission planning.

ID	Mission management-discrepancy.04
Service aspect	Trajectory uncertainty
Corresponding section in U-space ConOps	5.1.3.4.1 Trajectory uncertainty
IMPETUS Reference	D05.02 section 3.2.1.1 WX-1 Confidence level: Tested
Observation	Refinement
Description	Tests utilizing probabilistic micro-weather services showed great improvements on the mission planning capabilities of the operator, specifically concerning the associated **reduction of position uncertainty**

	along a pre-defined track. Results relate to trajectory type "D" of the example trajectories shown in the ConOps.  We found that the **use of probabilistic micro-weather services** greatly improved planning of fuel loading, mission time and vertical climb/descent profiles provided that it is **performed 3 hours in advance of the operation**. IMPETUS also analysed he impact of planning 6 hours and 18 hours in advance although we found that major deviations with respect to the real weather values can occur. This timeframe of 3 hours ahead in which the weather predictions are considered reliable enough could help to value the **Reasonable Time To Act (RTTA)**, the time period far enough before flight execution that a disturbance to the operations has minor repercussions, as it is defined in the ConOps.

ID	Mission management-discrepancy.05
Service aspect	Glide distance
Corresponding section in U-space ConOps	5.1.3.4.3 Contingency plans
IMPETUS Reference	D05.02 section 3.2.1.3 WX-3 Confidence level: Tested
Observation	Refinement
Description	Tests showed that it was possible to **predict the gliding trajectory** of an aircraft from cruise level to the ground with a high degree of accuracy, when utilizing **probabilistic micro-weather information**. This information could improve contingency planning for engine failure incidents, by predicting whether the aircraft is able to glide to a safe landing location. IMPETUS proved the benefits of using this probabilistic micro-weather service as an input to increase the robustness of the contingency plans 3 hours before the operation.

ID	Mission management-discrepancy.06
Service aspect	Contingency plan in case of failure of the weather service
Corresponding section in U-space ConOps	5.1.3.4.3 Contingency plans 4.3.5 Contingency plans for U-space services
IMPETUS Reference	D05.02 section 3.3.1 Safety and Failure modes. Failure of a dependent data source. Confidence level: Tested
Observation	Refinement
Description	U-space ConOps provides examples of contingency plans per service but they are mainly focused on how to keep the users informed about the failure of a service. As an example, *weather information* service contingency consists of warning all affected drones and drone operators. IMPETUS proved that contingency plans could benefit of the U-space architectural design. As an example, in case of failure of a dependent data source for other services such as weather information, we have successfully demonstrated the ability to switch provider when a dependent service failed. The mechanism consisted of **listing each provider in the system with an alternative data source**. The Discovery service allows keeping a categorisation system of data providers.

ID	Mission management-discrepancy.07
Service aspect	Drone operation plan data-pool
Corresponding section in U-space ConOps	5.1.3.3 Drone operation plan processing service
IMPETUS Reference	D05.02 section 3.2.2.1 FPM-1 Confidence level: Tested
Observation	Refinement
Description	In relation to the data pool containing the histories of all submitted flights that have not yet been archived, IMPETUS has defined which minimum set of data fields would be required in storage. After processing the submitted flight plan, the *drone operation plan processing* service stores the official flight plan including additional information, which can be summarized as follows:

Flight plan data field	Description
Flight ID	Unique Identifier assigned to the submitted flight plan
Priority level	Level assigned to the flight trajectory
Status	Requested, pending, valid/invalid, approved/rejected
Operator ID	Identifier assigned to the registered operator
Lateral, vertical path and timing	Sequence of waypoints and associated timestamps
Mission purpose	Description of the mission for priority assignment
Departure time	Date and time in standard format

3.1.1.4 Conflict management

Aspects related to conflict identification and subsequent resolution were tested within the exercises related to mission management. IMPETUS tested a conflict management scheme that differs slightly from the one defined in in the U-space ConOps. The following tables will explain these differences in more detail.

ID	Conflict management-discrepancy.01
Service aspect	Drone operation plan data for strategic conflict detection
Corresponding section in U-space ConOps	5.1.4.1 Strategic conflict resolution service
IMPETUS Reference	D05.02 section 3.2.2.1 FPM-1 Confidence level: Tested
Observation	Contradiction
Description	The strategic *conflict resolution* service is able to identify conflicts among flight plans that include a 3D or 4D trajectory definition utilising the following pieces of information:

Flight plan data field	Description
Operator ID	Identifier assigned to the registered operator
Lateral, vertical path and timing	Sequence of waypoints and associated timestamps
Mission purpose	Description of the mission for priority assignment
Departure time	Date and time in standard format
Estimated time of arrival	Date and time in standard format

Unlike the U-space ConOps, the strategic conflict resolution service was only detecting conflicts and not proposing solutions. This information was sent to the *drone operational plan preparation assistance* service together with a request to submit a different *drone operation plan*. IMPETUS proved the feasibility of this process that allows the drone operator to take the final decision on how and where to fly. IMPETUS proved that one single iteration with the drone operators was enough to de-conflict the trajectories.

ID	Conflict management-discrepancy.02
Service aspect	Criteria for strategic conflict detection among flight plans
Corresponding section in U-space ConOps	5.1.4.1 Strategic conflict resolution service
IMPETUS Reference	D05.02 section 3.2.2.1 FPM-1 Confidence level: Tested
Observation	Refinement
Description	The key criteria in the **conflict detection** process were as follows: • A **separation margin** in the spatial and temporal domain was defined for all the trajectories, independent of the mission type; • **Prioritization criteria**: the *drone operation plan processing* service assigned a priority level to the operation plan according to the mission purpose (e.g. search and rescue missions have higher priority than commercial missions). In case that the

	priority levels are equal, the controlling instance follows a first-come-first-serve principle.

ID	Conflict management-discrepancy.03
Service aspect	Prerequisites for pre-tactical conflict resolution of flight plans, including weather
Corresponding section in U-space ConOps	5.1.4.1 Strategic conflict resolution service
IMPETUS Reference	D05.02 section 3.2.2.2 FPM-2 Confidence level: Tested
Observation	Amendment
Description	IMPETUS proposes to **consider areas with weather restrictions as part of the strategic conflict resolution service**, introducing key criteria for conflict detection with certain areas with high wind velocities: • For wind speed measurements under an admissible threshold: condition regarded as not adverse and no conflict is detected; • For wind speed measurements over an admissible threshold, but still under the maximum admissible value: condition regarded as adverse and conflict is detected; • For wind speed measurements over the maximum admissible value: condition regarded as not feasible for proceeding with the flight planning. This process would improve safety as the decision of proceeding with the flight plan is not only taken by the drone operator. The utilisation of **local weather observations** and weather reports in METAR format, and subsequent **mapping thereof onto a grid-model** was sufficient to identify conflicts between drone flight plans and adverse weather. [5]

[5] The use of this weather data based on real observations (shortly before flight) proved to be sufficient for missions of short duration. However, for traffic planning further in advance (i.e. 3h before flight) the need of using higher-resolution weather services (such as the probabilistic micro-weather service proposed by IMPETUS) would be necessary.

	The conflict resolution algorithm shall include a 3D **digital elevation model** of the area to be de-conflicted to ensure a reasonable separation margin from the terrain. The criteria for specifying the clearance value in case of conflict detection was the following: • Small deviation in measurements from different sources in grid cell (**low weather uncertainty**): **small clearance value** from elevation model; Large deviation in measurements from different sources in grid cell (**high weather uncertainty**): **large clearance value** from elevation model.

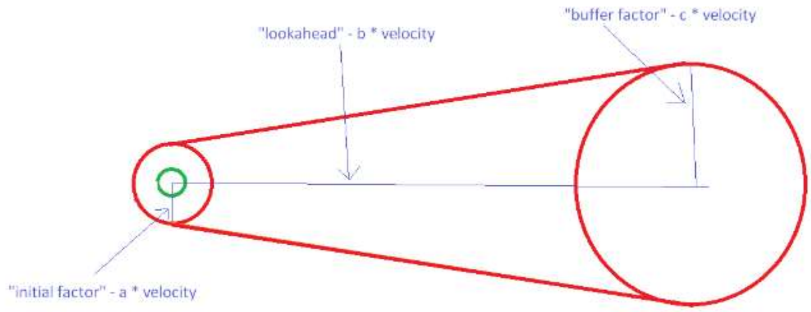
3.1.1.5 Tactical de-confliction and dynamic capacity management services

Concerning de-confliction of drones at a tactical level, the experiments performed by IMPETUS provide some examples of how dynamic de-confliction could be achieved for 'Zu'-airspace. IMPETUS proposed a dynamic de-confliction which is based on the *positive field theory* concept. This concept consists of adding virtual "weights" to each drone depending on a series of characteristics, which in turn define the separation criteria. Although other algorithms could be used to implement dynamic separation, IMPETUS experiments allow detailing the key parameters which should be considered for the definition of separation standards.

Furthermore, suggestions are provided on information to provide for service auditing and the utilization of probabilistic weather to define reference altitudes for separation purposes.

ID	Tactical de-confliction-discrepancy.01
Service aspect	Tactical de-confliction concept for 'Zu'-airspace
Corresponding section in U-space ConOps	5.1.4.2 Tactical conflict resolution
IMPETUS Reference	D05.02 section 2.4.4 Traffic Management Services dealing with dynamic airspace management (EXE 4) Confidence level: Tested
Observation	Refinement
Description	*Tactical de-confliction* of drone flights in 'Zu'-airspace can be achieved through the determination of separation bubbles[6] around each drone. These bubbles are initially of circular shape, however our tests found that

[6] IMPETUS implemented a "positive field theory algorithm". This type of algorithm uses weights to determine separation bubbles around each drone. We assumed, as stated by CORUS in [22] section 5.1.4.2 that the service is implemented on the ground and not as a distributed function within the aircraft.

	the shape would need to be adapted to a more conical one, to avoid issues with inefficient separation, exaggerated de-confliction behaviour and drones becoming “stuck”. The final separation bubble shall have the following shape: A circle drawn around the vehicle (an arbitrary numeric value, multiplied by velocity), with another circle projected out (distance defined by the same arbitrary value multiplied by velocity, with radius calculated similarly). These two circles are merged (with the space between them treated as a solid shape) to create a conflict resolution zone. This results in a **cone shape projection out ahead of the vehicle’s direction of travel.**  A **conflict** between two drones occurs when their **‘cones’ intersect**. **Conflict resolution** is achieved by having the drones **turn to the *right* of the drone they conflict with**; the amount they rotate/turn rate is determined by a *time to impact*, where the sooner the objects will collide, the more they will turn. These instructions are 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 instances where a drone conflicts with many other drones, the algorithm shall determine which other drone it is approaching is *furthest* to its right, and then turns right around it to avoid it.

ID	Tactical de-confliction-discrepancy.02
Service aspect	Dynamic separation criteria in ‘Zu’-airspace
Corresponding section in U-space ConOps	5.1.4.2 Tactical conflict resolution
IMPETUS Reference	D05.02 section 2.4.4 Traffic Management Services dealing with dynamic airspace management (EXE 4) Confidence level: Tested

Observation	Refinement
Description	Tactical de-confliction of drone flights in 'Zu'-airspace can be based on a set of **dynamic separation criteria**. These criteria are composed of **individual weightings of drone operations** depending on several factors, showcased below:

	Drone type (Fixed wing, rotary, etc.)			
Drone operation	Autonomous	Automated	Semi-automated	Human controlled
Standard separation	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Drone speed	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Endurance	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Mission (VLOS/ BVLOS)	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Location (Rural/ Suburban/ Urban)	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Mission Priority:				
Emergency service flight	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Commercial flight	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Recreational flight	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Drone electronic conspicuity:				
Plan only	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
ADS-B	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
LTE	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
combination	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Drone command:				
LTE	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
GCS	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Human control	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
LTE Coverage				
Poor	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Good	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Latency (poor)	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Weather data quality:				
National	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Regional	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Hyper local	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*	*[1,2,...,x]*
Actual weather; wind speed				

	Low	[1,2,…,x]	[1,2,…,x]	[1,2,…,x]	[1,2,…,x]
	Medium	[1,2,…,x]	[1,2,…,x]	[1,2,…,x]	[1,2,…,x]
	high	[1,2,…,x]	[1,2,…,x]	[1,2,…,x]	[1,2,…,x]

ID	Tactical de-confliction-discrepancy.03
Service aspect	Tactical de-confliction service auditing
Corresponding section in U-space ConOps	5.1.6.3 Legal recording; 5.1.6.4 Digital logbook
IMPETUS Reference	D05.02 section 3.2.4.3 TMS-3 Confidence level: Tested
Observation	Contradiction
Description	The U-space ConOps only states the necessity of providing an audit history for the monitoring service, however the provision of an audit history should be mandatory for other services as well, such as *tactical de-confliction*. The tactical de-confliction service should maintain a **full audit history** of all states and instructions. This allows all data collected for a logical flight, regardless of the originating service, to contribute to a singular audit repository with a known flight reference for querying. Audit data is categorised as either 'instrumentation' or 'action': • Instrumentation events were emitted periodically from services to log the state of their health, performance characteristics, etc. • 'Action' events were more specifically instructions generated by the service, or commands performed, that will have a specific effect on some other component. For example, a flight plan was stored as an 'action' when it was received.

ID	Tactical de-confliction-discrepancy.04
Service aspect	Reference Altitudes
Corresponding section in U-space ConOps	2.5.2 Altitude, North
IMPETUS Reference	D05.02 section 3.2.1.1 WX-1 Confidence level: Tested

Observation	Refinement
Description	For flights executed at constant pressure altitude, the resulting geometric altitude varies depending on the atmospheric conditions (pressure and temperature). Using the **micro-weather probabilistic forecast**, it is possible to have a robust **prediction of the potential geometric altitude variation** expected during the cruise. This is very valuable information to determine a safe vertical separation buffer between flights, specifically when a mix of operations using pressure and geometric altitude are present.

3.1.2 Conclusions on technical feasibility and architecture

IMPETUS performed several transversal analyses concerning the technical feasibility of the individual services and the proposed architecture based on the micro-service-paradigm. These analyses were integrated into the U-space service experiments and divided into individual research areas. This section highlights the main conclusions of these assessments per addressed research area, which are briefly summarized below, before going into the specific conclusions at service-level.

Safety & failure modes

The architectures tested for each of the analysed services have been confronted with the operation under failures. To this end, the analysis of failure propagation has been performed via dedicated resilience tests. These tests have measured parameters such as the time to detect failures, the delay of information due to service failure, the impact on other service functionalities, recovery time or availability of the information in percent. As a global conclusion, the tests have confirmed the inherent advantages of a micro-service oriented architecture to absorb failures and incorporate countermeasures able to react in real-time.

Data management

IMPETUS aimed to investigate the main issues related to data management within the proposed architecture. Specifically, the main challenges for the management of data within the U-space ecosystem are to **assure data consistency across all services** and to **provide critical data in real-time**. Within the micro-service paradigm, these challenges are especially tricky, because of the nature of the architecture itself. As every set of micro-services processes data in closed environments and utilises multiple mechanisms for external communication, a frictionless data flow is not automatically ensured. We found that applying reactive measurements and adjustments to the initially implemented micro-services (e.g. utilization of backup mechanisms, implementation of synchronous/ asynchronous communication simultaneously) has made it possible to address the initial objectives adequately.

Scalability & flexibility

One major benefit of a micro-service architecture is that can adapt to sudden increases or decreases in demand, that is, the architecture is capable of growing to absorb increases in demand with no substantial impact on certain performance targets such as response time and latency. Whenever demand exceeds the existing capacity, an additional one can be instantiated to reduce the load. On the contrary, when demand decreases, micro-service instances are decommissioned to optimize the use of computing resources.

3.1.2.1 Technical feasibility of the *weather information*-service

The *weather information* service was tested for safety & failure modes as well as scalability & flexibility. In relation to the CORUS architecture, the service falls in line with two concepts: First, the service functions as a complete a *supplemental data system*, providing support to various levels of drone traffic management (DTM) systems, but also in part as an *operator DTM system*, as the interface allows for direct interaction with end users. These interdependencies are highlighted in Figure 1.

