

INTEGRATING EMERGENCY RESPONSE UAS UNITS INTO U-SPACES: A SOLUTION FRAMEWORK FOR GERMAN AIRSPACES

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Abstract

A framework for the integration of emergency response UAS operated by state actors and public safety authorities into U-spaces is presented. The regulatory framework for U-spaces specifies the traffic management for civil UAS while for emergency response flights exceptions are in place. The integration of emergency flights has been identified as a challenge to be addressed before introducing real U-spaces. Based on use cases in Hamburg, the framework and architecture are being implemented and tested within the BLU-Space project.

Keywords

U-space; U-space airspace; UTM; State UAS; BOS; Emergency response UAS; U-space integration; Project BLU-Space

1. INTRODUCTION

The number of commercial Unmanned Aircraft Systems (UAS) in use has been increasing for years. In 2019, the European Commission therefore established a legal framework for UAS to harmonise their manufacture and operation (Regulations (EU) 2019/945 and (EU) 2019/947 [1]). In 2021, the Commission supplemented it with rules for an Unmanned Traffic Management system (UTM) that coordinates UAS with each other and other aircraft, named U-space (Implementing Regulation (EU) 2021/664 [2]).

However, the Commission has limited regulatory authority. It can only establish rules for civil aviation. The integration of *state* UAS and other state operations impacting civil UAS traffic is therefore not covered by the U-space regulatory concept (see Art. 2 (3a) Regulation (EU) 2018/1139 [3]). Nevertheless, U-space enables state entities to enforce Temporary Airspace Restrictions (TAR) within U-space airspace, permitting only state aircraft to fly (see Recital 13 Implementing Regulation (EU) 2021/664). The European Commission then leaves it up to the Member States. But due to the lack of a national regulatory framework questions remains still unanswered.

The BLU-Space project, funded by the German federal government, is investigating the instrument of TAR and the integration of state actors and public safety authorities into U-space. The BLU-Space project team brings together all U-space actors: air traffic control unit (ATC), U-space service Provider (USSP), Single Common Information Service Provider (SCISP), UAS operators and state actors such as the police and fire brigade. With all roles in a U-space involved, the project team takes a complete, cross-interface view of the functionality of a U-space network and considers overarching interactions and synergy effects between the individual systems.

2. IMPLEMENTATION

2.1. Architecture of U-space

A U-space network provides different roles with different functions. The aim is to digitally exchange information in

real time to provide civil UAS operators with information they need to fly safely. Figure 1 shows the U-space architecture according to the Commission Implementing Regulation (EU) 2021/664.

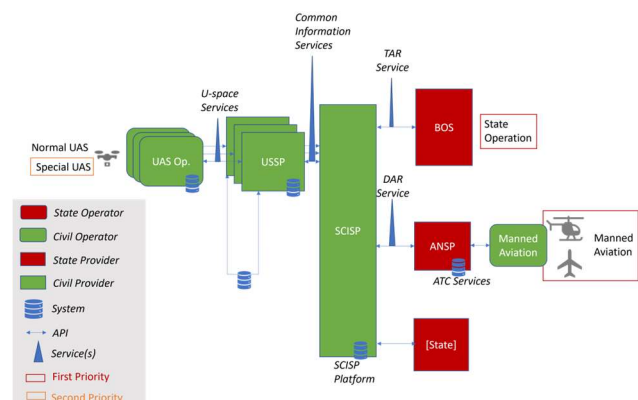


Figure 1. U-space architecture, in accordance with the U-space Implementing Regulation (EU) 2021/664.

In accordance with the U-space Regulation a UAS operator must connect digitally to a USSP of his choice in order to fulfil their obligation to use U-space services flying with his UAS in a U-space airspace. For USSPs to be able to offer UAS operators the full range of U-space services, they need information from other U-space actors.

