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A HIGH-FIDELITY RISK ASSESSMENT FOR BVLOS UAV RESCUE MISSIONS IN URBAN LAKESIDE AREAS

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This study introduces a precise risk assessment approach for UAV-based emergency response at lakesides, utilising 5G connectivity and adhering to SORA 2.5 standards. The system facilitates BVLOS missions via real-time surveillance, AI-powered video analysis, and automated flight planning informed by fluctuating demographic and environmental data. UAVs are centrally administered using a Remote Operation Control Centre (ROCC), facilitating prompt intervention in both temperate and frigid weather situations. Field testing confirms its capacity for decreased response times and enhanced coordination within EU regulatory frameworks. As SORA 2.5 restricts BVLOS operations in populated areas, it does not account for dynamic environmental factors or the presence of controlled safety zones within these areas.

This results in overly conservative restrictions that can hinder legitimate, safe UAV operations. Also, current SORA implementations largely rely on qualitative or class-based population risk models. To address this gap, the proposed methodology applies a quantitative, high-fidelity risk assessment using geospatial and real-time data layers like mobile network coverage, detailed population distribution, building structures, and weather forecasts. This enhances the precision of ground risk calculations, enables risk-informed decision-making, and supports regulatory compliance with improved operational flexibility. The proposed methodology aligns with the evaluation, demonstration, and submission phases proposed in recent updates, including tools like ZHAW's SORA Tool v3.0.0.

Keywords: *5G connectivity, AI-based video analytics, automated dock stations, BVLOS, SORA 2.5, UAV, urban air mobility.*

1. INTRODUCTION

Emergency response in urban lakeside environments poses significant operational challenges due to high population density, variable environmental conditions, and limited accessibility during critical incidents. Recent advances in unmanned aerial vehicle (UAV) technology, combined with 5G connectivity, offer new opportunities for enhancing situational awareness and response efficiency in such scenarios [1]–[3]. UAVs can provide real-time aerial surveillance, support rapid intervention, and extend operational reach Beyond Visual Line of Sight (BVLOS), which is crucial in wide-area rescue operations [4]–[6].

The integration of high-resolution optical and thermal sensors, loudspeakers, and AI-based video analytics into UAV systems further strengthens their utility for public safety applications [7]. These systems can be deployed from automated dock stations powered by green energy and managed through a Remote Operation Control Centre (ROCC), enabling centralised oversight and near real-time communication with ground teams. By leveraging dynamic data, such as population density, building layout, weather, and mobile network coverage, UAV missions can be planned and adapted based on evolving operational risk.

To ensure safe and compliant deployment, this study aligns with the Specific Operations Risk Assessment (SORA) methodology. However, while SORA provides a structured regulatory framework, it often relies on qualitative assessments that limit flexibility in urban environments. This research proposes a high-fidelity, data-driven risk assessment approach compliant with SORA 2.5, enhancing UAV safety and scalability through risk-aware mission planning, automated scenario activation, and real-time monitoring.

The methodology is validated through use-case scenarios at an urban lake, covering both warm and cold seasons. It supports mission planning under real-world constraints and contributes to the development of scalable, the EU-compliant UAV systems for public safety.

Within the European Union, UAV operations are regulated under Commission Implementing Regulation (EU) 2019/947, which defines categories based on operational risk: open, specific, and certified [8]. BVLOS flights in populated or complex environments, such as lakeside urban zones, fall under the "specific" category and require a comprehensive SORA [9], [10].

The SORA framework, currently at version 2.5 as published by JARUS, guides UAV operators and national aviation authorities (NAAs) through a step-by-step assessment of operational risk. It evaluates both ground and air risk and recommends appropriate Operational Safety Objectives (OSOs) and mitigation strategies. However, the current implementation of SORA often lacks spatial granularity; it tends to classify entire urban areas as high-risk based on population density, regardless of localized safety conditions.

For example, while SORA 2.5 restricts BVLOS operations in populated areas, it does not account for dynamic environmental factors or the presence of controlled safety zones within these areas. This results in overly conservative restrictions that can hinder legitimate, safe UAV operations. Moreover, current SORA implementations largely rely on qualitative or class-based population risk models [11], [10].

To address this gap, the proposed methodology applies a quantitative, high-fidelity risk assessment using geospatial and real-time data layers – such as mobile network coverage, detailed population distribution, building structures, and weather forecasts [12], [13]. This enhances the precision of ground risk calculations, enables risk-informed decision-making, and supports regulatory compliance with improved operational flexibility.

Furthermore, the methodology aligns with the evaluation, demonstration, and submission phases proposed in recent updates, including tools like ZHAW's SORA Tool v3.0.0 [14]. It facilitates not only UAV operator planning but also regulatory review by national aviation authorities, ensuring full alignment with SORA 2.5 and emerging EU-level standards.

Across Europe, several initiatives have explored the integration of UAVs and 5G connectivity for public safety and emergency management. Germany's DLR has employed UAVs in disaster response operations; Finland has tested autonomous UAV rescues over icy waters; and Italy's D-Flight system enables dynamic airspace monitoring using UAV data [15]. These projects demonstrate the growing relevance of UAV systems in safety-critical applications.