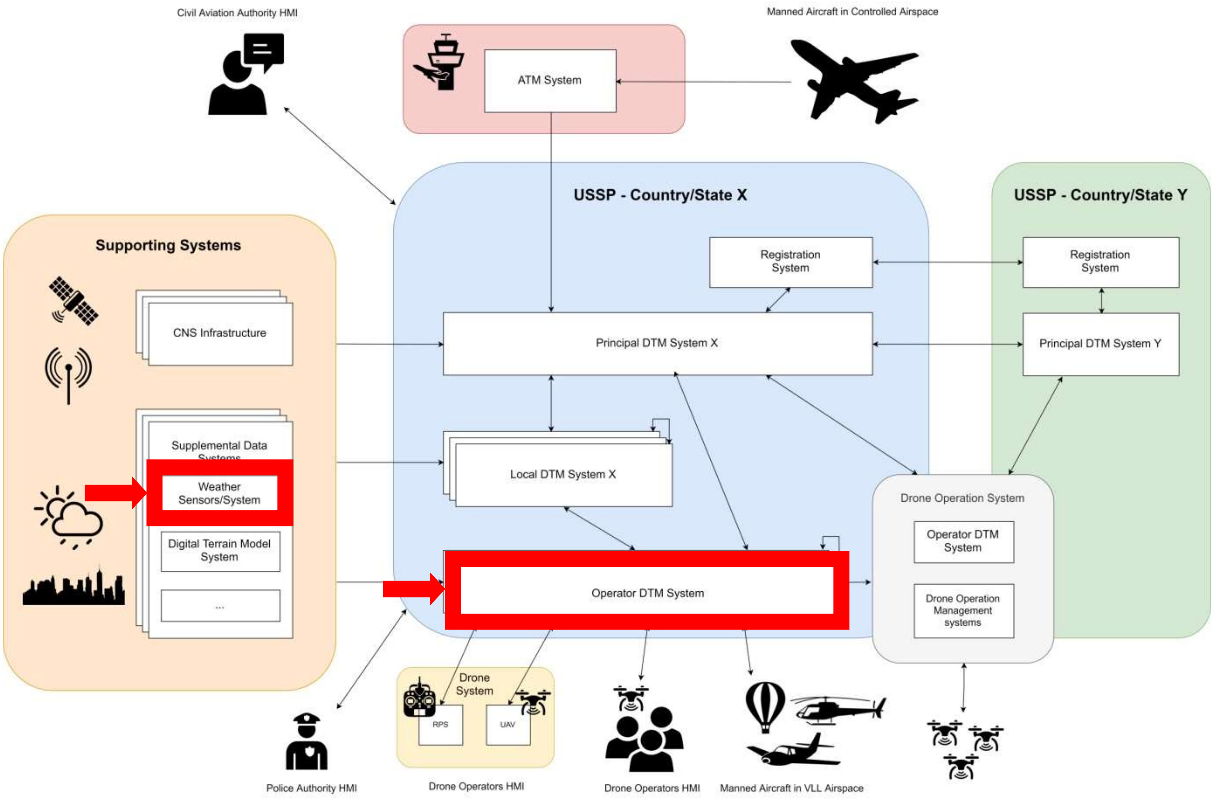


Figure 1: Positioning of the *weather information* service tested by IMPETUS in relation to CORUS high-level architecture

The implemented weather architecture can be summarized at a high level as follows:

Figure 2 below shows a schematic representation of the high-level architecture and main data flows of the *micro-weather service* prototype that was implemented and deployed to conduct the exercise. Following the IMPETUS micro-services architecture and in accordance with the design principles outlined in deliverable D3.1 [4], the service decouples the computation of weather forecasts from the provision of information extracted from those forecasts to the service's clients.

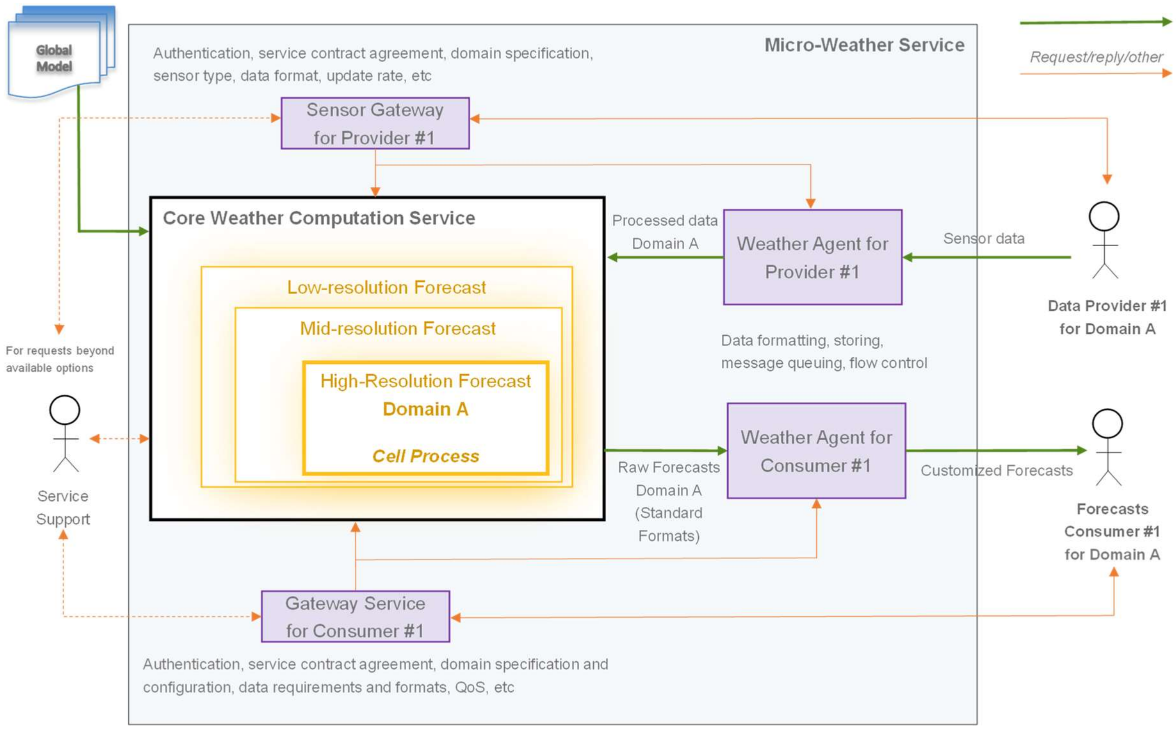


Figure 2: Micro-service prototype high-level architecture and main information flows

The *micro-weather service* has two types of clients: **forecast consumers** and **data providers**. *Forecast consumers* are clients that request meteorological forecast information from the service. *Data providers* are clients that interact with the service to deliver real-time data from meteorological sensors. The data is to be used by the service to improve the accuracy of its forecasts. A *forecast consumer* can also be a *data provider*.

When a consumer connects to the service in order to obtain meteorological data, a ***gateway service* assigned to that specific *consumer*** is instantiated by the micro-weather service. The *gateway service* manages all the interactions of its *consumer* with the micro-weather service and is in charge of marshalling the required resources to fulfil the *consumer's* requests. Among other tasks, the *gateway service* is in charge of establishing and managing a service agreement with the *consumer*, including data requirements, domain of interest, Quality of Service, security and authentication. Thus, the *gateway service* provides the tools to enable the *consumer* to define the domain for which meteorological information is required. This domain includes a geographical area of interest together with the time interval for which the data is required. In addition, the *gateway service* allows the *consumer* to define the specifics of the data it requires, including the format and granularity of the meteorological variables requested from the service. The *gateway service* may provide the *consumer* with pre-established options to define the domain and the data requirements or may require human intervention, i.e. *service support*, to customise them according to the *consumer's* requirements.

Once the *gateway service* has established an agreement with the *consumer*, a ***weather agent service*** is instantiated for that *consumer*. The Weather Agent is in charge of interacting with the *consumer* to notify the availability of the required data, instantiating the message broker required to deliver the data to the *consumer* and managing the corresponding message queues. The *weather agent* retrieves the weather forecasts provided by the *core weather service*, processes those forecasts to extract the data required by the *consumer*, transforms the data into the specified format and delivers the data to the *consumer* as per the agreed contract. Thus, the *weather agent* effectively decouples the computation of weather forecasts, performed by the *core weather computation service*, from the provision of weather data to *consumers*.

The ***core weather computation service*** at the heart of the *micro-weather service* is responsible for generating numerical weather forecasts for the domains of interest of the *consumers*. The forecasts are delivered to the *weather agents* in standard formats and, as indicated above, the *agents* are responsible for processing those raw forecasts, distilling the information required by the *consumers* and delivering it to them in the agreed format. As we will see below, the *core weather computation service* requires as input a global weather forecast, such as the one produced by the Global Forecasting System (GFS) provided by the National Oceanic and Atmospheric Administration (NOAA). GFS provides a global weather forecast that is used to initialise the numerical weather predictions processes carried out by the *core weather computation service*. In addition, the *core weather computation service* can leverage real-time meteorological observations to improve the accuracy of the forecasts it produces. These observations can be obtained from meteorological sensors deployed in the domain of interest or from other means such as satellites or indirect measurements such as using frequency variations in 4G/5G signals. For example, drones flying in the domain of interest may provide meteorological data measured during flight back to the service.

An entity providing meteorological data to the micro-weather service is considered a ***data provider client*** to the service. Within the CORUS framework this entity would act as another *supplemental data system*, but providing information to the weather information service, which by itself is a *supplemental data system*. The meteorological data provider's interactions with the service are analogous to those of *consumers*, as it is shown in Figure 2. Thus, the *gateway service* for each *data provider* instantiates a *weather agent* for the provider *agent* that manages the data ingestion process, decoupling the data delivery to the *core weather computation service* from the data stream fed to the service by the *provider*. The data is delivered to the *core weather computation service* in a standard format and at the expected rates, while the *providers* may deliver data in different formats and at different rates in accordance to their measurement and communication capabilities.

3.1.2.1.1 Safety & failure modes

In order to tests the benefits of a micro-service approach and data flow the functionality of the micro-weather service was packaged with different approaches. The main difference between the individual approaches was the way in which the functionality was packaged, from a single service instance offering all interfaces to clients to a fully compartmentalized one, running a dynamic amount of Docker *containers*. In total, four different approaches were tested:

1. Fully monolithic: Single service running all clients' interactions plus a single broker for clients;
2. Separation in two services: Gateway for service configuration and single client agent for managing all clients (threaded);
3. Fully micro: Gateway for service configuration and an independent container with a single agent for one client;
4. Fully micro plus exclusive broker per client: Same as before but adding a separate light Advanced Message Queuing Protocol (AMQP) broker to every agent container instead of an external broker.

It is guaranteed that the continuous data flow of each client is not disrupted by the actions of other clients when they misbehave (slow data consumption from queues, report corrupted data, make malformed petitions, or simply disconnect abruptly). Whereas all the analysed architectures are fully capable to handle the load in the absence of errant clients, **micro-service architecture is more robust facing clients with faulty behaviour**, and maintains a low percentage of unsuccessfully served clients even in environments with more than 80% of faulty clients. Besides, it presents a sustained and predictable behaviour, whereas other possible implementation approaches present a **degraded behaviour** over a certain threshold in the percentage of faulty clients.

In a fully monolithic case the number of errors rises very quickly with the percentage of errant clients, as once a non-managed exception rises the service is aborted and has to restart, terminating all present clients. A two-service based architecture (gateway plus single client agent) shows a bit more resilience as the two independent blocks are reset independently, but it also increases dramatically the number of unsuccessfully served clients above the threshold of 50% of faulty clients.

Adding a lightweight message broker per client additionally eliminates inter-client error propagation and reduces the percentage of unsuccessfully served clients to 5% with a 90% of errant clients.

3.1.2.1.2 Scalability & flexibility

The IMPETUS micro-service-based approach has also identified the benefits of **separating micro-services that obtain and process business-related data of those that manage clients petitions** and demand activity. As an example, in the *weather information service*, the weather-related data in the set of geographical cells covering the whole area should be kept updated based on the frequency and prediction requested, in the event that any client agent starts reading from them. This approach provides a robust, scale solution to offer the service to a highly variable number of clients. The required flexibility is provided through individualized agents per client that can accommodate the information provided by the *core weather service* to every user needs and to a large amount of clients at a sensible cost isolating client errors from affecting each other.

Load tests were then performed to see how the micro-weather service solution front end behaved under an increasing load of requests. As the core part of the service in independent of the actual number of clients this test focused on the front end for data delivery using synthetic data. Requests were scaled from zero up to 1000 clients and the development of the total RAM and CPU usage was registered. Both results showed linear increases in load, as was expected (see Figure 3).

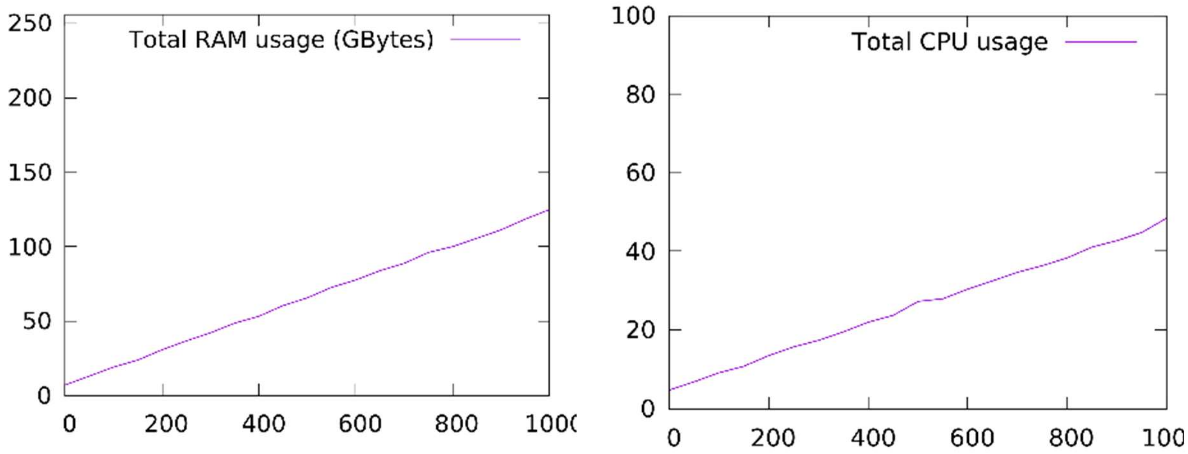


Figure 3: Total RAM (left graph) and CPU (right graph) usage as a function of the load (x-axis) on the weather service

3.1.2.2 Technical feasibility of the *monitoring* and *traffic information* services

These services were tested in conjunction as part of a more elaborate platform. This was done to investigate data management aspects between the two services alongside safety, failure mode and scalability implications. Therefore, for the purpose of elaborating the technical feasibility of the services, they will be considered jointly. In relation to the CORUS architecture, the services fall within the CNS infrastructure component of the supporting systems, as highlighted in Figure 4.

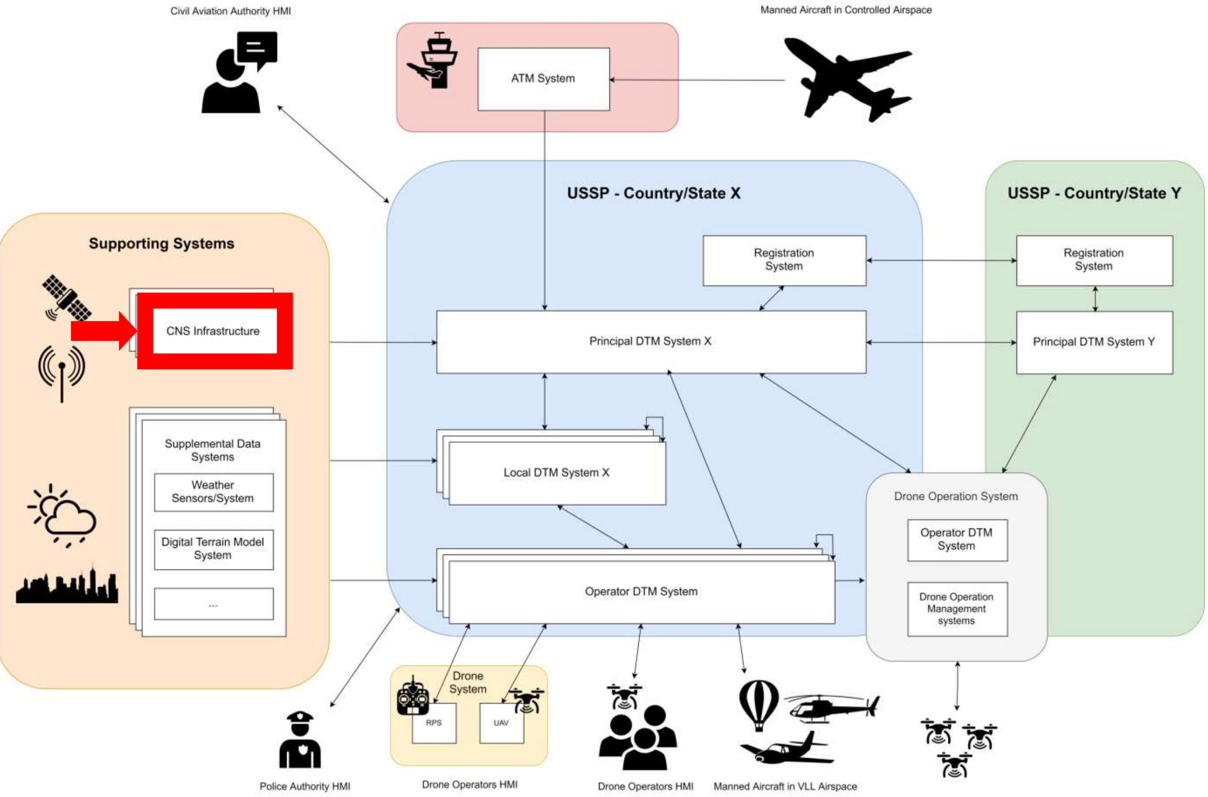


Figure 4: Positioning of the *monitoring* and *traffic information* services tested by IMPETUS in relation to CORUS high-level architecture

The *monitoring* service was tested using synthetic data based on real operations. The platform was capable of filtering them to process only the messages related to the position, battery status and attitude of these flights (orientation, speed, flight mode, etc.). The communication with this module was based on MAVLink protocol, highly compatible with most of the flight controllers in the market.

The *traffic information* service then gathered and processed all the information from the *monitoring* service(s), obtaining the complete view of all drone operations. Their updates are shown in an HMI, a web server in which each drone can be represented and the most representative data can be checked.