The other U-Space actors are first of all the other USSPs. Unlike ATC, there are several USSPs operating side by side. They must connect with each other in order to share information about all UAS flying in this U-space airspace and UAS flight authorisations issued. Secondly, USSPs need information from state actors. This affects the ATC, if the U-space airspace is located in a control zone. The ATC must provide the USSPs with information on (civil) crewed air traffic for which it provides ATC containing information about crewed manned aircraft in or in the immediate vicinity. The ATC also provides the so-called Dynamic Airspace Reconfiguration (DAR) to the USSPs, which aims to restrict parts of the U-space airspace from UAS operations and to ensure coordination with (civil) crewed

aircraft, ensuring the spatial separation between (civil) crewed and uncrewed aviation. Lastly, USSPs must connect to state organisations in order to obtain information about static (permanent) or dynamic (temporary) airspace restrictions in U-space airspace, the latter known as temporary airspace restriction (TAR).

Figure 1 shows a U-space with a central distribution structure for so-called common information. In the central U-space model, USSPs connect to the central unit SCISP, which in turn is connected to ATC and state authorities and is responsible for distributing certain (common) information between USSPs, state operators, ATC and other authorities. Depending on the priority of the operation, UAS operators conduct flights with the status either normal or special.

2.2 BLU-Space Architecture of BOS integration

Under current EU requirements, the U-space architecture is not clearly defined for the safe and efficient integration of state operations conducted on the ground or in the air in a U-space airspace that affects civil UAS traffic.

As previously mentioned, the U-space concept enables Member States to designate authorities that are permitted to issue a TAR. Civil UAS operators are not allowed to fly in these designated areas, allowing state actors to operate undisturbed (e.g. TAR over accident sites, TAR for air rescue helicopters and their operation volume, or TAR for a (state) UAS supporting the fire brigade in fire analysis and their operation volume). The EU Commission leaves it up to the Member States to implement and decide which authorities are allowed to issue TARs, what requirements should be placed on the system and the process for generating, processing and forwarding a TAR. It also remains unclear how the use of TARs should be coordinated among different state actors.

The challenge to integrate emergency response UAS has been already addressed by public safety authorities [4]. To cope with this challenge, the BLU-Space project has expanded the U-space architecture with accordingly systems, digital services and service interfaces (Application Programming Interfaces, API) (see Figure 2).

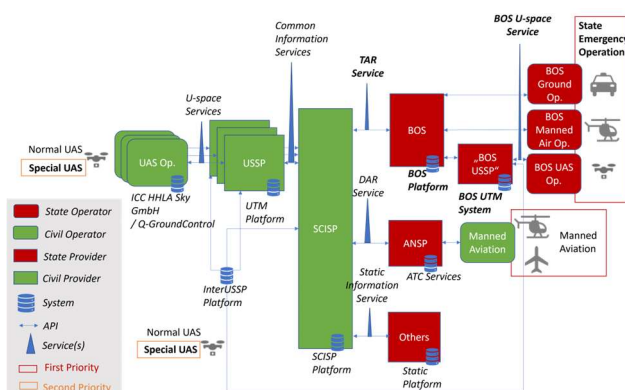


Figure 2. U-space architecture supplemented by research results of BLU-Space for efficient and secure integration of state actors and operation into the U-space network.

First, BLU-Space expands the U-space architecture with 'authorities and organisations with security tasks (German:

Behörden und Organisationen mit Sicherheitsaufgaben, BOS)', which are responsible for issuing TARs. Secondly, BLU-Space assumes that two systems will be necessary for the integration of BOS. The first is the so-called BOS platform, which is available to every BOS actor for generating a TAR, regardless of whether it is a national, regional or local BOS task or whether it performs its state duties on the ground or in the air. The BOS platform thus fulfills the U-space requirement to inform civil UAS operators about TARs.

Furthermore, BLU-Space addresses the question of how a BOS can ensure that its (BOS) UAS can fly safely (e.g. searching for people in urban areas with the help of UAS). In this case, the BOS operator is responsible for informing civil UAS operators (via TAR) of areas where flying is prohibited. They also act as a BOS UAS operator and require information about the air situation. Even if it can be assumed that civil UAS operators will not fly within the required airspace designated as TAR, there may be other BOS UAS that the BOS UAS operator, as a UAS pilot, needs to be aware of to ensure safety in the airspace. The BLU-Space project envisages the BOS UTM system for this coordination of BOS UAS among themselves. In this system, a priority status BOS/emergency is introduced which has the higher priority over special flights (and consequently over normal flights).

2.2.1. TAR Service

TAR zones are no-fly zones for civilian UAS operators and potential operating areas for BOS UAS operators. The TAR zone thus fulfils different functions: safeguarding the public interest in an efficient emergency response and rescue chain, guaranteeing air safety and protecting people within the TAR zone. So, in principle a TAR zone is triggered for every BOS operation that affects the airspace and endangers aviation safety.

In addition to the position of the trigger for an operation, the locations where the BOS resources are operating (e.g. a helicopter landing site, the search area for missing people, staging area for emergency services, etc.) are also mapped in the TAR zones. This means that TAR is more of an operational area than a single location.

To ensure that the information on an operational area is effectively generated and distributed as TAR information, the information is automatically obtained from existing operational data rather than being created manually. Receipt of operational data from relevant sources, conversion of this information into TAR geometries, and provision to the SCISP are carried out as part of the BLU-Space project via the BOS platform implementation.

2.2.2. BOS Platform

The BOS platform derives the TAR geometries from the received mission information and based on a predefined set of rules. In the final development stage, the system will be connected to as many BOS mission control systems as possible, enabling the automatic creation of TAR zones from the scheduled missions of the BOS organisations.

If a BOS UAS takes-off outside the operational area and thus outside the TAR zone (Beyond Visual Line of Sight,

BVLOS flights), it must also be possible for the UAS to reach the operational area safely and efficiently. This can be achieved through trajectories and three-dimensional airspace management, as well as technical and organisational measures such as airspace separation. Both approaches are discussed in Section 3.

2.2.3. BOS UTM System

As the BOS UTM system stands in the focus of the following trials, it will be presented in detail below. First its functions will be described (2.2.3.1.) and second the workflows that result from specific scenarios will be outlined (2.2.3.2.).

2.2.3.1 Functions of BOS UTM System

The BOS UTM system is directly connected to the BOS platform and thus offers BOS UAS operators the option of requesting a TAR. Once the TAR has been issued by the BOS Platform and forwarded by the BOS UTM system, the BOS UAS operator can start its mission within this TAR. In this case, the BOS UTM system does not perform a conflict management as it would be case for flights of civil UAS operators.

As the BOS UAS operator starts its mission, it uses the network identification service interface to send its remote identification to the BOS UTM system. This remote identification is then exchanged with the others active BOS UAS operators active in the same U-space airspace in a standardized data format [5]. In return, the BOS UAS operator receives crewed and uncrewed traffic information through the traffic information service interface. The BOS UTM system further provides a user interface to monitor the U-space traffic and the active BOS UAS operations. Depending on the BOS organisation role that operates the BOS UTM system, the visualisation of the active BOS UAS operations can not only inform about the ongoing BOS UAS operations, but it can also support the BOS organisation to internally coordinate the BOS operators and their BOS UAS flights. A further functionality to support flights of multiple UAS operators in the same TAR is a mobile application interface that they can use to create BOS sectors within a TAR. These sectors are exchanged with the systems of the BOS operators, allowing them to plan their respective flight in the defined sector.

Further, the BOS UTM system supports flight authorisations requested with the emergency/BOS classification (highest priority). In an ecosystem with multiple BOS USSPs, this type of flight authorisation requests can be coordinated with the other BOS USSPs in a standardised information exchange format [6]. Initially, the coordination can be implemented by strategic deconfliction and with a priority system after the first-come-first-serve principle, but it remains to be seen if other coordination mechanisms and priority rules are better suitable depending on the needs of the BOS UAS operators active in the particular U-space airspace.

In the same way as the UTM platform with civil UAS operators (USSP), the BOS UTM system provides also the digital and automated U-space services to provide the BOS UAS operator with all the information they need for safe operation. When the UAS operator requests a flight authorisation with normal (lowest priority) or special (second highest priority, according to Art. 10(8)

Implementing Regulation (EU) 2021/664) classification, the BOS UTM system performs the original USSP functions as strategic deconfliction to ensure that the flight has no conflict in space and time.