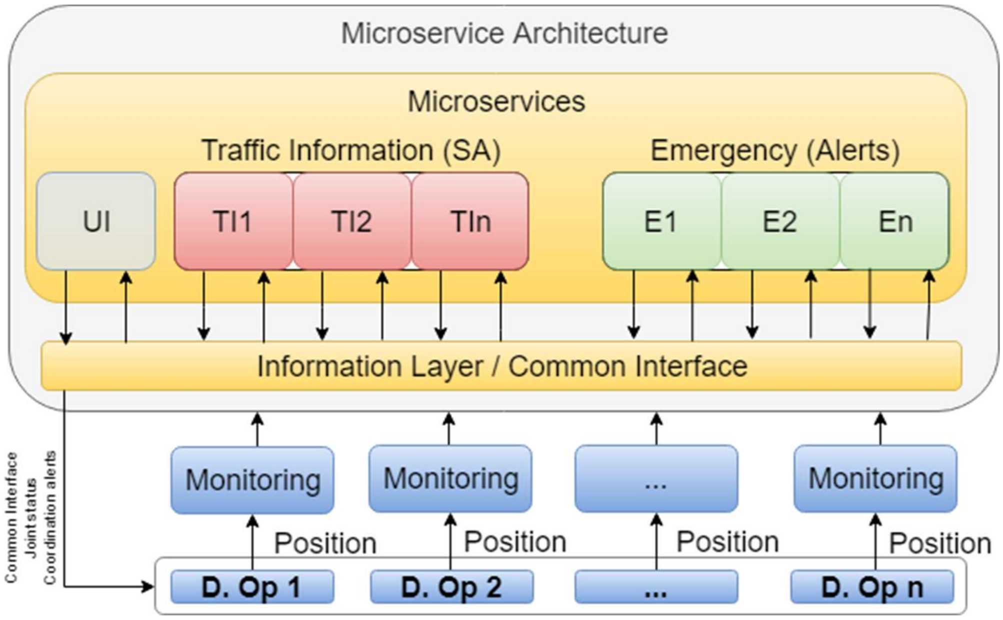


Figure 5: High-level functional architecture of the *monitoring* and *traffic information* services and their main information flows

The services were developed using some existing products that provide the basic capabilities for information management:

- NGNIX: an **asynchronous high-performance web server** configured to receive all the messages generated by the drone operations using **MAVLink protocol**, redistributing them to the micro-services that show these positions in a web interface and store the datasets in distributed databases ready to be queried;
- MongoDB: storing the **historical information** of the platform and, in this specific case, the messages filtered by the MAVlink micro-service (this module is capable of skipping messages defined by the user, allowing to focus only on the topics of interest). The use of a NoSQL and distributed database allows this platform to store large amounts of information and provides access to these datasets to exploit them in an efficient, quick way;
- ActiveMQ: an open source **message broker** that implements the Java Message Service (JMS) specification (a communication framework in which the integration of different applications that accept the same messaging protocol/service is easily deployable). The use of a messaging system allows decoupling the functionalities of these micro-services and allows their scaling. The messages are processed using two different methodologies:
    - **P2P (Point to Point, Sender/Receiver)**: it is guaranteed that the message is processed once, regardless the number of possible processors or instances of the same micro-services. If a receiver is not available or overloaded, the message is stored until it can be delivered to a defined receiver. To do this, message queues are available;
    - **Publisher/Subscriber**: the message is broadcasted and received by all receivers subscribed to a Topic. In this case, two topics are used: **POS and ALARM**. The sender and receiver can be even more decoupled, as the sender does not need to know which one of the receivers processes the message.

- PostgresXL/PostGIS: consists of a **distributed relational database management system** based on PostgreSQL (object-oriented and open source relational database management system). The main objective of this product is to provide the same functionality of PostgreSQL while distributing the workload in clusters. On the other hand, PostGIS is a plugin that provides the necessary capabilities to process spatial information in an efficient way and store, analyse and transform geographic information. It can also be executed in a distributed way, allowing scaling and skipping the limitations of a monolithic architecture;

- IGNITE: **cache-memory database** whose main objective is to store the incidents generated by the Alert micro-service. It generates the reports to users and delivers them using the MQ Telemetry Transport system;

- Kubernetes: consisting on an open source framework that is capable of **automating deployment and scaling** the systems that have been previously containerized. In other words, it allows to activate a certain set of predefined functionalities while monitoring the status of the entire system, providing automated roll-outs and roll-backs and self-healing mechanisms;

- Amazon Web Services: **elastic cloud computing resources** are also integrated in this environment, providing the necessary infrastructure to deploy all the modules described and implemented for this architecture.

3.1.2.2.1 Safety & failure modes

The following conclusions have been extracted regarding the failure-mode performance of micro-service approach in these exercises:

- A micro-service architecture is defined as a failure-resistant structure. The environment around the micro-services has a suite of core functions that are **continuously monitoring and reporting the status** of the architecture. As an active/reactive system, it is also capable of recovering from failures, clearing and closing the micro-services in error mode and creating new instances with the same functionality with quick response times.

  The time for detecting overloads is less than 0.1 sec. For critical functionalities, a low delay of information transmission (up to 4 seconds), due to the implementation of a failure mode, can be achieved by implementing redundancy in certain micro-services and avoiding waiting time for initialization of newly created ones.

- The higher degree of **robustness achieved by design** is a clear advantage of the micro-service approach. Although the code in a monolithic approach can be hardened to have a better management of exceptions, it is difficult to cover all cases, complicating the internal code flow and making it prone to memory leaks or even security bugs due to the increased complexity.

3.1.2.2.2 Data management

The architecture allows for **each client to set their own requirements** in terms of data management. This is very relevant since the number of clients consuming and reporting data is dynamic (variations in drone traffic density) and may vary in usage patterns (depending on the operator/ user profile).

Tests on data management aspects were specifically focused on the **timeliness of the reception of information**. Within U-space, information provision to some services (like monitoring or traffic information) will be time-critical.

The timely provision of information to users is highly dependent on internal processes to exchange the information between all the modules of the architecture. One solution for streamlining flow processes and reduce backlogs is to **duplicate the information ingestion methods** (filters, message layers). These can be parallelized and decoupled, allowing certain parts of the architecture to be in charge of processing specific types of information and ensuring that the acquisition of new datasets is not affected by bottlenecks. This concept was exemplified in the *traffic information* and *monitoring* service exercises. Information transfer between the services was based on simple messages. This made it easy to read and parse information without significant delays or increases in workload, and increased the agility and efficiency of data processing.

Apart from the streamlining of internal processes, another issue to be considered is which information is necessary to be presented to end-users and at which **update rates**. Interfaces should only show the required information and avoid bottlenecks in the final part of the chain. It is clear that this approach must be based on an operational point of view, analysing the criticality of each operation, the congestion in specific areas, the capabilities of each aircraft and operator to react to sudden issues and the use of critical U-space services. The *traffic information* and *monitoring* service exercises defined a **one second latency as the baseline**, which may be a viable solution in low-congested environment, but this number should be modified dynamically after analysing the whole set of components in U-space.

3.1.2.2.3 Scalability & flexibility

The architecture needs to implement a set of mechanisms to detect, mitigate and stabilize the system to keep certain Quality of Service criteria. These mechanisms, that should be more or less part of any micro-service architecture implementation, do not require significant computation resources and allow for detecting changes in the demand on time.

It is relevant to identify the acceptable limits beyond which the Quality of Service criteria are not met, and also to identify the time in advance to create new instantiations ensuring the required continuity of the service. As an example, when implementing the traffic *monitoring* service, although any overload is detected within 0.1s and the creation of a new instance improves clearly the performances – e.g. reduction of response time to a new request in 75%, however the set-up time to execute a new instance of the service is around 200s, which is not an acceptable value.

To mitigate this effect, the architecture shall be configured so that the **maximum workload admitted by each micro-service is 60% to 80%** of its capacity – depending on the criticality of the service, in order to deploy additional instances on time when the demand increases.

In case of critical and **safety-relevant services**, they shall be deployed **duplicated** regardless of the actual load situation. These duplicated micro-services can work by balancing constantly the demand or one of them in stand-by as a back-up of the other until the 60% demand threshold is reached.

On the other hand, the micro-service approach ensures that the system is not over provisioned, with the subsequent impact on the commercial feasibility. It was feasible to decommission the additional instances when the load is within the acceptable margins.

Message filtering greatly reduces the amount of latency in processing time. As an example, the data flowing into the *monitoring* service was filtered to just information about position, battery status and altitude. This technique greatly improved the service's performance (in some cases, latency was reduced by a factor of 40). As an example, the following figure (Figure 6) shows results of latency tests on the number of messages processed as drone operations were increased for the *monitoring* service. Sudden increases in messages accumulated delays which were absorbed when the architecture balanced the load between several micro-service instances. Moreover, the use of message filtering techniques (top image) greatly reduces message latency compared to non-filtered messages (bottom image). Thus, it is **relevant to implement message filtering services in parallel**, to avoid sequential processing of messages and improve performance.

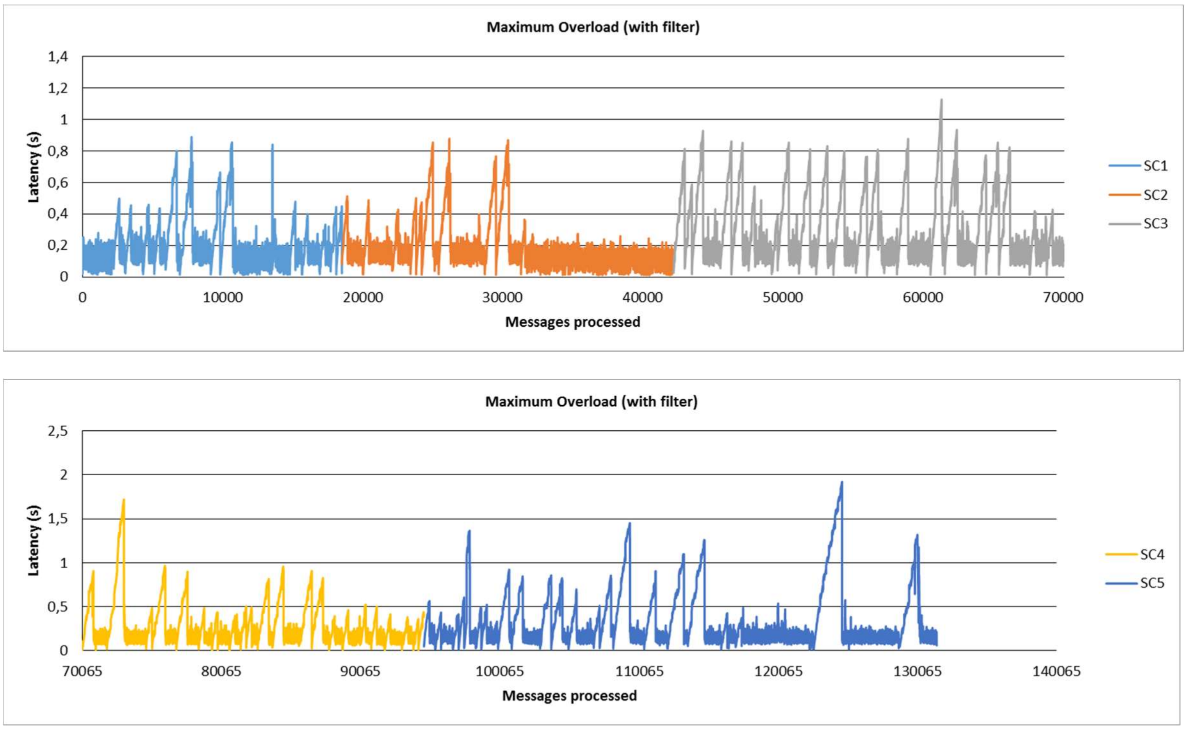


Figure 6: Latency of the system with message filtering.

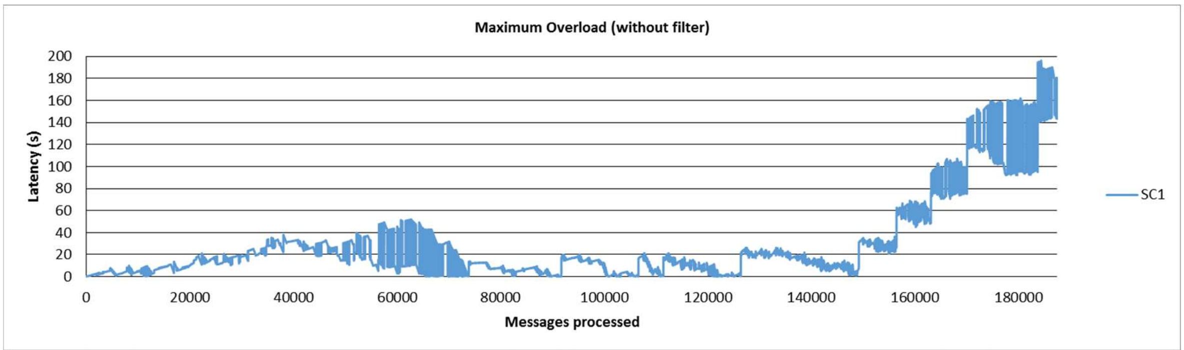


Figure 7: Latency of the system without message filtering.

3.1.2.3 Technical feasibility of the *operation plan preparation assistance* and *drone operation plan processing* services

Operation plan preparation assistance and *drone operation plan processing* services were developed jointly, in order to test the **division of responsibilities** between (in the definition of the CORUS architecture) *Operator DTM Systems* and a centralised *Principal DTM System* regarding the **strategic de-confliction of flight plans**. Therefore, for the purpose of elaborating the technical feasibility of the services, they will be considered jointly. The relation to the CORUS architecture is as highlighted in Figure 8.

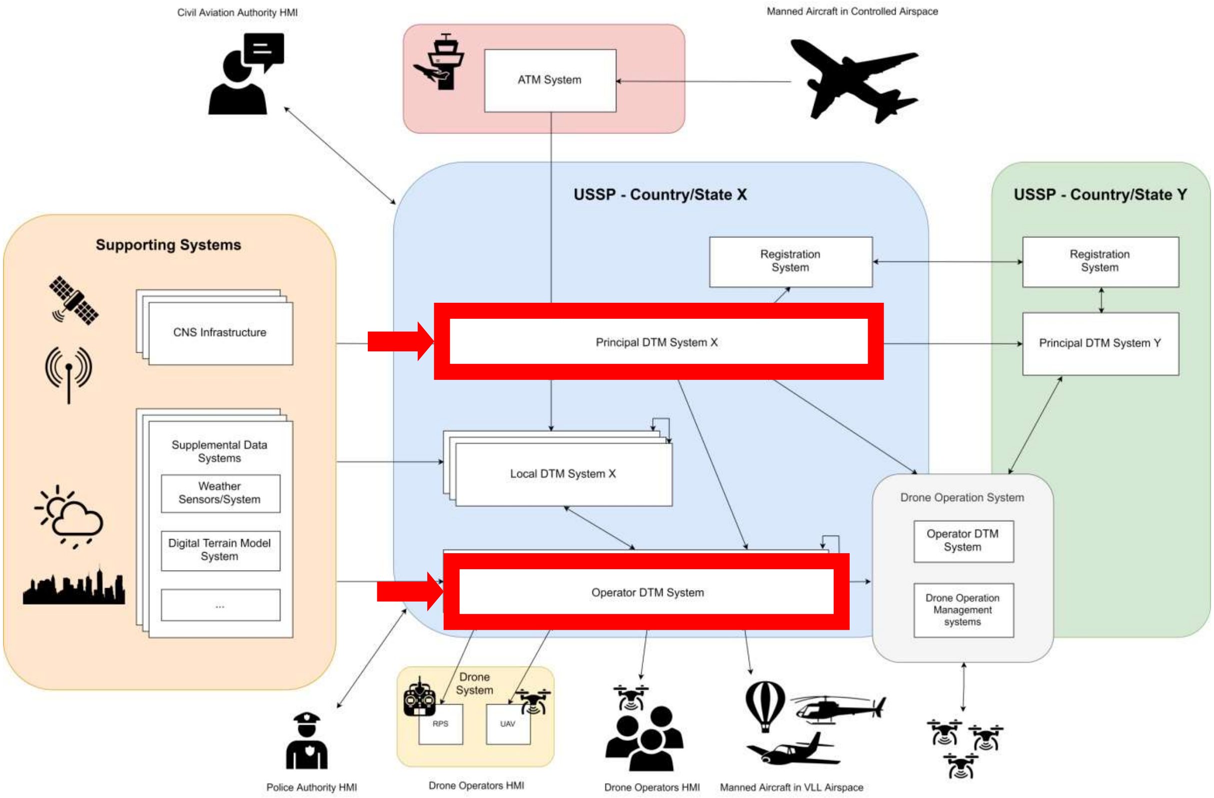


Figure 8: Positioning of the *operation plan preparation assistance service* (*Operator DTM System*) and the *drone operation plan processing service* (component of *Principal DTM system*) tested by IMPETUS in relation to CORUS high-level architecture

The interface of the *operation plan preparation assistance* service allows the *drone operator* to select a flight trajectory suitable for his/her needs in a defined airspace. The created **flight plan request is sent to the *drone operation plan processing* capability of the *Principal DTM System***.

The main task of the *drone operation plan processing* service at the planning phase is the **verification and validation of the submitted flight plan** and also the allocation of the validated flight plan in the overall drone traffic management. For the validation of the flight trajectory, a **conflict assessment process** is carried out where an intersection detection in the legs of the modelled trajectories is performed. Based on the result of this assessment the service will approve or reject the submitted flight plan and consecutively notify the client. In case that the flight planning capability do not approve the flight plan, the *drone operator* will be notified through the *drone operation plan processing* service.

An approval or a final rejection of the flight plan is also conducted in the same manner and will take part of the exercises as well.

The interconnections of the above described processes are marked with a straight black line in Figure 9 as they are considered foundation interactions that are assumed for the examinations and are invariant to the particular experiments. The remaining interrelations that are marked with a dotted line in grey colour represent the various additional functionalities which were integrated to the *drone operation plan processing* service and *drone operation plan processing* services:

- The **consideration of the weather information** in the *drone operation plan processing* service was supported by a weather model that combines a local weather forecast with a standardized local weather report (in this case METAR report);
- The provision of **non-permanent airspace sectorisation information** was carried by a processing instance which analyses NOTAMs and further temporary flight restriction (TFR) notifications relevant for drone operations.
- A **terrain model** was used for the trajectory modelling by the *drone operation plan processing* service in order to model a feasible trajectory within the considered urban environment;

This information is assimilated by a ***data processing module*** within the *drone operation plan processing* service. The relevant information for the intended spatial and timeframe of the operation is extracted and provided through the ***operational module*** to the *drone operator*. The ***modelling processing module*** is in charge of handling the *drone operator* mission requirements and model a flight plan that suits the needs of the drone operator.