2.2.3.2. Workflows of the BOS UTM System

The following section describes two workflows of the BOS UTM system that are unique of the platform.

First, we will look at the UAS of a BOS operator. If the BOS UAS operator classifies their UAS as BOS/emergency flight, its UAS has the highest priority status as previously mentioned. Figure 3 shows that the flight of the BOS UAS operator has the highest priority. Figure 4 shows that all flights with normal and special status generate a conflict in the UTM platform when the TAR has a spatial and temporal overlap with the mission. This is not the case for flights with emergency/BOS status.

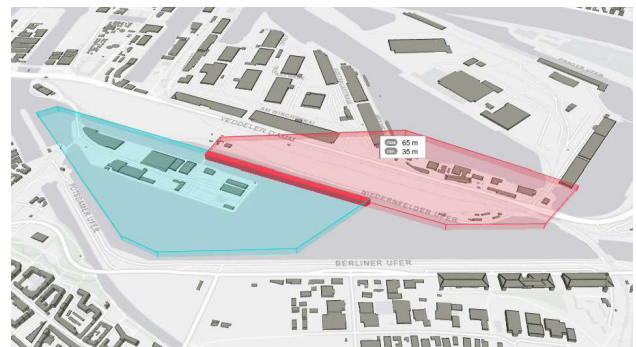


Figure 3. Flight with emergency status (blue volume) having priority over flight with special status (red volume).



Figure 4. Up: flight with normal status in conflict with TAR (red volume); Down: flight emergency status not in conflict with the same TAR (blue volume).

Now, the BOS UAS operator is able to create multiple sectors under a BOS mission, such as a person search in water or on land. Figures 5 and 6 show how the sectors are displayed in the user interface. The sectors are shown in

the BOS UTM system and sent to the BOS UAS operator.

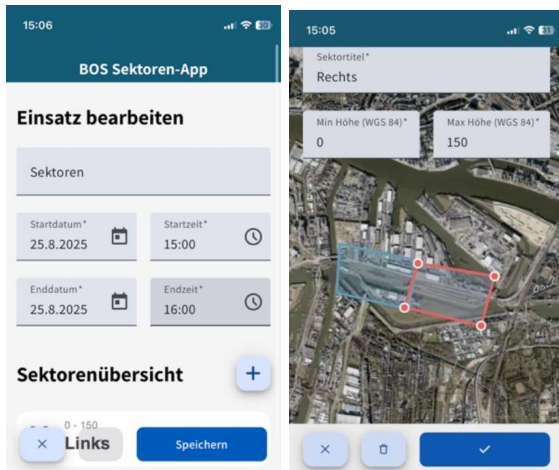


Figure 5. Mobile application user interface for creating a BOS UAS operation (left) and defining two sectors (right).



Figure 6. Creation and visualization of two sectors in BOS UTM system.

The Figures 7 and 8 show the interaction between the BOS UTM system (in the role of a BOS USSP) with the other U-space systems mentioned and presented above. They provide the sequence of information exchange that is required for an emergency/BOS flight of the BOS UAS operator in U-space. Depending on the actor that triggers the TAR creation, two options result.

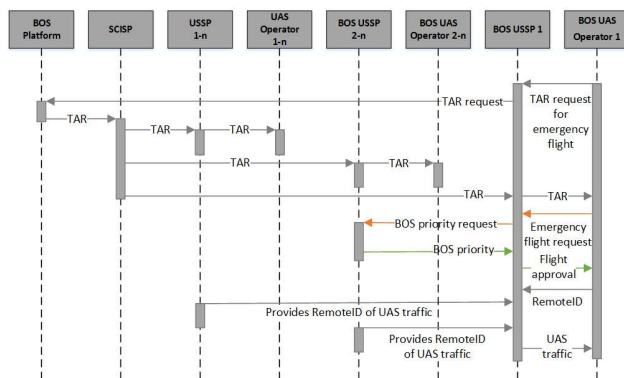


Figure 7. Lifecycle of emergency/BOS flight in the case of the BOS UAS operator triggering the TAR creation.

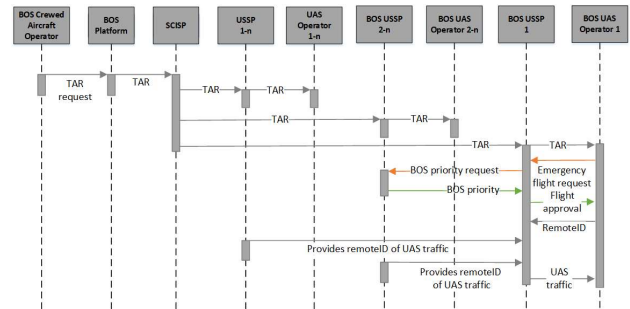


Figure 8. Lifecycle of emergency/BOS flight in the case of a BOS crewed aircraft triggering the TAR creation.

3. TRIALS

The implemented BOS UTM system has been tested in a simulation environment and by means of real UAS flights (see Figure 9) to ensure the expected functioning of the service capabilities and system interfaces. All simulated and real flights performed with the emergency/BOS status had priority over normal and special flights by means of deconfliction. Both in strategic and tactical flight phases.



Figure 9. Camera view from UAS during flight tests in the port of Hamburg.

3.1. Scenario Setup

The focus of the trials is to test and evaluate the capabilities of the developed BOS UTM system based on defined scenarios that have been discussed with state UAS operators and are orientated to real use cases in the city of Hamburg.

The project consortium has looked at two potential scenarios in particular that are challenging when multiple state UAS operator would fly in a U-space airspace along the civil UAS traffic:

- Scenario 1: A BOS UAS reaching a created TAR from its base station and part of its flight route is not within the TAR.
- Scenario 2: Multiple BOS UAS flying inside a TAR.

For both scenarios the following assumptions are made (compare with sequence diagrams from the previous section):

- Only 1 BOS USSP (and 1 BOS UTM system) is active in the U-space airspace.
- The trials start at the point in time where the TAR has been created and has reached the BOS UAS operator.

3.2. Scenario 1

In response to an emergency situation requiring immediate polder control measures, a Temporary Airspace Restriction (TAR) is established to ensure the safe and coordinated use of airspace. Despite the activation of the TAR, civil Unmanned Aerial Systems (UAS) could be still operating within the restricted area, potentially interfering with emergency procedures. To support the emergency response, a single flight was authorized to be conducted by a BOS UAS operator. It is important to mention that the take-off location for this emergency flight is situated outside the boundaries of the designated TAR, requiring special coordination to facilitate safe entry and operation within the restricted zone.

For this scenario, the BLU-space project envisages 2 solutions, each requiring operational and technical adjustments of U-space airspace rules and systems:

- Solution 1.A: Designating a crown above the U-space dome exclusive for BOS UAS flights (emergency flights).
- Solution 1.B: Creating TAR corridors for connecting the UAS base to the TAR that has been implemented.

Solution 1.A could use the separation buffer between the upper U-space boundary and the minimum height of the SERA rule for crewed aircraft (VFR flights). This would require defining a crown that is for exclusive use by the BOS UAS operators (see Figure 10).

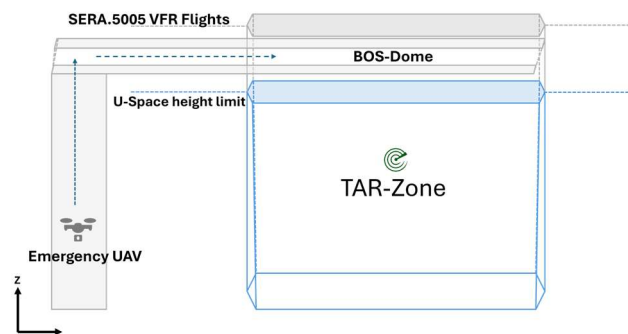


Figure 10. Graphical visualisation of solution 1.A for an emergency UAS flight.