The submitted or updated flight plan is processed by a ***trajectory processing module***. Here, the specific information concerning the flight trajectory is extracted. Through the ***data processing module***, the flight planning capability communicates specifically with the *local weather service* and the official *NOTAM management database*. This interaction shall prepare the relevant information to be validated for the proposed flight trajectory. Ultimately, the validation occurs in the ***flight conformance module*** which is also responsible for notifying the *drone operation plan processing* service in the case that a pre-approved flight plan requires to be updated.

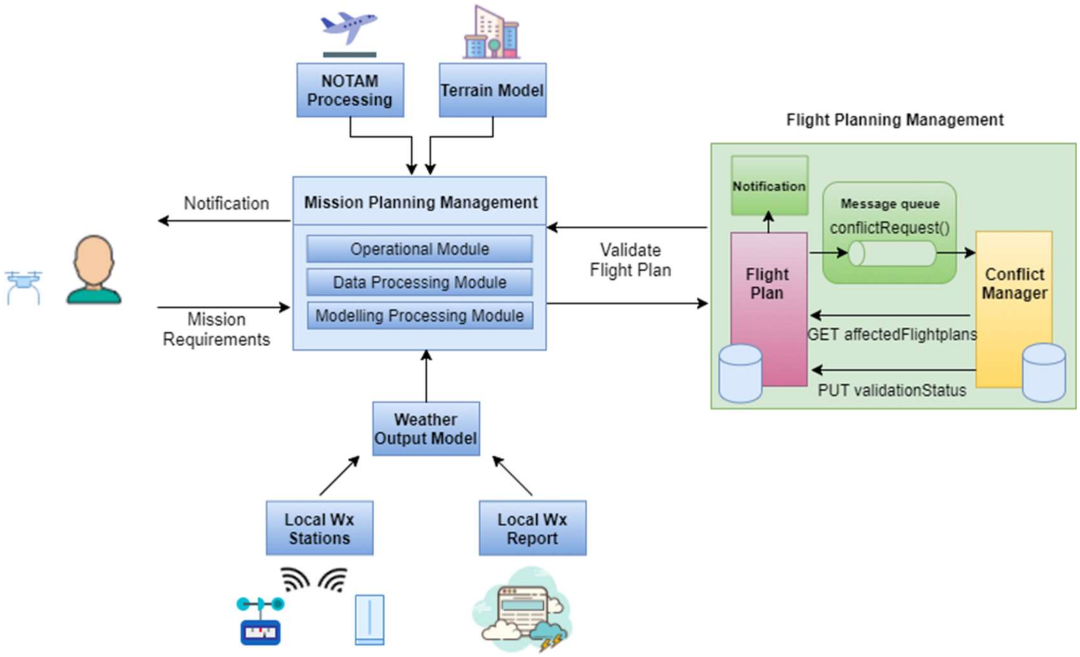


Figure 9: High-level functional architecture of the *operation plan preparation assistance* service (shown as *mission planning management*) and *drone operation plan processing* service (shown as *flight planning management*) and their main information flows.

3.1.2.3.1 Data management

Specific exercises were performed to assess consistency of data between the two services. **Data consistency** refers to the uniqueness of datasets, maintaining data quality and integrity as well as combining information from different sources and databases.

We have found several means of assuring data consistency within a micro-service environment. These include the use of a single point of truth for critical data and continuous update streams assuring that data is constantly refreshed.

In this exercise, the utilisation of a "**single point of truth**" was tested (the use of continuous data streams was tested in the tactical de-confliction service experiments). The *drone operation plan processing* service experiments utilized a **centralised database** as the single source of information for flight plan data. The database in the *flight plan* service can be considered as single point of truth for validated and officially approved flight plans. Data is replicated from this source which ensures that all independent copies are up-to-date and globally consistent within a single operation transaction (i.e. **instantaneous consistency**).

3.1.2.4 Technical feasibility of the *tactical de-confliction* service and *dynamic capacity management* service

The *tactical de-confliction* service was tested for safety & failure modes, data management as well as scalability & flexibility. In relation to the CORUS architecture, the service falls in line with the de-confliction component of the *Principal DTM System* (highlighted in Figure 10).

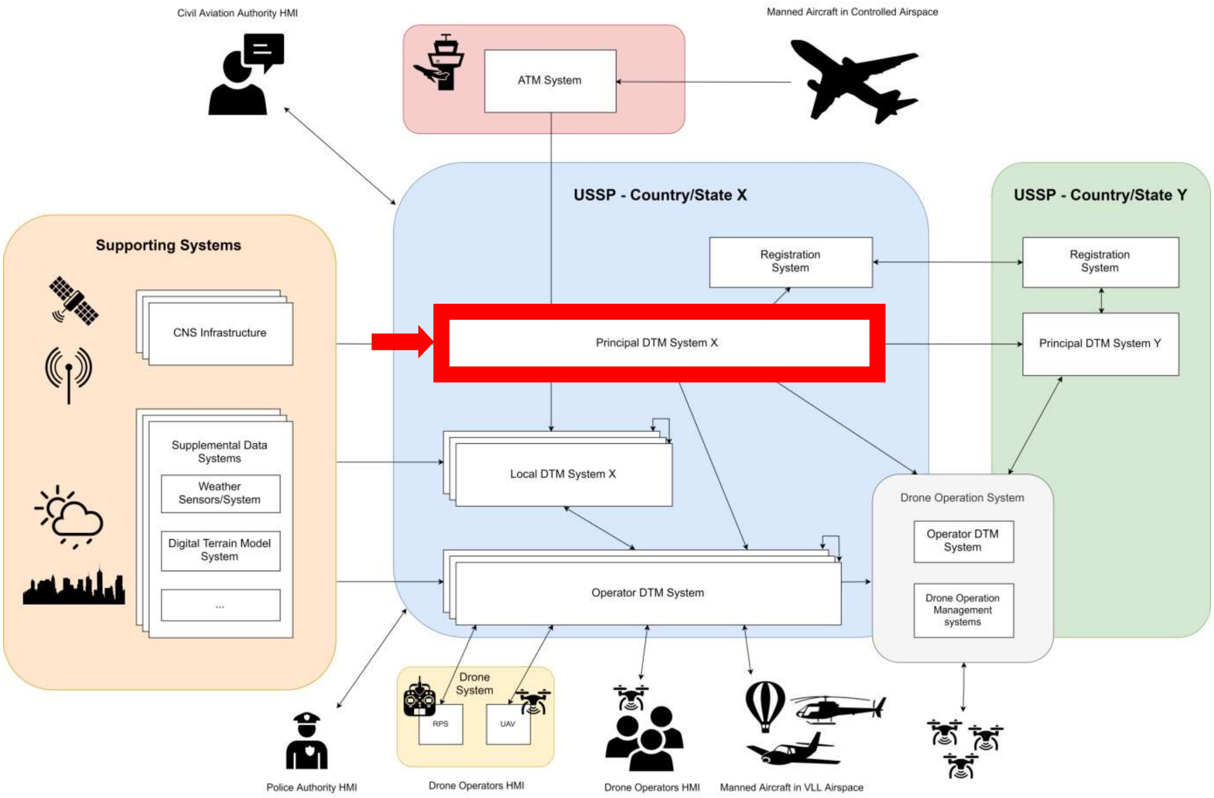


Figure 10: Positioning of the tactical de-confliction service tested by IMPETUS in relation to CORUS high-level architecture

Considering the federated deployment of the U-space system proposed by CORUS, a number of core *traffic management* services will be centralized and provided by one single actor, the so called *orchestrator* within IMPETUS (or *Principal DTM System* by CORUS), and other information can be provided by other external services. The centralised set of services will interface with data feeds from many different sources, all brought together to establish a single point of truth for all DTM providers.

In the case of drone operations, because of the ad-hoc and more dynamic nature of their mission trajectories, the system needs to deal with diverse and multiple changes affecting the flight plans that can be received at short notice. These changes could be reduced by establishing large static protection volumes (geofences) which would be simpler to manage but dynamic volumes would enable higher capacity, but at the prize of entailing higher complexity in the management of solutions provided by the *traffic management* services, and the required capabilities of the UAS operating in such volumes.

To explore the **best approach to deal with dynamic changes in the traffic picture** a *tactical de-confliction* service and *dynamic capacity management* service were developed addressing the balance between minimizing the impact to the existing drone operations and maximising the capacity. The service was based on the capabilities of the GuardianUTM platform. The high-level architecture of this service is provided below (Figure 11).

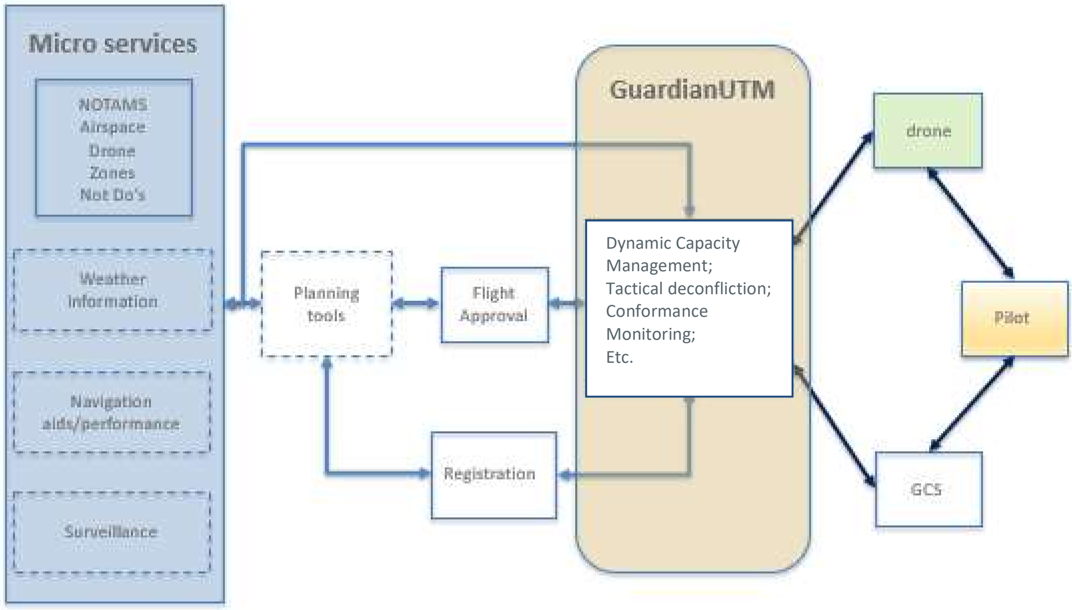


Figure 11: High level architecture of the *dynamic capacity management* service, *tactical de-confliction* service and their relationships with other services

This exercises took place in a **synthetic environment**. The computer modelling was based on CesiumJS 3D Mapping and the modelling utilised a pseudo registration solution.

All drone "safety buffers" were initially the same size and shape fields according to U-space ConOps. However, **changes to the size and shape fields were introduced**. Using positive field theory, the shapes and sizes of the fields around the drones were modified depending on drone characteristics.

3.1.2.4.1 Safety & failure modes

For **distributed systems** such as the ones conforming U-space services, it is important to consider geographic separation and the effects that this will have on replication, disaster recovery, and latency during failover. The service design "in-datacentre" allows that individual nodes handling compute and storage can fail in a deterministic manner. It is also important to go beyond load monitoring and also control other, **service-based, key performance metrics**, monitored by an independent set of software components. These metrics may be related to time to resolve dependent services or number of alerts shown.

Depending on the type of failure, the micro-service architecture facilitates different **automated mitigation actions**:

- For the failure of a node, or the failure of an individual subsystem upon which a node is reliant, it is performed the automatic de-provision and provision of new node members in the same cluster. For example, for a service as critical as tactical de-confliction, no capability is lost with removal of 25% of nodes in a state of 70% total load;
- In a total cluster failure, it is requested instantiation of a new cluster. Cluster failures are harder to recover from if only one cluster exists in a single datacentre, when time-to-failover can take up to 1-2 minutes;

- The failure of a dependent data source is treated differently according to the categorisation of the data provider. For example, for *tactical de-confliction*, weather data is regarded as a lower priority to connections to ADS-B data feeds, or the NOTAM system. Each provider in the system is listed with an alternative data source, and in case the priority is high, it is possible, through the **discovery service** to “call-out” to see if any alternatives exist at regular intervals during a degraded performance scenario, and switch to them automatically.

3.1.2.4.2 Data management

In the previous exercises (those related to the interactions between *operation plan preparation assistance* and *drone operation plan processing* services) the concept of instantaneous consistency was tested, which utilises a centralised database to assure consistency. However, common massive-scale systems consisting of diverse micro-services typically embrace “**eventual consistency**” – which was tested in this exercise; The fundamental concept is that at some point throughout a defined period, all copies of information will be consistent. One example of this type of implementation was showcased in the traffic management service experiments. To make eventual consistency work in practice, services that associate users with nodes that store data that is logically consistent with their use of the service is important. Applied to the *tactical de-confliction* service for example, a service instance de-conflicting traffic in and around London would need to have the most up to date version of information for its area, with for example backup nodes based in Amsterdam being able to reach the consistent state at a higher latency.

In the simulations that were performed, several regional traffic management instances called Region Management Simulation Test Environment (RMSTE) were instantiated. RMSTE was able to operate on the basis that **data providers** have been assured to be of a **minimum quality bar** and so it is not the duty for RMSTE or the *node manager* to ensure consistency within data suppliers’ systems. However, it is important that the consistency of the “state” managed within each micro-service and across a cluster of micro-services is assured.

Considering operational data, there is the minimum set of data consistency required to maintain an **adequate air situation picture** and to provide the service. The way the system is implemented assures that the failover characteristics of the cluster are, for node-level failures, sub second. In this mode, since the primary state for each node is saved in the micro-service’s volatile memory, if it goes offline, the state of traffic handled by that micro-service is effectively lost. However, vehicles operating through that micro-service report their location to RMSTE at least every 2 seconds, thus the maximum exposure window for information loss is 2 seconds. It was therefore not considered necessary in these experiments to share node state across nodes since the entire cluster state is rebuilt every 2 seconds anyway.

3.1.2.4.3 Scalability & flexibility

An aspect to take into consideration is that the capacity limits of the micro-service are not necessary aligned with a certain number of drone operations. As an example, in the case of the *tactical de-confliction* service, we have observed that computation usage increased as the number of drones which were marked as “in-conflict” increased, rather than from the increase in the number of drones in the area.

3.1.3 Conclusions on performance assessments

The IMPETUS project did not obtain any specific conclusions on human performance and security, as these aspects were out of the scope of the project. It was however possible to obtain results relevant to the **safety of operations,** gather quantitative and qualitative **evidences on the benefits of U-space services** that were tested as well as conclusions on the **economic feasibility of some of these services**. These conclusions are highlighted below, in individual sections per service tested.

3.1.3.1 *Weather information* service

IMPETUS tested a *probabilistic micro-weather* service for drone operations. This service was used to provide probabilistic weather predictions for areas with a size of only a few square kilometres. These forecasts were then applied to drone trajectories. Results were compared to calculations using current available aviation forecasts (static and deterministic) and to calculations using probabilistic low-resolution forecasts. These comparisons allow showing up to which point higher fidelity probabilistic weather predictions lead to different operational decisions and associated merits, regarding mission and flight planning as well as traffic management processes. These results are further detailed in section 3.2.1 of D5.2 [7].

Regarding the **benefits on the flight planning processes** of using the *probabilistic micro-weather* service, the IMPETUS assessment was twofold:

1. Quantify how the uncertainty associated with the forecast of atmospheric conditions of relevance to the drone trajectory (pressure, temperature and wind) can be translated into trajectory prediction uncertainty in terms of 3D position, timing and fuel/energy consumed, and
2. Determine up to which point the use of this service as a source of information to the other core U-space services can benefit safety.

In particular, probabilistic high-resolution forecasts allowed **estimating the maximum range and maximum flight time** achievable by the drone for a given set of mission requirements. IMPETUS results showed that the probabilistic high-resolution forecasts reduced the maximum range prediction error from over 7 kilometres (using traditional aviation weather forecasts) to approximately 300 meters. Thus, these weather forecasts could be used as an input to improve the *operation plan preparation assistance* service.

On the other hand, these forecasts allowed **estimating whether the drone could safely reach a suitable landing area** in the event of an engine failure – relevant to *contingency planning* service. At 3-hour look-ahead time, probabilistic weather forecasts were used to estimate a vertical glide profile at three different approach speeds. They were then compared to the actual trajectory to quantify the amount of deviation. Predictions using the probabilistic high-resolution forecasts showed the most accurate results, being very close to the true distance.

Regarding the **benefits on the mission planning processes** of using these high-resolution probabilistic forecasts, IMPETUS compared the predicted flight time and fuel burn for two possible mission patterns aimed at fulfilling the same mission objectives (e.g. forest fire surveillance mission through an East-West pattern or a North-South pattern). The micro-weather probabilistic forecast improved the accuracy of results for both patterns and **allowed capturing the differences in mission flight time and fuel burn for both patterns**. This capability would allow accurate and robust adjustments to the timing requirements as well as optimizing the sequencing of the successive take-off times when several sorties are required to sustain a given level of surveillance continuity in the described mission. As an example, for an East-West pattern, the probabilistic high-resolution forecasts to predict flight time 3 hours before take-off delivered 80% and 60% error reduction when compared to static deterministic forecast and probabilistic low-resolution forecast respectively. In the case of the fuel consumption, the error was reduced by 90% and 70% as shown in the figure below (Figure 12) which depicts a comparison of all forecasts with the true values. It is important to mention that we also quantified these metrics in other timeframes such as **6 hours and 18 hours before the execution. In those cases, the benefits were not so evident** in comparison with current deterministic or probabilistic low-resolution forecasts (refer to the figures included in section 3.2.1 of D5.2 [7] for more detail). In any case, we consider that due to the dynamic nature of the drone operations, mission and flight planning processes will be initiated in a shorter timeframe than in today's manned aviation processes.