Figure 11 shows how a BOS UAS flight that is supported by the UTM platform to reach the proposed crown above the U-space dome.

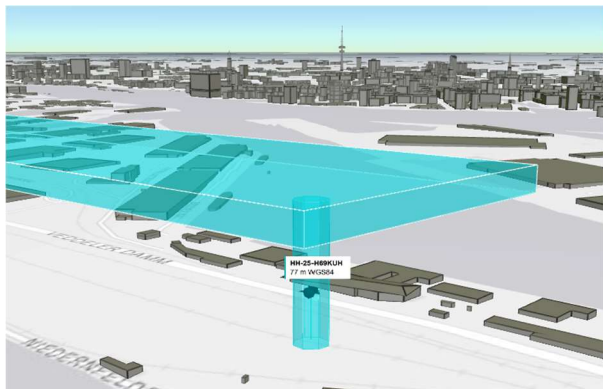


Figure 11. BOS UAS flight (blue volume) in the BOS UTM system starting from the DronePort.

In solution 1.B, the flight plan of the BOS emergency flight could be used to create a TAR corridor that would ensure the separation with the civil traffic (see Figure 12).

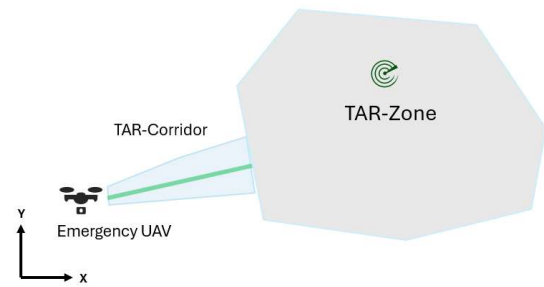


Figure 12. Graphical visualisation of solution 1.B for an emergency UAS flight.

Figure 13 shows how a BOS UAS flight that is supported by the UTM platform to reach a TAR zone and how the TAR corridor could be defined

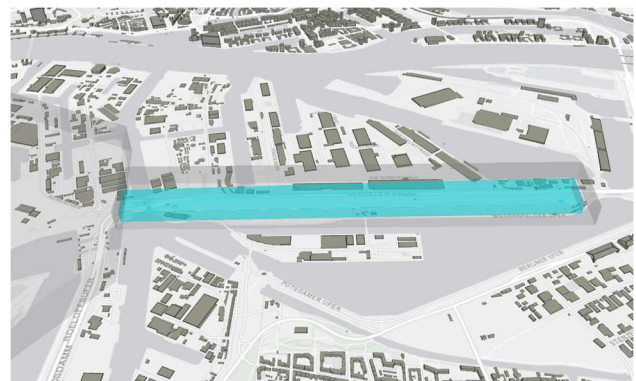


Figure 13. BOS UAS flight in the BOS UTM system with a corridor (grey volume) around the flight volume (blue volume).

Both solutions are compared to evaluate their benefits and drawbacks by means of simulation flights. A simulation scenario has been defined and it includes a UAS base station from a state UAS operator and 7 potential locations where TARs could be created (see Figure 14). The locations have been selected based on the input of state UAS operators and these are within the total operational area of the UAV (area that the UAV system can cover to perform a state UAS operation).

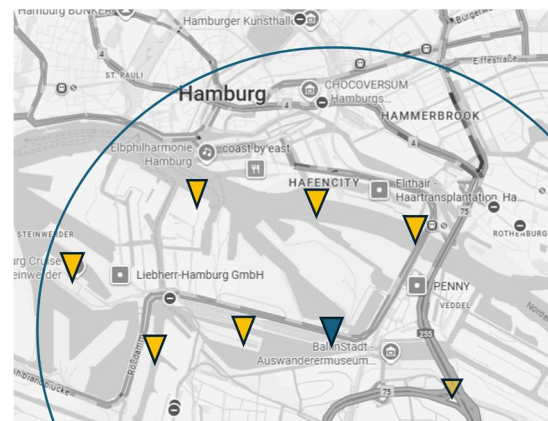


Figure 14. Location of UAS base station (at HPA's DronePort, blue marker) and total operational area (blue circle). Location of potential TARs (yellow markers).

Two relevant metrics have been defined for the comparison of solution 1.A and 1.B:

- Use of airspace (M1): the use of U-space airspace required to perform the UAV flight in relation to the operational volume of the UAV.
- Use of battery (M2): the energy consumption required by UAV to perform the emergency flight.

Table 1 shows the results of the simulation flights and it includes the assumptions taken for the flights and considering the solution constraints.

Table 1. Metrics comparison of solution 1.A and 1.B for a total operational volume of 3.42 km^3 and a multicopter UAV with 6 propellers and a battery total energy of 532Wh.

Solution	Use of airspace	Use of battery
Solution 1.A	Assumptions: • Take-off radius: 20m • Ascent speed: 4m/s • Ascent distance (to BOS crown): 110m	
	Use of airspace in relation to total operational volume: 0.004%	Use of battery for the vertical phase of the flight: 1.21%
Solution 1.B	Assumptions: • Corridor width: 20m • Corridor height: 40m • Ascent speed: 4m/s	
	Average use of airspace in relation to total operational volume: 0.041%	Use of battery for the vertical phase of the flight: 0.44%

With the simulation results obtained the comparison of the solutions has been completed and this is provided in Table 2.

Table 2. Comparison table of solution 1.A and 1.B.

Solution	Benefits	Drawbacks
Solution 1.A	Reduced U-space airspace occupancy	Increased air risk due to proximity to crewed aircraft
	Less strategic coordination required for all UAS traffic	Increased battery use of emergency flight.
		Suitable for Hamburg (quite flat ground surface), but not a suitable blueprint solution for other regions with elevated terrain.
Solution 1.B	Minimizing flight time and increasing emergency response time	Increased airspace occupancy and potentially blocking civil UAS traffic

Currently Solution 1.A, in which an altitude band within the U-space is reserved exclusively for BOS UAS operators, is considered the most promising approach for a city like Hamburg. There would be an increased battery use compared with flights in Solution 1.B, but the simulation values show that the increase is relatively low compared to the total battery percentage. Further, the use airspace in Solution 1.A is around 10 times less as in Solution 1.B but most important it would solve the drawback in Solution 1.B in terms of blocking airspace for civil UAS traffic. However, Solution 1.A remains to be discussed with the regulatory bodies and air traffic control (given the air risk due to proximity with crewed aircraft).

3.3. Scenario 2

In response to an emergency situation involving a missing person search, a Temporary Airspace Restriction (TAR) is established to ensure safe and coordinated aerial operations. Within this framework, two emergency flights are planned, each to be conducted by a different BOS UAS operator. To facilitate effective coordination between the two operators, one of them was assigned the additional role of creating operational sectors within the TAR. This sector-based structure enables clear limitation of flight areas and responsibilities, thereby enhancing the efficiency and safety of the joint aerial search effort. In comparison to the first scenario the take-off point is inside the TAR.

For this scenario, the BLU-Space project envisages 2 solutions, each being suitable to different use cases:

- Solution 2.A: Use of BOS sectors horizontally
- Solution 2.B: Use of BOS sectors vertically.

Solution 2.A foresees the sectorisation of the TAR horizontally (see Figure 15).

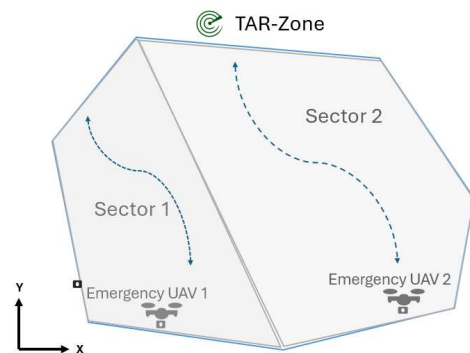


Figure 15. Graphical visualisation of solution 2.A for 2 emergency UAS flights.

Figure 16 shows how 2 BOS UAS flights are supported by the BOS UTM system and are flying in different sectors.