We also need to **highlight the limitations of the benchmarking against the assumed true values**, since those values are estimated using the same simulation infrastructure employed to calculate the predictions. Thus, prediction errors obtained are very small even with the static forecast, which results in errors in the order of **1 % for flight time and 1.5% for fuel burn** in total.

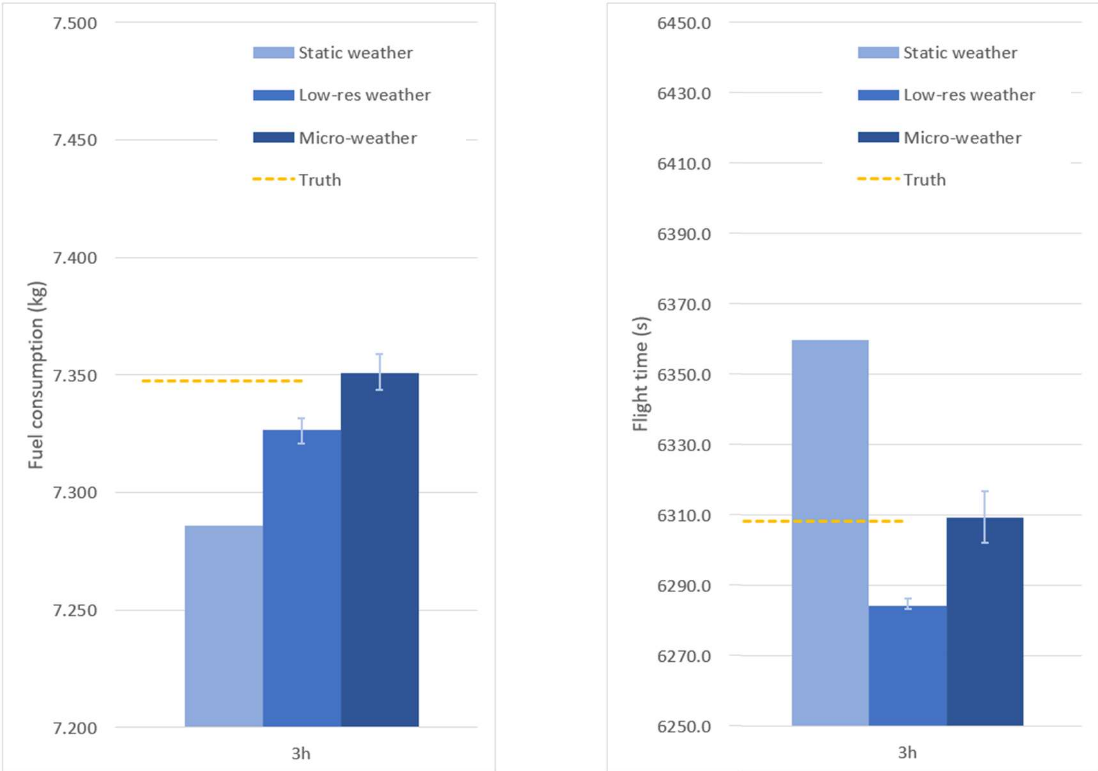


Figure 12. Flight time and fuel burn prediction results at 3-hour look-ahead time

Regarding the **benefits on the traffic management processes,** these high-resolution probabilistic forecasts were used to predict mission times at pre-defined points along the trajectory which were relevant for traffic management. As an example, the predicted entry and exit times to a given airspace volume were obtained. The probabilistic micro-weather forecast enabled a very accurate prediction of the entry (in-time) and exit (out-time) – on an order of magnitude of around 7-second deviation from the truth. This was more than 50% of error reduction in comparison with deterministic and probabilistic low-resolution forecasts.

In summary, a probabilistic approach to weather information provides higher quality information in comparison with existing weather forecasts, improving the quality of many services built on top of it such as the *operation plan preparation assistance* service, the *drone operation plan processing* service or the *strategic de-confliction*.

While the cases executed in our demonstrations clearly showed the specific advantages when using probabilistic weather information for the different planning or executing tasks, they also showed that each use of this information is going to **require an adaptation of the client's process in order to take full advantage of the statistical nature of the information**. That is, the probabilistic weather information offers many opportunities to improve services that depend on weather information but adaptation on the client's side to ingest probabilistic weather data, in numerical format, will be required.

With respect to the **confidence in the results**, it is important to highlight that these results, albeit encouraging, are limited in scope and cannot be generalised. The objective was to illustrate the potential benefits of the approach and we focused only on a very specific case on a specific day with certain meteorological conditions. Further tests considering different weather scenarios, potentially with more uncertainty and a higher influence of micro-scale atmospheric effects should be conducted to further validate the results.

The following table summarized the pros and cons of this service.

***Probabilistic Micro-Weather* Service**	**Description**
Benefits	The service improves quality of many U-space services built on top of it such as the *operation plan preparation assistance* service, the *drone operation plan processing* service or the *strategic de-confliction* from 3-hours ahead.
Constraints	The service requires adaptation of the client's process in order to take full advantage of the statistical nature of the information.
Level of confidence	Medium, due to the following reasons: • Comparison of the high-resolution probabilistic forecasts against true weather values needs to be done to highlight all benefits of the service. • Further tests considering different weather scenarios, potentially with more uncertainty and a higher influence of micro-scale atmospheric effects should be conducted.
Applicability	Drone-dense environments where the need of highly reliable flight, mission and traffic planning compensate the costs of adapting the services to the probabilistic approach. E.g. urban and sub-urban environments
Cost Implications	The scalability test has shown that the cost of the client agents and data brokers grows mostly linearly, being able to use a single middle size server (see tests for hardware details) for 1000 clients, easily scaling to more with multiple servers. While it looks like the *cloud* provided solution would be more expensive, it has to be taken into account that there would be no need

	to use an instance of this size in the number of users is smaller and the service could be seamlessly migrated from one instance type to another when the number of users significantly changes. That is, the cost would be more expensive per user but only actual use would be charged so depending on the capability to predict demand this could not be only a simpler solution but even a cheaper one.

3.1.3.2 *Monitoring* and *traffic information* services

Traffic *monitoring* and *traffic information* services were tested together in a congested airspace (up to 250 simultaneous operations) in which most of the drone flight plans interacted with each other. This exercise was done in a simulated area of 10 km^2. The *monitoring* service obtained information and filtered it to process only the messages related to the position, battery status and attitude of drone flights (orientation, speed, flight mode, etc.). Then, the *traffic information* service processed all positions and displayed them on a drone operator's HMI through a dedicated web server. This service also compared the relative position of each pair of drones and, when the distance between them reached less than 50 m (customizable), it raised an alarm message that was shown in the drone operator's HMI.

Performance characteristics of these services within a micro-service-based architecture were gathered from stress tests on the data exchange processes between the *monitoring* and *traffic information* services. The objectives of this exercise were refined and new objectives and deviations with respect to the D5.1 [6] were detailed in section 2.4.3 of D5.2 [7].

IMPETUS demonstrated that the implementation of these services in a micro-service-based architecture had enough capacity to process the huge amount of inputs expected in congested environments. Once the drone positions were collected by the system, it only took an insignificant amount of time (0.001s) to process the data and prepare it for the user interface. The atomicity of processes in this service and the use of simple messages based on predefined standards (JMS, MQTT and REST) were the cause of a **lightweight execution that was not significantly affected by overloads**. Through the use of basic messages, the data processing stages proved to be agile and efficient, as it was easy to read and parse this information without significant delays. Moreover, the use of simple micro-services and parsing methods ensured that the system workload was not increased significantly when the number of data sources, e.g. additional tracking sources, was increased.

IMPETUS also measured how many alerts about dangerous interactions between drones were received on time by drone operators. Results showed that **the processes for treating alert messages are simple enough to avoid significant delays** while increasing the number of drones in operation, rising from a maximum of 0.24s to 0.28s between 10 and 200 drones. Furthermore, 100% of the alert messages sent were successfully shown on the HMI, meaning that all users were alerted and no information was lost during the information flow. These performances were degraded when the mechanisms to manage and filter the data sent by the drones to the services were not implemented. In this case, the latency between the reception of drones' position and the alerts shown to the U-space users was around 44s when 200 drones were in operation. Consequently, it is recommended to design **proper mechanisms to filter and collecting only the messages of interest** received by such services, i.e. 3D position, attitude, battery and drone status. This filtered information can be sent to a web browser to be represented and stored in the message queue, waiting for another service that will use it. IMPETUS showed in the experiments that it is possible to use existing products in the market that provide the necessary capabilities to manage such information maintaining the required performances e.g. MAVLink protocol to receive and filter the messages of interest. The use of this standard protocol provides the micro-service the necessary speed to meet the demands of the requirements U-space.

However, some performance issues on the provision of alerts were encountered as the number of drones was increased to 250. Therefore, although it is crucial that resource allocation is managed incrementally to allow the system to expand and adapt to the expected growth of traffic, this issue may impact the airspace capacity as **the number of drones that can be managed simultaneously for a certain area and during a certain timeframe should consider system limitations** in some way.

It is relevant to mention that, although the services treated tracking information without any significant delays, the drone operator's HMI processed and showed all the positions with a latency of 1.92s when 250 drones were simultaneously operating. The reason was that the limited capacity of the web browser required the messages to be stored in the queue, waiting for the previous streams to be represented and delaying the delivery of new information. As this latency can be a constraint, the outputs of these processes are data streams that shall be transformed into simple, eye-catching messages and rendered for easy interpretation, it is therefore important **to define which information is necessary for users and the update rates in these outputs**, allowing the interfaces to show all the required information and avoiding bottlenecks in the final part of the chain. This approach must be based on an operational point of view, analysing the criticality of each operation, the congestion in specific areas, the capabilities of each aircraft and operator to react to sudden issues and the use of critical U-space services. These factors will determine the acceptable latency, that should be modified dynamically after analysing the specific environment in which the services will be implemented.

With respect to the confidence in the results, it is important to highlight that the experiments did not consider stress tests in which the system is not capable of recovering, meaning that the failure is caused in the management mechanisms of the architecture. **Contingency scenarios must be defined** and rules for actuation developed in further steps. These could include the use of on-board capabilities of the drones for direct drone-to-drone coordination in case the U-space system fails entirely.

All previous results are detailed in section 3.2.3 of D5.2 [7]. The following table summarized the pros and cons of these services.

***Monitoring* and *traffic information* services**	**Description**
Benefits	No significant overloads or latencies thanks to the lightweight execution of the services and the implementation of mechanisms to manage and filter the data sent by the drones to the services. Use of existing commercial products that provide the required capabilities. It is possible to attach other U-space services to this architecture with the only condition of sending the request in a predefined format e.g. Pre-tactical Geofencing and Tactical Geofencing can obtained information from these services.

Constraints	Need to define standards to provide the necessary mechanisms to process the information. If the system is planned to introduce more micro-services, for different issues, all must talk the same language, in case they have to collaborate among them. Need to ensure that update rates in the drone operator' HMI are aligned with the required performances in a certain area and timeframe.
Level of confidence	Medium, due to the following reason: • Further tests considering contingency scenarios in which the services are not capable of recovering, meaning that the failure is caused in the management mechanisms of the architecture .
Applicability	Any type of environments (high, medium or low density) provided that the maximum number of drones that can be managed simultaneously consider system limitations.
Cost implications	The micro-service architecture that has been used for the provision of traffic information services has been mainly implemented using open source technologies (MongoDB, ActiveMQ, PostregsXL/PostGIS, IGNITE and Kubernetes). The cost of this platform, despite the efforts to develop it, relies in the initial Listener to process the information and the physical support that contains this architecture and, even in this case, the NGINX module (listener) is already integrated in Amazon Web Services (AWS), so the cost is also reduced.

3.1.3.3 *Mission management* services

Current drone operations follow very different mission planning procedures. The goal of this experiment was to outline and streamline the associated processes based on foreseen operational requirements for U-space, which include the consideration of drone-specific aeronautical information, local-scale meteorological models and local meteorological measurements. To do so, *operation plan preparation assistance* and *drone operation plan processing* services were prototyped in an environment scenario having a density of 15 drone operations per square kilometre[7]. The first one utilized a cost function to achieve mission requirements whilst adhering to safety-critical considerations such as the avoidance of restrictions, maintaining adequate ground clearance and considering wind-speed limitations. Flight plans generated by the *operation plan preparation assistance* service were then sent to a centralized *drone operation plan processing* service that de-

[7] Compared with the projection in ConOps (section 2.5.7) this can be regarded as a high projection.

conflicted trajectories from each other as well as from adverse weather areas[8]. These results are further detailed in section 3.2.2 of D5.2 [7].

IMPETUS demonstrated that the *operation plan preparation assistance* service can improve the overall level of safety of the approved missions as opposed to standard mission planning. As standard mission planning is considered legacy solution (e.g. QGroundControl, Mission Planner) where route planning can be conducted as a sequence of waypoints defined by the operator. In many cases the *drone operation plan processing* service detected a conflict in the submitted flight plans with external trajectories previously approved and stored in the flight plan database. To de-conflict, this centralized service sent information about the nature of the conflict (conflicted leg with timing characteristics) to the *operation plan preparation assistance* service. Using this information, the *operation plan preparation assistance* service re-modelled the 4D trajectory while taking the mission requirements into consideration. The *drone operation plan processing* service never restricted the updated 4D trajectory proposed by the *operation plan preparation assistance*. Furthermore, the provision of information about the reason for conflict was sufficient for the *operation plan preparation assistance* service to generate a new feasible trajectory that met defined mission and safety requirements. Besides considering operational safety-critical aspects, a great emphasis was placed in the mission planning capability for fulfilling the overall mission requirements. The employed modelling functionality considered multiple factors (power consumption, clearance from ground surface) for the modelling of a feasible trajectory.

IMPETUS also demonstrated that stability of using *strategic de-confliction* based on trajectory models was not significantly affected by the uncertainty of predicted weather conditions and inaccuracies in local measurements. Whenever a conflict with weather was detected, the de-confliction algorithm generated a new trajectory with a larger clearance volume in three-dimensional domain from the digital elevation model. Whenever a conflict with another drone was detected, the de-confliction solution was able to produce a new 4D trajectory. However, the deviation in the newly generated trajectories from the original is as large as 7% of the trajectory length in the spatial domain. However, only in less than 10% of the cases the adapted trajectory deviated more than 5% from the initially created trajectory in the spatial domain. The maximum 7% deviation in the de-conflicted trajectory from the original did not affect the overall mission goals (maximum flight duration of de-conflicted trajectories was less than maximum accepted).

The experiment also tested up to which point the current definition of temporal airspace restrictions i.e. official standard NOTAMs, are suitable for drone operations. The de-confliction algorithm extracted the relevant characteristics of the NOTAM publication (applicability to drone operations, coordinates and duration) and compared this information with the modelled 4D trajectory. When a conflict was detected the trajectory was adapted for not violating the occupying NOTAM volume in the spatial domain. Deviations of the trajectories from the originally planned routes reached as high as 39% in the spatial domain. Moreover, in less than 36% of the cases the adapted trajectory deviates more than 10% from the initially created trajectory in the spatial domain. Consequently, there were de-conflicted trajectories that were not able to meet one of the mission requirements which was related to the maximum flight duration.

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[8] The *strategic de-confliction* service is seen as part of *drone operation plan processing* service in this approach.

Functionalities for conflict detection and resolution were developed for conflicts involving two trajectories, trajectory-to-weather and trajectory-to-airspace restriction. For weather-based de-confliction, it was useful to complement weather models with measurements from available local sensor platforms with official reports. However, it is relevant to consider resulting deviations in the measurements from different sources and special attention has to be placed in the employed interpolation methods.

For the de-confliction solution based on airspace restrictions it still remains a challenge to extract all the necessary information from temporal airspace sectorisation publications in order to accurately model a restricted volume and therefore perform a *strategic de-confliction* in the spatial domain. Additionally, given the large occupying volume of current airspace restrictions, it becomes challenging to work with de-conflicted trajectories that can also still meet the overall mission goals, such as a maximum flight duration.

As a constraint, one relevant aspect that was not considered is the **operational uncertainty when modelling trajectories in the spatial and temporal domain**. This is where the utilization of advanced weather services would be of utility. Furthermore, according to the type of the mission and location, additional aspects should be considered for the trajectory optimization, such as population density and further geospatial information in the case of urban environments.

During the simulation campaign of the mission and planning processes the data flow management has been measured and analysed in terms of processing time. Compared with the processing time required by the *operation plan preparation assistance* service for the flight plan generation, the processing time required by the *drone operation plan processing* service was significantly lower, which shows that the micro-services implemented in the *drone operation plan processing* service are lightweight functionalities that can respond efficiently to flight plan requests. Although the *drone operation plan processing* service is not the most critical among the set of U-space services when it comes to workload and response time demands, it becomes relevant on the other hand to supervise and monitor to ensure a consistent flight plan database within the centralized system.

It should be stressed that the conflict resolution capability involving two trajectories has been placed on the side of the service provider (*operation plan preparation assistance* service) in this framework. If this shall not be the case, there has to be further research on how to exchange flight plan data between the *drone operation plan processing* and *operation plan preparation assistance* services during the conflict management phase. In case that the centralized *drone operation plan processing* service shall cover the conflict detection and resolution functions, it is expected that the drone operator will still be part of the renegotiation process when formulating a de-conflicted feasible flight trajectory. When looking back to the proposed framework, a further aspect yet to be evaluated in conflict management is the potential design of a set of proposals or recommendations that can help the operator in his/her re-planning of the mission.

All previous results are detailed in section 3.2.2 of D5.2 [7]. The following table summarized the pros and cons of these services.