Figure 16. 2 BOS UAS flights in the BOS UTM system, each flying in a left and right sector.

Solution 2.B foresees the creation of height bands as the emergency mission requires.

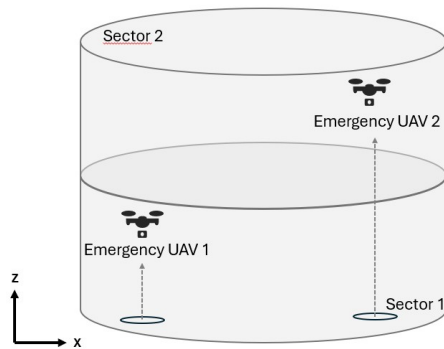


Figure 17. Graphical visualisation of solution 1.B for an emergency UAS flight.

Figure 18 shows how 2 BOS UAS flights are supported by the BOS UTM system and are flying in different sectors

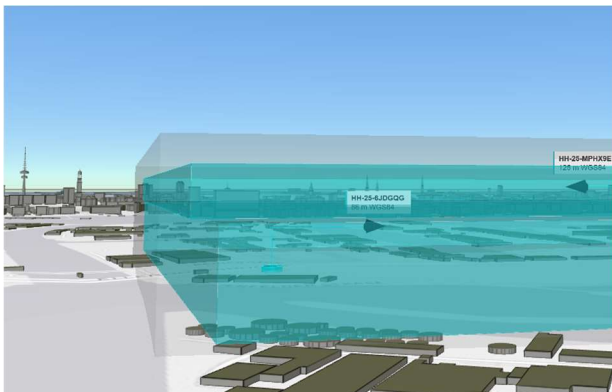


Figure 18. 2 BOS UAS flights in the BOS UTM system, each flying in an upper and lower sector.

After interviews with state UAS operators in Hamburg it was found out that each proposed solution has benefits and challenges. These are summarized in Table 3.

Table 3. Benefits and challenges for solutions 2.A and 2.B

Solution	Benefits	Challenges
Solution 2.A	Suitable for use cases such as person search (water and land), perimeter controls of large places etc,	Increased coordination required in case UAV 1 and UAV 2 takeoff from the same starting point
Solution 2.B	Suitable for use cases such as point of interest (e.g. traffic accident or fire) and its surroundings etc.	Increased coordination required for UAV accessing higher sectors

4. CONCLUSIONS AND OUTLOOK

In this work the BLU-Space architecture that integrates BOS UAS operations has been introduced and the system interfaces have been described. The implementation of the BOS UTM system has been detailed, and the workflows show how the information can be exchanged with the other U-space systems, such as SCISP, BOS platform and the tools of the BOS UAS operators. It has been shown that with the implemented platform capabilities, the BOS USSP can exchange all safety-relevant information with other USSP and BOS USSP systems active in the same U-space airspace. The tests with simulated and real flights have demonstrated that the implemented BOS UTM system is not only able to support BOS UAS flights with emergency status inside a TAR, but it also can support multiple solutions for bringing BOS UAS flights to TAR zones, and for managing multiple BOS UAS flights inside a TAR zone.

In the remaining course of the project the interfaces of the BOS UTM system will be tested with systems that are to be completely implemented, such as the SCISP and BOS platform. Also, the solutions presented in Section 3 will be discussed with further state organisations to ensure the suitability of the BOS UTM system and potentially refine it. Lastly, regarding the coordination of multiple BOS UAS flights inside a TAR area, it will be discussed with the BOS organisations how the role of the BOS USSP should be defined. Particularly when sectors need to be created or dynamically adjusted.

5. FUNDING

This project has received funding from the Federal Ministry of Transport.

Abbreviations

BOS	BOS is the German synonym for all authorities or organisations commissioned by the state that are excluded from the scope of European law application, according to Article 2(3)(a) of Regulation (EU) 2018/1139, and for U-space Regulation see also Recital (13) of the U-space Regulation (EU) 2021/664
TAR	Temporary Airspace Restriction

References:

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