Mission management services	Description
Benefits	Provides a framework for de-conflicting trajectories from each-other, weather and airspace restrictions without the need for a centralized de-conflictor or requiring additional information from other planned drone missions (beneficial in terms of privacy).
Constraints	Additional aspects, such as a possible need for trajectory optimization, or the inclusion of restrictions due to population density and geospatial information (in the case of urban environments) were not considered
Level of confidence	High (for low and medium density environments). According to the type of the mission and location, additional aspects should be considered for the trajectory optimization, such as population density and further geospatial information in the case of urban environments.
Applicability	Low and medium density environments as advanced weather services and the associated measurement of uncertainty could be a constraint to implement these services in high density environments.
Cost implications	Assessing the average processing time of these service request made it possible to assign the consumption of resources to computational costs. In the analysis performed in this exercise, it has been demonstrated that the most resource demanding service requests can be identified and quantified. This is quite beneficial for economic aspects, as it could be assessed and estimated how the various flight planning service requests could be precisely (and potentially individually) billed based on the computational resources that they consumed in a cloud computing environment.

3.1.3.4 *Tactical de-confliction* and *dynamic capacity management* services

Today, all drones operate under the same operating conditions defined by their level of certification, regardless of their actual mission. This operating method hinders the growth drone operations. Mission-adaptive traffic management services need to be in place in order to facilitate drone operations in the future. The proposed service uses information stored in a registration system to influence the flight plan approval process through performance & permission-based airspace access and dynamic separation criteria. Access to the airspace will be determined by capability, equipage levels and exemptions. Separation criteria will be based on the drone's manoeuvring capability and mission constraints. This way, drone operators will only need to equip their drones for the operating areas and missions they attempt to fly. Furthermore, all data will be recorded for post flight analytics.

IMPETUS verified the **applicability of dynamic separation criteria based on drone performances** which adapt the size and shapes of the safety buffers around drones. Using positive field theory, a standard size and shape of a field was established around individual drones. The number of drones was increased until their operations could no longer be carried out safely and/or efficiently. The size and shapes of the fields were changed to mimic differing types of operations, such as emergency operations. The type of operation and the types of drones being used needed differing separation requirements, which were modelled to assess the effects on airspace capacity.

The service was able to manage up to a maximum of 1,000 drones within a fixed area of approximately 60 km^2, i.e. **16 drones per km^2, and with at least one conflict per drone flight plan**. That is the service was able to handle high density and high complexity environments without having any loss of separation incident.

We have observed that, as the number of drone flights increased, there was a threshold in which the average efficiency for each drone operation started to decrease due to required conflict resolution actions. Thus, this **capacity threshold was more clearly linked to the decrease of the efficiency of the missions than to the increase of encounters**, which were all solved by the service. We considered that a reduction in efficiency below 50% is the point in which the capacity limit is reached. 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.

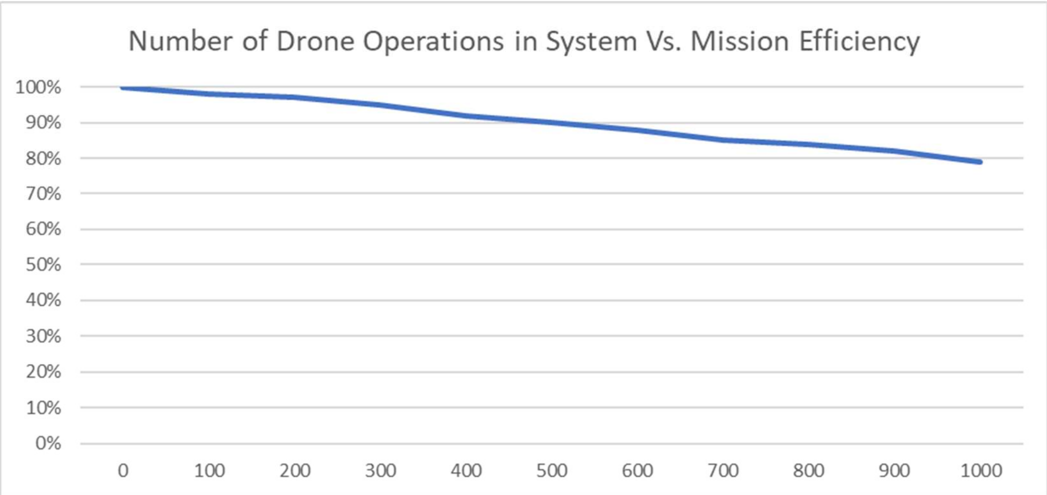


Figure 13: Number of drones versus drone operations efficiency

The service was able to identify every drone to which new airspace restrictions applied during the execution of the mission, and reroute the drone without causing any hindrance to the completion of the mission objectives. Conflict resolution was achieved by having the drones turn to the *right* of 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.

We have also found the need to strategically de-conflict the drone flight plans in order to reduce the amount of *tactical de-confliction* actions, and therefore decrease the number of in-flight conflict resolutions. This process increased the overall efficiency of the system’s drone operations. The original modelled algorithms required some adaptation due to edge cases where drones were taking unexpected deviations or even getting stuck as part of their tactical conflict resolution actions. The algorithmic changes primarily focused on adding **additional *strategic de-confliction* recalculations where tactical resolution was required.**

It is noted that while IMPETUS used a foundation technique for *tactical conflict resolution* there is still room for **improvements to these algorithms to increase efficiency**. The weights used in the experiments have been tweaked, however are still on the more cautious side of things. It is possible that these could be decreased further over time as higher degrees of certainty and confidence is built in the data feeding the system, as well as those to services used to communicate with drone operators or the drones themselves.

We acknowledge that no attention was paid to remaining flight capabilities/characteristics and that the placement and volume of the new temporary flight restriction would, for example, have a potentially significant impact on the ability of participating drones to be able to conduct their flight "without hindrance". Further research would be required here.

IMPETUS also showed that all data applicable to post-operational analysis can be recorded and replayed in post-ops. Being able to **replay and trace tactical conflict resolution activities has helped review and improve efficiency of the service**.

The following table summarized the pros and cons of this service.

***Dynamic Capacity Management* Service**	**Description**
Benefits	The service is able to manage a maximum density of approximately 16 drones per km^2 and with at least one conflict per drone flight plan without any loss of separation. This is supported by the application of an easy-to-implement logic for *tactical conflict resolution* which consists of turning to the right of the drone which is in conflict.
Constraints	Availability of information about the type of operations and type of drones operating in the area to be able to dynamically manage the separation based on drone performances and mission targets.
Level of confidence	Medium, due to the following reasons: • Further study is required to optimise guidance given to conflicting drones such that additional attention is paid to their flight capabilities. • Criteria for separation need to be further validated with drone manufacturers.
Applicability	Drone-dense and high-complex environments where the costs of implementing new services such as *dynamic capacity management* and *tactical conflict resolution* are balanced by the efficient use of airspace capacity. E.g. urban and sub-urban environments
Cost implications	Not tested.

3.1.4 Conclusions on maturity of the services/capabilities

IMPETUS is located at the first phases of the investigation, covering fundamental science and outreach, and investigating the initial applications of this science for U-space. At the end of the project, the initial expectations were that solutions had to reach the Technology Readiness Level 2 (TRL) paving the way towards TRL3. IMPETUS assessed the maturity criteria per service tested and attached this information in Appendix C of this document. Additionally, a summary can be found in the following sections highlighting the contribution of the project to evolve the state of the art of each service under test.

3.1.4.1 *Weather information* service

The *probabilistic micro-weather* service proposed and tested in IMPETUS is very much aligned with the *weather information* service that the CORUS concept, which mandates such a service as required at the U2 phase for all kinds of air volumes, defines.

In our opinion, the proposed service meets all three requirements expressed through the ConOps document with some limitations, mostly not covering all possible scenarios (see gaps listed below):

- **Provide weather forecast** with all relevant parameters for operations and enough resolution when required by the application.
- **Provide alarms to the users of the service when not enough data** is available to make predictions with enough quality while also providing the degraded prediction.
- **Assist the *drone operation plan processing* service** to predict a construction of **a probabilistic 4D model of the flight**'s likely airspace occupancies.

The developed service also offers functionality not required in the U-space ConOps further enabling the concept. Basically the probabilistic nature of the output of the service allows to meet the second and third requirement surpassing the definition.

In the second case, as the *weather information* service provides not only a single prediction but a whole set of them, the uncertainty of the output is measurable, explicit and not hidden away from the user. This means that every user is able to decide internally when to rise alarms due to the lack of certainty in the weather information, effectively evolving from the simpler externally provided alarm that can only be present or not to provide the means to measure the precise impact of the uncertainty of the provided weather information. The experiments we performed reflect the advantages of this approach for many types of weather service clients such as mission planners and trajectory predictors.

In the third case, the proposed *weather information* service does not only provide a forecast so that the *drone operation plan processing* service can estimate probabilistic 4D models of the expected trajectories, but allows it to actually measure the impact on the uncertainty that is due to the weather information quality. In this regard, we should mention that, although the ConOps does not mention any statistical approach to weather information, we have shown the benefits of this approach and we recommend its inclusion.

The presented *weather information* service has also been developed and deployed following the micro-service approach internally. The tests performed to stress test it shows that this approach is very scalable and economically feasible for most scenarios. These tests were performed by using realistic scenarios using real data and real planning tools based on Base of Aircraft Data (BADA) models for realistic vehicle dynamics simulation.

As indicated in the scenarios tested, the potential benefits for drone operations and its full service ecosystem of using weather information from a service that provides probabilistic information can have far-reaching consequences, increasing safety and predictability of the overall system.

For the implementation of this service, weather information data standards have been applied and, as IWXXM in its current form (both version 2.1 and proposed 3.0) already support embedded GRID data, no new standards have been identified.

The work conducted complies with some maturity criteria of SESAR defined TRL2 and TRL4 categories, and no blocking point for further maturity was identified. In any case, there are some aspects which were not addressed in the experiments and that could be transversal to any implementation in the cloud such as cyber-security implications.

3.1.4.2 Monitoring and traffic information services

Traffic Monitoring and Traffic Information services were tested together in a congested airspace in which most of the drone flight plans interacted with each other with a density of 25 drones / 10 km^2. However, relevant functionalities which are part of these services according to the U-space ConOps [22] were not implemented as the exercise was more focused on testing the benefits and drawbacks of the micro-service architecture itself than on the specific services functionalities. In particular, *traffic monitoring* should retrieve data from tracking service and combine it with information related to non-cooperative obstacles and vehicles to provide air situation status. Additionally, this service should include *operation plan conformance monitoring*, *weather limit compliance monitoring*, *ground risk compliance monitoring* and *electromagnetic risk monitoring*. IMPETUS researches neither on the integration of tracking sources nor on this set of monitoring aspects. The service provided only the drone pilot or operator with traffic information and warnings about other flights – manned or unmanned - that may be of interest to the drone pilot. We can conclude that, **although the IMPETUS implementation was aligned with the U-space ConOps [22], only a limited set of functionalities of these services were tested** given that the exercise was mainly focused on testing safety & failure modes, data management processes, scalability, flexibility and commercial implications of the micro-service-based approach through an architecture which is consistent with the U-space architecture principles.

With respect to the performances[9] of the services, IMPETUS demonstrated that the services have enough capacity to process the envisioned amount of data in congested environments, allowing to show tracking information and alerts with surrounding traffic to the drone operator on time. It is relevant to mention that, although the services treated the tracking information without no significant delays, the drone operator’s HMI processed and showed all the positions with a higher latency that could impact the safety of the operations. This issue needs to be mitigated by defining which **information is necessary for users to operate and the update rates in these outputs**, allowing the

[9] We are referring here to the system performances (latency, processing time…) and not to the SESAR key performance areas (KPAs) which are not fully applicable to U-space in our opinion.

interfaces to show all the required information and with a level of performances that could vary depending on the specific environment in which the services will be implemented[10].

3.1.4.3 *Operation plan preparation assistance* service

The *mission planning management* service proposed and implemented in IMPETUS provides many of the features that the ***drone operational plan preparation assistance*** service from the U-space ConOps envisages:

- Allow the operator to prepare a flight plan and submit it to the *drone operation plan processing* service.
- Allow the operator to check on the status of a flight plan that has been submitted.
- Allow the operator to cancel or submit an update to a flight plan that has been submitted.

The *operation plan preparation assistance* service is mature enough to generate and exchange the **flight plans** using a common data format (JSON) and takes into account the most relevant flight plan information (as identified in D2.2). Most notably, the trajectory modelling capability is able to output a trajectory with a 3D geometry profile and corresponding timing for a **multicopter** drone type.

Furthermore, the trajectory derived from the modelling capability results from an optimization process where typical **mission requirements** (e.g. power consumption, obstacle avoidance) are considered as constraints in the optimization problem. The service is able to produce a feasible 4D trajectory within a reasonable period of time.

3.1.4.4 *Drone operation plan processing* service

The *flight planning management service* proposed and implemented in IMPETUS represents the functionality of the ***drone operation plan processing* service** from the U-space ConOps in the way that:

- Ingests drone flight plans for assessment and is responsible to maintain them in a single instance (database).
- Performs syntax, semantic checks and assigns unique identifiers.
- Processes the drone trajectory and assesses for conflicts with existing trajectories laying in the database.
- Interacts with the operator for updating or cancelling a submitted flight plan.

The *drone operation plan processing* services is mature enough to not only interact with *operation plan preparation assistance* services from different service providers, but also to interact with other U-space services (e.g. *traffic management*) that required certain flight plan information. This is made

[10] U-space Very Large Demonstration (VLDs) such as DOMUS have also identified the need of improving the drone operator' HMI in their Human Performance Assessment. IMPETUS did not perform this type of assessment but a similar conclusion was obtained by analysis the performances of these services.

possible through the definition of specific request methods which are based on a **common protocol** (for instance: HTTP).

The **notification feature** included in the *drone operation plan processing* service is able to keep the operator informed about any changes related to the submitted flight plan and that may originate from external factors (e.g. incoming flight plan with higher priority).

3.1.4.5 *Tactical de-confliction* and *dynamic capacity management* services

During this project, IMPETUS focused on *tactical conflict resolution* (*tactical de-confliction* within the CORUS definition) in the context of *dynamic capacity management*.

Tactical conflict resolution is all about ensuring separation during flight, in circumstances where *strategic de-confliction* (pre-flight or when re-planning) is not possible due to uncertainties in a dynamic airspace.

The exercises were based on Altitude Angel's existing GuardianUTM technology and updated with elements related to *tactical conflict resolution*. This platform was (and continues to be) the state of the art at the time of the execution of the exercises. From this, we were able to build a technical proof of concept and model to test a dynamic capacity management capability, optimised for the predicted increase in UAS traffic over the medium and long term in high traffic areas (Type Zu) and around congestion points such as those over Frankfurt and London.

IMPETUS has achieved this not only by optimisations within the algorithms themselves, but critically using a plethora of information that is expected to be made available to the system before and during flight.

The work conducted falls somewhere between the SESAR defined TRL2 and TRL4 categories, but it is critical to acknowledge that the focus of this project was on experimental research (development and testing of a model through simulations), rather than a real-world demonstration, which is a future step. In fact, since the delivery of IMPETUS, further work is already underway to push the some of the results of the research conducted into Altitude Angel's product roadmap.

3.2 Recommendations and requirements

3.2.1 Recommendations and requirements for next phase

Based on the previous maturity assessment, IMPETUS can provide the following recommendations to improve the level of service maturity for the next phase. The content is presented on a service-by-service basis and provides identified gaps which are relevant to increase the current maturity of the services.

3.2.1.1.1 *Weather information* service

There are mainly two gaps that need to be filled to further mature the service in our opinion:

- **Perform tests on dense urban scenarios**: Performing simulation tests covering dense urban scenarios would allow us to measure the effect of **adding computational fluid dynamics** (CFD) to compute the effect of building at a hyper local scale on the weather variables, mostly wind. Work is being done to add this functionality to the core weather service to achieve this.

- **Assess the required work on client services** to make use of the probabilistic nature of the predictions provided by the service. In the tests we have performed during this project we have used ad-hoc software to simulate the consumers of weather information such as mission and trajectory planners. This has allowed us to measure the advantages that this approach brings versus a traditional one in a quantitative way. A study on the cost of these modifications on existing services should be performed to be able to perform a cost benefit analysis from each potential client's point of view.

3.2.1.1.2 *Monitoring* and *traffic information* services

The experiments did not consider stress tests in which the system is not capable of recovering, meaning that the failure is caused in the management mechanisms of the architecture. **Contingency scenarios must be defined** and rules for actuation developed in further steps. These could include the use of on-board capabilities of the drones for direct drone-to-drone coordination in case the U-space system fails entirely.

Other relevant aspects to be consider in further steps are the need of a standard definition for the format of the data provided by the different actors. We used simulated drones (synthetic ones), so the format of the data was uniform and known by the *monitoring* service. In case the service has to listen to other different devices, they should adapt to this format, or all of the actors should use a standardized protocol.

The security in communication should be reinforce and probably, the redesign of a new refreshing procedure for the HMI should be taken into consideration, or at least redefine the latency or refresh time for the information directed to the HMI.

3.2.1.1.3 *Operation plan preparation assistance* service

Although the optimization capability is able to include safety aspects in the trajectory modelling (avoidance of airspace restrictions), it is necessary to further consider the **ground risk** (e.g. in populated areas) in the creation of a feasible trajectory.

To increase the maturity of the current modelling solution, it is necessary to account for the uncertainty in the path definition. Particularly, for drone operations the trajectory is highly dependent on the mission (e.g. inspection purposes). In consequence the definition of uncertainty buffers needs to be further examined.

The proposed flight plan definition should also be expanded with procedures applicable for foreseeable **off-nominal scenarios**, such as loss-of-link, and its associated contingency measures.

Lastly, a remaining gap is the definition of an entire mission plan that encompasses the operation of **many drones** following the same mission purpose, which is becoming common practice for numerous mission types, such as photogrammetry, phenology or drone shows.

3.2.1.1.4 *Drone operation plan processing* service

An assessment against other drone trajectories has been implemented and tested. However, further **boundary checks** (e.g. NOTAMs and general geofences) as well as an assessment against **adverse weather conditions** should be integrated in validation feature.

Within the scope of the exercise, no interaction between the *drone operation plan processing* service and a general ***dynamic capacity management*** capability has been examined. Given the tested scenario (drone trajectories with a precise 4D specification, density of drone operations: 15 per square kilometre), the resulting planned traffic did not have a large impact in the re-planning processes resulting from conflicting cases. However, **trajectories with uncertainty** (or for instance trajectories occupying complete volumes) should also be considered. The resulting demand for airspace utilization could impact capacity and therefore lead to more requests for re-planning than the ones observed in the examinations.

The validation process of the *drone operation plan processing* service is highly automated (response rate: 12 flight plan requests per second). To increase the maturity of the solution the interaction with the ***procedural interface with ATC*** should be examined additionally. This could indeed have a large impact in the response rate of the *drone operation plan processing* service.

The **scalability** of a micro-service implementation of the *drone operation plan processing* service in relation to increasing computing power to resolve large de-confliction and re-planning features is a remaining gap to be further researched.

3.2.1.1.5 *Tactical de-confliction* and *dynamic capacity management* services

With regards to the U-space definition, it is likely that the *tactical de-confliction* and *dynamic capacity management* definitions could be broadened to include aspects of IMPETUS (i.e. the production capability level for example between the service in U3 and then U4).

Safety performance, security assessments and environmental assessments are all relevant to the solution, however, were out of scope and assumption based in the focus of the model and proof of concept. These are all covered in relation to state-of-the-art production systems, however IMPETUS did not focus on advancing these outside of their current scope at this time.

The project did not focus on the economic or commercial aspects of the future system, which are still hypothetical as associated non-U-space related technology costs. Business use cases for U-space maybe addressed in a separate project with the estimated running cost of IMPETUS services feeding into such analyses.

There is a gap within the standards required for the information management systems, in order to facilitate seamless cooperation of complementing U-space services from different suppliers.

Further information systems will need to be developed and existing ones optimised to improve the performance of *de-confliction* and *dynamic capacity management* services. Focus should be on improving the situation picture and advancing the system's ability to predict changes to the airspace environment and those operating within it.

3.2.2 Recommendations and requirements for updating the master documents

This section summarizes the discrepancies in the U-space services that were tested by IMPETUS with respect to their description in the U-space ConOps. Each section lists the main aspects of the service that have been tested in reference to the definitions in the ConOps in a tabular form. The structure of the table is explained below.

Table 6: Overview of the tabular structure used to describe discrepancies between the service definitions in IMPETUS and those provided within the U-space ConOps

ID	*Identifier of the table. The structure of the identifier is as follows:* *[SERVICE]-discrepancy.01*
Service aspect	*Aspect of the service that has been refined.*
Corresponding section in U-space ConOps	*Reference and title of the corresponding section in the U-space ConOps main document.*
Observation	*Definition of how the discrepancy affects the description of the service in the U-space ConOps. Titles are limited to one of the following:* • *Refinement;* • *Amendment; or* • *Contradiction.*
Updated description in U-space ConOps	*Proposal of how to update the content of the U-space ConOps.*

Based on the tabular discrepancy lists of section 3.1.1, we propose the following updates to the texts of the U-space ConOps main document:

ID	Weather information-discrepancy.01
Service aspect	Service enablers
Corresponding section in U-space ConOps	5.1.7.1 Weather information
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **The *weather information* service is an integral part of the architecture, which offers basic functionalities to other services (such as mission planning or traffic separation control). Therefore, the implementation thereof should aim to enable its client services, just as much as providing weather information. The following enablers should be offered to clients of the weather service:** • **Maximise automation: In order to achieve the desired U-space high capacity and low cost per actor.** • **Uncertainty measurement: As required by the drone operation plan processing service to predict a construction of**

	a probabilistic 4D model of the flight's likely airspace occupancies. • **Service robustness: As the weather service is a primary service its failure would lead to a cascade of services that can't perform their tasks or at most do it sub optimally**

ID	Monitor and Traffic Management -discrepancy.01
Service aspect	Redundancy of the services
Corresponding section in U-space ConOps	5.2.1 Architecture principles
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **Service reinstating: The architecture should provide the mechanisms to create new instances when an overload or a fault of a service occurs.**

ID	Monitor and Traffic Management -discrepancy.02
Service aspect	Status of the drone.
Corresponding section in U-space ConOps	5.1.6.1 Monitoring service
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **The minimum dataset to be sent from the drone to the system must include the drone ID, position and battery status. Optionally It should include a mechanism to validate the data received, something like a CRC or Checksum to guarantee the reception quality of the received data.**

ID	Mission management-discrepancy.01
Service aspect	Mission planning capabilities

Corresponding section in U-space ConOps	5.1.3.1 Drone operational plan preparation assistance
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **To ensure mission feasibility and other "Quality of Service" aspects, a modern mission planning service shall consider the performance characteristics of the UAV platforms and payloads to be allocated to the mission, as well as all context information relevant to the mission.** **For single UAV missions, the mission planning service shall output a plan that includes the flight plan along with the specific tasks to be performed by the on-board and ground mission execution resources in coordination with the trajectory execution resources.** **For multiple UAV missions, the service shall output a consolidated plan that breaks down into the specific mission plan for each single UAV; when dynamic mission re-planning is required upon mission, flight or traffic execution events, mission planning shall interact with flight planning to safely accommodate mission plan changes that involve trajectory changes.**

ID	Mission management-discrepancy.02
Service aspect	Operational plan optimisation
Corresponding section in U-space ConOps	5.1.3.1 Drone operational plan preparation assistance
Observation	Amendment
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **The utilization of techniques for refining 4D trajectories based on a cost function of the variables provided below is a viable solution mission trajectory optimisation. This cost function could include aspects related to power consumption (P), the overall distance (D), the flight time over safety-critical areas (R), clearance from the ground surface (G) and further restricted airspace volumes (A).** **As these parameters are closely linked to the SORA processes, the *risk analysis assistance* service could be incorporated into the *drone operational plan preparation assistance* service. In this way, the service will generate an initial drone operational plan which will comply with SORA requirements. This will imply to extend the**

	proposed cost function with other parameters which are relevant in the SORA processes.

ID	Mission management-discrepancy.03
Service aspect	Probabilistic weather factors affecting mission planning
Corresponding section in U-space ConOps	5.1.7.1 Weather information
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	The service to collect and present relevant weather information for the drone operation. This includes hyperlocal weather information when available/required. **The use of high fidelity probabilistic weather predictions of meteorological variables that can be relevant to the mission can improve assessment of whether the mission is feasible, safe to execute or economically viable before actually planning the flight trajectory.**

ID	Mission management-discrepancy.04
Service aspect	Trajectory uncertainty
Corresponding section in U-space ConOps	5.1.3.4.1 Trajectory uncertainty
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **Trajectory uncertainty can be greatly reduced through the use of *probabilistic micro-weather* services which improve the planning of fuel loading, mission time and vertical climb/descent profiles when performed 3 hours in advance of the operation. The weather predictions are considered reliable enough could help to value the Reasonable Time To Act (RTTA), the time period far enough before flight execution that a disturbance to the operations has minor repercussions.**

ID	Mission management-discrepancy.05
Service aspect	Glide distance

Corresponding section in U-space ConOps	5.1.3.4.3 Contingency plans
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **Contingency plans can be supported through the utilisation of probabilistic weather information. This information could improve contingency planning for engine failure incidents, by predicting whether the aircraft is able to glide to a safe landing location.**

ID	Mission management-discrepancy.06
Service aspect	Contingency plan in case of failure of the weather service
Corresponding section in U-space ConOps	4.3.5 Contingency plans for U-space services
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the table provided in the ConOps section, we propose to add the following paragraph:* **Service contingency plans also benefit the U-space architectural design. In case of failure of a dependent data source for other services, the ability to swiftly switch to another provider can be achieved by listing each service in the system with an alternative data source. The architecture´s *discovery* service would keep a categorisation system of data providers.**

ID	Mission management-discrepancy.07
Service aspect	Drone operation plan data-pool
Corresponding section in U-space ConOps	5.1.3.3 Drone operation plan processing service
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	The *drone operation plan processing* service maintains a pool of data containing the histories of all submitted flights that have not yet been archived. Archiving occurs at some time after the flight lands or is cancelled. The data in this pool is considered to be commercially sensitive and may additionally be restricted for other reasons – such as

<table>
<tr><td></td><td>for state operations. Hence access to this data is controlled. The following data fields should be included in storage:
<table>
<tr><th>Flight plan data field</th><th>Description</th></tr>
<tr><td>Flight ID</td><td>Unique identifier assigned to the submitted flight plan</td></tr>
<tr><td>Priority level</td><td>Level assigned to the flight trajectory</td></tr>
<tr><td>Status</td><td>Requested, pending, valid/invalid, approved/rejected</td></tr>
<tr><td>Operator ID</td><td>Identifier assigned to the registered operator</td></tr>
<tr><td>Lateral, vertical path and timing</td><td>Sequence of waypoints and associated timestamps</td></tr>
<tr><td>Mission purpose</td><td>Description of the mission for priority assignment</td></tr>
<tr><td>Departure time</td><td>Date and time in standard format</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>ID</td><td>Conflict management-discrepancy.01</td></tr>
<tr><td>Service aspect</td><td>Drone operation plan data for strategic conflict detection</td></tr>
<tr><td>Corresponding section in U-space ConOps</td><td>5.1.4.1 Strategic conflict resolution service</td></tr>
<tr><td>Observation</td><td>Contradiction</td></tr>
<tr><td>Updated description in U-space ConOps

(updates are highlighted in bold writing)</td><td>In addition to the text provided in the ConOps section, we propose to add the following paragraph:

The drone operation plan processing service is able to identify conflicts among flight plans utilising the following pieces of information:
<table>
<tr><th>Flight plan data field</th><th>Description</th></tr>
<tr><td>Operator ID</td><td>Identifier assigned to the registered operator</td></tr>
<tr><td>Lateral, vertical path and timing</td><td>Sequence of waypoints and associated timestamps</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td></td><td>
<table>
<tr><td>Mission purpose</td><td>Description of the mission for priority assignment</td></tr>
<tr><td>Departure time</td><td>Date and time in standard format</td></tr>
<tr><td>Estimated time of arrival</td><td>Date and time in standard format</td></tr>
</table>
Another possibility for strategic conflict resolution is to leave the process of resolving conflicts to the operator. Conflict information can be sent to the drone operational plan preparation assistance service together with a request to submit a different drone operation plan. This process allows the drone operator to take the final decision on how and where to fly.
</td></tr>
</table>

ID	Conflict management-discrepancy.02
Service aspect	Criteria for strategic conflict detection among flight plans
Corresponding section in U-space ConOps	5.1.4.1 Strategic conflict resolution service
Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	Detection broadly involves examining the probabilistic 4D trajectories predicted by the *drone operation plan processing* service and looking for pairs which have a reasonable probability of coming closer than is allowed in any given airspace. **The key criteria in the conflict detection process are as follows:** • **A separation margin in the spatial and temporal domain is defined for all the trajectories, independent of the mission type;** • **Prioritization criteria: the *drone operation plan processing* service assigns a priority level to the flight plan according to the mission purpose (e.g. search and rescue missions have higher priority than commercial missions). In case that the priority levels are equal, the controlling instance follows a first-come-first-serve principle.**

ID	Conflict management-discrepancy.03
Service aspect	Prerequisites for pre-tactical conflict resolution of flight plans, including weather

Corresponding section in U-space ConOps	5.1.4.1 Strategic conflict resolution service
Observation	Amendment
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **Apart from the resolution of conflicts between trajectories, this service may also de-conflict trajectories with weather or terrain. This can be achieved through the utilisation of local weather observations and weather reports in METAR format, and subsequent mapping thereof onto a grid-model. Conflict resolution with terrain must include a 3D digital elevation model of the area to be de-conflicted.** **The key criteria for conflict detection with areas of high wind velocities are defined as follows:** • **For wind speed measurements under an admissible threshold: condition regarded as not adverse and no conflict is detected;** • **For wind speed measurements over an admissible threshold, but still under the maximum admissible value: condition regarded as adverse and conflict is detected;** **For wind speed measurements over the maximum admissible value: condition regarded as not feasible for proceeding with the flight planning.** **The criteria for specifying the clearance value for conflict resolution with adverse weather and terrain is the following:** • **Small deviation in measurements from different sources in grid cell (low weather uncertainty): small clearance value from elevation model;** • **Large deviation in measurements from different sources in grid cell (high weather uncertainty): large clearance value from elevation model.**

ID	Tactical de-confliction-discrepancy.01
Service aspect	Tactical de-confliction concept for ‘Zu’-airspace
Corresponding section in U-space ConOps	5.1.4.2 Tactical conflict resolution
Observation	Refinement

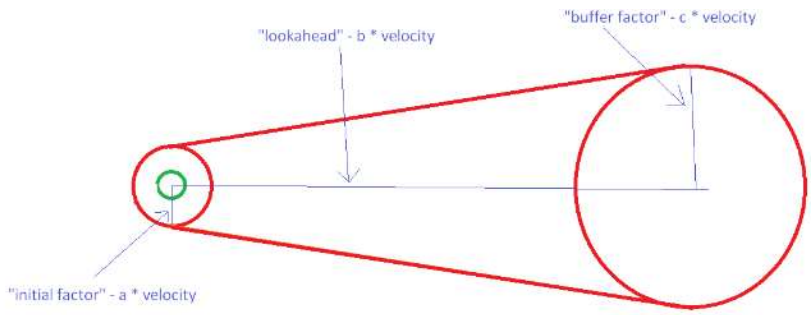
<table>
<tr>
<td>Updated description in U-space ConOps

(updates are highlighted in bold writing)</td>
<td>

In addition to the text provided in the ConOps section, we propose to add the following paragraph:

***Tactical de-confliction* of drone flights in 'Zu'-airspace can be achieved through the use of a *positive field theory* algorithm. This type of algorithm uses weights to determine separation bubbles around each drone. The separation bubble shall have the following shape:**

A circle drawn around the vehicle (an arbitrary numeric value, multiplied by velocity), with another circle projected out (distance defined by the same arbitrary value multiplied by velocity, with radius calculated similarly). These two circles are merged (with the space between them treated as a solid shape) to create a conflict resolution zone. This results in a cone shape projection out ahead of the vehicle's direction of travel.



A conflict between two drones occurs when their 'cones' intersect.

Conflict resolution is achieved by having the drones turn to the *right* of the drone they conflict with; the amount they rotate/turn rate is determined by a "time to impact", where the sooner the objects will collide, the more they will turn.

These instructions are 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 instances where a drone conflicts with many other drones, the algorithm shall determine which other drone it is approaching is *furthest* to its right, and then turns right around it to avoid it.

</td>
</tr>
</table>

ID	Tactical de-confliction-discrepancy.02
Service aspect	Dynamic separation criteria in 'Zu'-airspace
Corresponding section in U-space ConOps	5.1.4.2 Tactical conflict resolution

Observation	Refinement
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph, after the paragraph proposed in Tactical de-confliction-discrepancy.01:* ***Tactical de-confliction*** **of drone flights in 'Zu'-airspace can be based on a set of dynamic separation criteria. These criteria are composed of individual weightings of drone operations depending on several factors, showcased below:**

	Drone type (Fixed wing, rotary, etc.)			
Drone operation	Autonomous	Automated	Semi-automated	Human controlled
Standard separation	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Drone speed	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Endurance	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Mission (VLOS/ BVLOS)	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Location (Rural/ Suburban/ Urban)	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Mission Priority:				
Emergency service flight	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Commercial flight	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Recreational flight	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Drone electronic conspicuity:				
Plan only	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
ADS-B	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
LTE	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
combination	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Drone command:				
LTE	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
GCS	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Human control	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
LTE Coverage				
Poor	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Good	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Latency (poor)	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*
Weather data quality:				
National	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*	*[1,2,…,x]*

	Regional	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]
	Hyper local	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]
	Actual weather; wind speed				
	Low	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]
	Medium	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]
	high	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]	[1,2,...,x]

ID	Tactical de-confliction-discrepancy.03
Service aspect	Tactical de-confliction service auditing
Corresponding section in U-space ConOps	5.1.6.3 Legal recording; 5.1.6.4 Digital logbook
Observation	Contradiction
Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph, after the paragraphs proposed in Tactical de-confliction-discrepancy.01 and Tactical de-confliction-discrepancy.02:* **The *tactical de-confliction* service should maintain a full audit history of all states and instructions. This allows all data collected for a logical flight, regardless of the originating service, to contribute to a singular audit repository with a known flight reference for querying.** **Audit data is categorised as either 'instrumentation' or 'action':** • **'Instrumentation' events were emitted periodically from services to log the state of their health, performance characteristics, etc.** • **'Action' events were more specifically instructions generated by the service, or commands performed, that will have a specific effect on some other component. For example, a flight plan was stored as an 'action' when it was received.**

ID	Tactical de-confliction-discrepancy.04
Service aspect	Reference Altitudes
Corresponding section in U-space ConOps	2.5.2 Altitude, North
Observation	Refinement

Updated description in U-space ConOps (updates are highlighted in **bold writing**)	*In addition to the text provided in the ConOps section, we propose to add the following paragraph:* **Some of the issues related to altitude reference can be overcome by implementing micro-weather probabilistic forecasts in specific areas. These forecasts make it possible to have a robust prediction of the potential geometric altitude variation expected during the cruise. This is very valuable information to inform the determination of a safe vertical separation buffer between flights, specifically when a mix of operations using pressure and geometric altitude are present.**

3.2.3 Recommendations and requirements on regulation and standardisation initiatives

This section summarizes recommendations and requirements concerning standardisation and regulations based on the conclusions obtained from the IMPETUS exercises. These are presented on a service-by-service basis.

3.2.3.1 Needs for regulation and standardisation related to the *weather information* service

From the results that were obtained from the exercises related to the ***weather information* service** IMPETUS can provide the following conclusions on regulatory and standardisation needs for this service.

3.2.3.1.1 Standards for minimum performance

The use of pure numerical formats as an output of the weather service allowed IMPETUS to fully automate the testing of the scenarios and, thus, the provision of weather information. In contrast, legacy formats, even in their modern XML form such as METARs and TAFs, do include field values that are designed for human consumption (text fields), making their use much harder to automate. For this service, we therefore recommend the following points:

- All weather service **information has a purely numerical output in all its fields**.
- *Weather information* services, instead of the mandatory alerts for lack of precision, shall **include numerical information about the quality of the prediction**. While other options could exist, the approach of creating ensembles of many iso-probable predictions has proven successful for IMPETUS. We consider that this recommendation should be a requirement for operations in the most complex scenarios. For example, for shared airspace with manned aviation and urban scenarios.
- After successful stress tests, we recommend that a micro-service architecture is used internally to construct the weather service in conjunction with asynchronous data middleware such as AMQP (heavily used by Eurocontrol's Network Manager and FAA's NextGen) in order to **fully decouple weather prediction calculation processes from user consumption** and eliminate any cascade errors between users.

3.2.3.1.2 Standards for interoperability

Regarding interoperability, we **recommend reusing the existing SWIM data formats** whenever possible in order to facilitate future ATM–U-space coexistence. We used a compressed GRIB2 format that is already an established format but any table driven code forms (TDCF) would by valid. IWXXM already has support for all GML and numerical types required but a specific class defining weather prediction ensembles including all variables of interest for the different predictions that constitute the ensemble would help with interoperability.

3.2.3.2 Needs for regulation and standardisation related to the *monitoring* services

From the results that were obtained from the exercises related to the ***monitoring* service** IMPETUS can provide the following conclusions on regulatory and standardisation needs for this service.

3.2.3.2.1 Standards for minimum performance

For the monitoring service, IMPETUS recommends the use of the following standards:

- **MAVLink**: This is a transport protocol developed for drone communication. It can be found as a light library that implements all the necessary information for the data interchange between the drone and the *monitoring* service. The information can be customised so it is very easy to configure which data obtained from the drone can be sent. This aspect is very important for the standardisation of the minimum data to be exchanged. Our recommendation is that at least the position (coordinates plus altitude) and battery status should be provided to the *monitoring* service. The performance of this protocol is quite good, however a major disadvantage is that it has to be encapsulated into a higher level secure protocol such as DTLS in order to provide the necessary security that MAVLink lacks. This is the protocol used for the listener service (in charge of receiving data from the drones).

- **MQTT (Message Queueing Telemetry Transport)**: This is another standard based on a machine to machine protocol oriented for the internet of things (IoT). It is a simple and light protocol based on the TCP/IP stack, but it keeps connections open, making the communication process faster. The way it works is based on the publish/subscribe pattern. The data is labelled with a topic which the MQTT has the ability to filter and therefore forward the correct message to the correct service subscribed. This protocol needs a very narrow bandwidth, so it is ideal for this type of application. Nowadays it is the best standard used for data ingestion, for its speed, its lightness and its simplicity. This is the protocol used by the monitoring service (which processes and distributes information to the correct clients).

Through the use of these protocols in the exercises we have been able to gather datasets from 250 drone operations (meaning a reception of over 130000 messages) with a latency peaks of a mere 1.92 seconds.

3.2.3.2.2 Standards for level of safety

IMPETUS has not been able to identify standards regarding the level of safety of this service, however we can provide the following suggestion:

It is very important for the *monitoring* service to detect and spread information related to incidents or alerts to the services which are in charge of processing them. For this purpose, it is mandatory to **define the maximum acceptable latency for reporting safety occurrences**. These occurrences may be based on data losses, delays in transmission or alert messages needing to be processed.

3.2.3.2.3 Standards for interoperability

Each service usually incorporates its own schemas. Therefore, in order to be supported by other service providers, there should be set a common language for supporting the processes in the information flow.

In the case of the *listener* service, it can implement several types of protocols for the communication with the drones, and depending on the type of interactions the communications protocol will differ. This can be achieved with different types of drivers, but the internal communication with the rest of the services should be defined and standardised. The standard way to communicate between micro-services is defined by REST.

- **REST**: An interface for communicating several systems based on HTTP. The data can be structured in XML or JSON format. The latter one is lighter and more legible, so is the preferred format used. It provides the following methods to interchange data:
    - **Post**: Create new resources
    - **Get**: Gets a defined resource
    - **Put**: Modifies a resource
    - **Patch**: Modifies a resource that is not a data type
    - **Delete**: Deletes a resource

In a micro-service based architecture this type of interface should be used for data interchange. The IMPETUS results proved that it is a very fast and feasible interface between the clouds of services that were used in the exercise.

When common information shall be shared between services, it is mandatory to centralise this in a single entity, for instance the orchestrator. The orchestrator shall consume all the datasets and provide the users with the required common information, ensuring that the added value provided by a U-space Service Provider (USSP) is not affected.

In this case, the *monitoring* service communicates with the *information layer*, which acts as the *orchestrator*, and it is the one that distribute the information around the services, using REST interfaces and Sub/Pub patterns for the correct distribution.

3.2.3.2.4 Standards for security

IMPETUS has not been able to identify specific standards for security; however, we can provide the following suggestion:

Concerning operational security, one of the most important things about this issue is the registration process which should be monitored closely, because it is mandatory that it should fit with the requirements defined for it, no matter the technology used by the U-space Service Provider. **Only registered drones should be able to communicate with the *monitoring* service**, and this way, the service should reject the datasets receives from un-registered entities. This service must provide to the *monitoring* service the list of registered drones to discriminate all the valid data from the non-registered ones.

This process should be defined and turned into a new standard. It would need to account for the needs of the system and define the minimum data that should be used in the registration of drones. In any case, the existing SWIM architecture should be taken into consideration before defining a proprietary standard, as there is already a defined procedure on how to register into the system as a valid data provider.

Concerning security in the communication layer it is recommended to use secure transport layers/protocols, such as HTTPS (HTTP with SSL) in the case if the communication between the services. However, if communications take place within the same ecosystem, this may not be necessary for performance reasons. This should be used if de system is deployed on different sites using the Internet as a transport layer.

3.2.3.3 Needs for regulation and standardisation related to the *traffic information* service

Conclusions on regulatory and standardisation needs for the ***traffic information* service** are the same as for the ***monitoring* service** (see section 3.2.3.1), because they were tested in tandem. However, we can provide an additional recommendation for standardisation concerning minimum performance.

3.2.3.3.1 Standards for minimum performance

As stated in the *monitoring* service sections (see section 3.2.3.2.1), the use of REST with HTTP protocols, encapsulating data in JSON format could be the best way to guarantee a minimum performance.

Apart from defining protocol standards, IMPETUS recommends that, for this service, there should be a defined maximum latency requirement in the generation of alarms, as well as a reference refresh-rate for the information that has to be shown in the HMI. This last aspect was the most problematic in our exercises, since we tried to show all the drone positions in real time which surpassed browser capacity.

To improve service performance, another solution could be the use of the Java Message Service (JMS), but it requires all dependant services to be deployed in Java. If this is the case, and there is no need to communicate with any other entity or service, this is a very good option.

3.2.3.4 Needs for regulation and standardisation related to the *operation plan preparation assistance* service

From the results that were obtained from the exercises related to the ***operation plan preparation assistance* service** IMPETUS can provide the following conclusions on regulatory and standardisation needs for this service.

3.2.3.4.1 Standards for level of safety

We recommend the following **minimum set of weather information** for ensuring a high level of safety:

- Location and time of the observation (or valid time of the forecast);
- Wind direction and speed (including maximal gust speeds);
- Height of the model layer;

- Indicators of precipitation;
- Temperature;
- Humidity; and
- Barometric Pressure.

Additionally, aviation typical information like dew point, visibility and cloud reporting would support the planning of feasible operations.

Need for definition of Quality of Service drone-related NOTAM information for mission planning. We recommend the following **minimum set of information** for ensuring a high level of safety:

- Geometry of restricted airspace;
- Validity date; and
- Basic description of the activity.

3.2.3.4.2 Standards for interoperability

Need for definition of Quality of Service weather information for mission planning. Particularly with regard to the utilisation of **different weather sources**. We recommend to include the main characteristics (distribution of measurement stations, uncertainty level) of the weather models resulting from different sources.

3.2.3.4.3 Requirements for regulations

It is required for the *operator DTM system* to provide a **regulated interface** to the drone operator that enables the interaction with the *principal DTM system* for *drone operation plan processing*. Based on **agreed data exchange protocols**, the interface shall provide drone operators the necessary framework for sharing the flight plan characteristics that ensure an acceptable level of safety.

It is required for the drone operator to use an authorized and trusted weather source that is able to provide **local and micro-scale** forecast and actual weather information. Especially in complex urban environments it is necessary to provide weather data that encloses the very low-level airspace.

It is required for the drone operator to use an authorized and trusted source that provides temporary airspace restrictions which are **especially relevant to drone operations in the very low-level airspace**. Typically, temporary airspace restrictions, such as NOTAM publications, are coded text messages and alerts following a specific format. However, for drone operations it is required to transmit the relevant aspects of the airspace restriction (e.g. geometry of restricted airspace) in a manner that the drone operator can use it efficiently for mission planning.

3.2.3.5 Needs for regulation and standardisation related to the *drone operation plan processing* service

From the results that were obtained from the exercises related to the ***drone operation plan processing* service** (or *flight planning management* service as denoted internally to the project) IMPETUS can provide the following conclusions on regulatory and standardisation needs for this service.

3.2.3.5.1 Standards for minimum performance

Need for **minimum set of flight plan data** fields to be provided from the drone operator to the *principal DTM* system. We recommend to include the following data fields:

- Operator identification;
- Departure time;
- Estimated time of arrival;
- Lateral, vertical path (or occupying airspace geometry) and timing; and
- Mission purpose.

3.2.3.5.2 Standards for level of safety

Need to define a **separation margin** in the spatial and temporal domain that supports conflict detection and resolution, independent of the mission type. To increase the level of safety we recommend to include the following aspects in the separation management:

- Separation among flight trajectories;
- Separation with restricted airspaces; and
- Separation with the ground surface.

Need to define a prioritization criterion that a *principal DTM system* can use for conflict management. We recommend to consider the following criteria:

- Assignation of priority level to the flight plan according to the mission purpose.
- In case that the priority levels are equal, the controlling instance follows a first-come-first-serve principle.

3.2.3.5.3 Standards for interoperability

Need for a common communication interface that supports *drone operation plan processing* between the principal and the operator DTM system.

From the results of the experiments we recommend to use a **synchronous communication** through a REST API for the flight plan data exchange with the principal DTM system in order to ensure a timely response to the clients (drone operators). Through the utilization of typical HTTP methods (such as POST, GET, DELETE) it is possible to allow the submission, update and cancelling of flight plans, so as request for retrieving the status of the flight plans.

On the other side, since the validation process is highly time-variant and includes multiple assessment checks, the implementation of a synchronous communication is not practical in this case. Therefore, we recommend to incorporate **asynchronous communication mechanisms** (publish/subscribe) additionally to notify subscribed clients about the result of the validation process and emerging updates in the status of the pre-approved flight plans.

3.2.3.5.4 Requirements for regulations

It is required to assure a centralized and controlled flight plan database for flight plan execution and post-flight analysis. Due to the safety-critical aspects of the flight plans submitted from various *operator DTM systems*, the database shall not only fulfil defined **security** requirements but also **availability** requirements.

3.2.3.6 Needs for regulation and standardisation related to the *tactical de-confliction* and *dynamic capacity management* services

From the results that were obtained from the exercises related to the ***tactical de-confliction* and *dynamic capacity management* services** IMPETUS can provide the following conclusions on regulatory and standardisation needs.

3.2.3.6.1 Standards for minimum performance

IMPETUS was able to determine some gaps concerning minimum operational performance standards (MOPS). There are several standards that relate to services where these equate to equivalent manned aviation aspects. e.g. Air Traffic Services, but currently these address a human based ATM/ATC process (and limits associated to humans) hence these would need review and **amendment/replacement to properly deal with automated capabilities**. Automated capabilities are clearly an area where the IMPETUS project focused its simulation to achieve the scale expected in the future.

Similarly, most available technical standards provide a means to address the functional capabilities as implemented in the current manned frameworks, so further consideration is required as to how the new capabilities need to function. For example, they do not **address the latency aspects for a command and control system** over radio link – this doesn't exist in manned systems. As per this example, the exercises on tactical de-confliction increased separation as latency increased, but the specific parameters of this increase will be determined by the performance requirements of the system.

Similarly, the implementation of some technical elements place increased dependency/reliance on aspects beyond their initial consideration, e.g. GNSS, such that the implications of failure are more wide-ranging, or require much wider consideration than has been made, e.g. cyber implications for a fully connected system of systems.

3.2.3.6.2 Standards for level of safety

Concerning standards for the target level of safety (TLOS), currently there is no clear **decision of which areas of U-space will be required for 'safety to life'** activity and therefore the level of safety that's needed. For example, do we require levels of safety that meet a figure of 10^{-9} or 10^{-6}? Operations in urban (e.g. Type Zu), as simulated in the *dynamic capacity management* exercise, will require a different level of safety to operations carried out in rural areas, so reliability of systems will vary.

Within manned aviation the system-of-systems provides TLOS only for specific elements, e.g. the aircraft. It does not **clearly specify TLOS for other aspects such as services**, e.g. ATM/ATC. However, service-related aspects do have mechanisms to assure that the capability provided does address this to an appropriate degree – usually via minimum service levels and reactive responses to problems that may arise (e.g. unacceptable rate of infringement). Some aspects are focused on the tools/systems and competency of the organisations/individuals providing the services, whilst others are addressed via the operational framework, e.g. basic separation distances (as a function of aircraft size/mass/wake vortex). In principal these may be considered as performance standards.

3.2.3.6.3 Standards for interoperability

Overall, interoperability standards should be led by industry and should be, where possible, an **open standard to ensure the broadest level of interoperability**. However, there are gaps even If you include the ATM standards which could apply to U-space. In the experiments this has been observed in relation to information services feeding the *tactical de-confliction* service, via commands being issued to drones (e.g. "go to waypoint X").

Within IMPETUS we found that the **data exchange standards were immature for a number of the ingested data sources**. For instance, seen in relation to the information services feeding *tactical de-confliction*, commands being issued to the drones should be issued in a standard format. Therefore, standards need to be established to **ensure that the data parcels, data format, units, and the order of information being transmitted are homogenous**. These may be similar to what's been adopted in manned aviation and flight plan data exchange which will allow information supporting critical services to be passed in a recognised format, thus supporting services such as *tactical de-confliction*. This will arguably improve safety, reduce complexity of the system and encourage a competitive environment by reducing costs.

3.2.3.6.4 Standards for acceptability of privacy/noise

Privacy laws are well defined in so far as collection and use of specific personal data, however, these may need refinement to address the potential concerns raised by future use cases, such as BVLOS delivery drones etc.

There are many aspects surrounding privacy which were not included in the IMPETUS Project, but as one of the key public concerns, these must be addressed before drones become a common sight in our cities. Privacy can be referring many aspects of the drone eco-system, information about the payload/task been carried out, information about the drone operator and/or the privacy of the possible commercial sensitivities relating to the operation. All of which will require careful consideration. Privacy issues also affect *tactical de-confliction*. The types of operation been carried out will affect the **priority of flight when a confliction occurs, who should give way to whom**. Standards need to be established which would enable approved authorities to take the right decision without one entity gaining a commercial advantage and/or adversely affecting people on the ground.

The privacy issues go well beyond the example here, so we need to add clarification, for example, around the wider issues of sharing operational information between service providers, potential commercialisation of aggregated (anonymised) data and even if/how sensor data collected during flight might be allowed to be used.

3.2.3.6.5 Standards for security

Currently, when basic surface vulnerability and protection is being discussed existing standards already exist. However, these do not adequately **address the response and recover elements** for when there is an issue. Currently, most (if not all) assume the effect will be limited to the single entity compromised – and do not address the implications on the wider network – especially if that effect compromises safety.

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

The IMPETUS experiments tested aspects of individual services and the main dependencies among them in the context of a co-federated architecture, with a central, unique set of orchestrator services. These experiments helped us draw general conclusions on the services themselves and also on the added value of an implementation based on micro-services. IMPETUS tested important aspects and requirements of a modern, scalable micro-service based service architecture for U-space (i.e. service discovery modules, common information layers and message brokers). However, we did not test means for multiple USSPs, specifically those that deal with traffic management, to co-exist within the same, unsegregated airspace in a fully federated service architecture – implying that no centralized services are provided. As far as we are aware, this issue was not addressed by any U-space exploratory research project or very large demonstration. Seeing that the implementation of a fully federated architecture will become necessary due to the latest EASA opinion on U-space [23], we propose the following research areas for the next R&D phase:

- Technical implementation of a fully federated U-space service architecture for unsegregated airspace;
- Definition of standards for inter-USSP communication without centralised services;
- Research on specific use cases and safety-critical services which are impacted by this federated approach e.g. tactical resolution services.
- Research into maintaining data integrity and consistency within a fully federated U-space service architecture; and
- If needed, definition of VLL rules of the air to guide traffic management via multiple USSPs.

We believe that these types of research areas will be essential to provide the building blocks for a coordinated implementation of a federated U-space service architecture.

4 References

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4.2 Project Publications

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4.3 Other

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[23] EASA. (2020). Draft Opinion: High-level regulatory framework for the U-space, European Union Aviation Safety Agency, Brussels, 2020.

Appendix A Requirements

IMPETUS_U-space requirements_Baselin

Appendix B Services coverage

U-space Services
coverage_IMPETUS.xls

Appendix C Maturity Checklist

IMPETUS - U-space Maturity Criteria (OPE

IMPETUS - U-space Maturity Criteria (TAC

IMPETUS - U-space Maturity Criteria (WE/