In parallel, risk assessment methodologies for UAV operations have evolved significantly. Studies have explored UAV risk modelling using dynamic population data, meteorological conditions, and mobile network information to enhance situational awareness and mission safety [11]–[13]. Recent literature also highlights the limitations of qualitative SORA methods and the need for data-driven, quantitative approaches to assess UAV ground risk more accurately [16].

The ZHAW SORA Tool v3.0.0 [14] reflects this shift, offering a digital interface for SORA implementation through structured evaluation, mitigation demonstration, and regulatory submission workflows. While promising, such tools are often limited in scope or localization.

2. METHODOLOGY

The methodology is divided into two high-level phases:

- Mission Planning: Defines the flight mission using the SORA 2.5 methodology, high-fidelity risk assessment, and generates all required documentation for flight authorization.
- Mission Monitoring: This service offers advanced tools for situational awareness, including real-time risk visualization and in-flight plan updates, to maintain safety levels throughout the mission.

The methodology's core is adopting a high-fidelity risk assessment approach that can use a quantitative approach to assess the ground risk of a UAV operation. The high-fidelity risk assessment uses population density data to estimate the distribution of people on the ground. Then it estimates the number of people who can be involved in an hypothetical collision event with the UAV after an uncontrolled crash. The methodology described is a risk-informed decision-making tool introducing several benefits for UAV operators and NAAs. On the one hand, UAV operators can use the SORA methodology to design a safe UAV operation and assess the risk using a high-fidelity risk assessment. Moreover, the methodology can be used as a risk mitigation strategy, providing a quantitative risk assessment. On the other hand, the National

Aviation Authority (NAA) can also benefit from the methodology because it can exploit the tool to verify the risk of a flight mission submitted for an authorisation request. This requires the NAA to review the methodology and tool. Even if the proposed method is tested, it meets the regulatory framework's requirements and is valid at the European level.

A UAV can be operated in the "specific" category when it is operated outside of the operational limitations laid out under the "open" UAV category. If the risk of the operation is even higher, the UAV must be operated in the "certified" category. The specific category covers UAV flights that do not meet the limits of the open category. This includes BVLOS flights, operations above 120 m, aircraft over 25 kg, flights in populated areas with aircraft over 2 kg, cargo drops or spraying, flying multiple drones at once, automated flights, and other activities restricted in the open category. There are four different ways to operate in the specific category: submit a declaration based on a Standard scenario, obtain an operational authorisation following a Pre-defined Risk Assessment (PDRA), obtain an operational authorisation without a PDRA, or have a LUC. For research, the option is "Authorisation without a PDRA". All flight operations must undergo SORA. The interaction between on-site lifeguards and remote UAV operators is designed to facilitate new services. UAVs are operated in a network under centralised supervision – a dedicated Remote Pilot at the Remote Operation Control Centre (ROCC) manages, monitors and controls the UAVs beyond visual line of sight. The combination of lifeguards and this remote operator function as a unit, communicating via the existing police radio network or dedicated 5G connected devices. For example, suppose a lifeguard observes a swimmer disappear underwater at a location outside the designated swim zone. In that case, they will immediately alert the ROCC remote pilot (over radio) and request UAV support at those coordinates. The remote operator/pilot then launches the UAV from its dock and guides it to the incident area, while the lifeguard moves to respond on the ground. Throughout the UAV's flight, the ROCC operator updates the lifeguard ("UAV on scene in 30 seconds, it has visual on the victim") and can even relay information to other responding units. Conversely, the lifeguard on scene feeds situational info to the operator – for instance, confirming a missing person's description so the UAV camera can zoom in on the right target. The platform essentially creates a real-time link between the lifeguard station and the remote operations centre: the UAV acts as an intermediary, sending live video to the operator and potentially directly to rugged tablets carried by lifeguards. Remote operators continuously monitor the UAV network (multiple UAVs covering different zones), ready to alert lifeguards if they see an issue. For instance, the ROCC pilot might spot through the UAV feed a group of swimmers being pulled out by a strong current outside the buoys and immediately radio the beach lifeguards to intervene. In such a case, the remote operator could use the UAV's onboard loudspeaker to shout warnings until lifeguards reach the swimmers. This tight interaction loop ensures that no critical event goes unnoticed: the lifeguard initiates a UAV mission when something is reported locally, or the ROCC operator prompts lifeguards when the UAV autonomously detects an anomaly.

UAVs will be equipped with thermal imaging cameras to detect body heat, and 5G connectivity enables real-time transmission of data and images to search and rescue teams. 5G and UAVs are important for locating people in a specific area because they can provide a bird's-eye view of the search area and help search teams identify potential hiding places or hazards. UAVS will be equipped with high-resolution cameras and other sensors to gather data, and 5G connectivity enables real-time transmission of data and images to search and rescue teams. UAVs will be equipped with specialised sensors such as sonar to detect underwater objects, and 5G connectivity enables real-time transmission of data and images to search and rescue teams. UAVs will be equipped with high-resolution cameras and other sensors to gather data, and 5G connectivity enables real-time transmission of data and images to search and rescue teams for analysis. The remote Operation Control Centre connectivity architecture is depicted in Fig. 1.

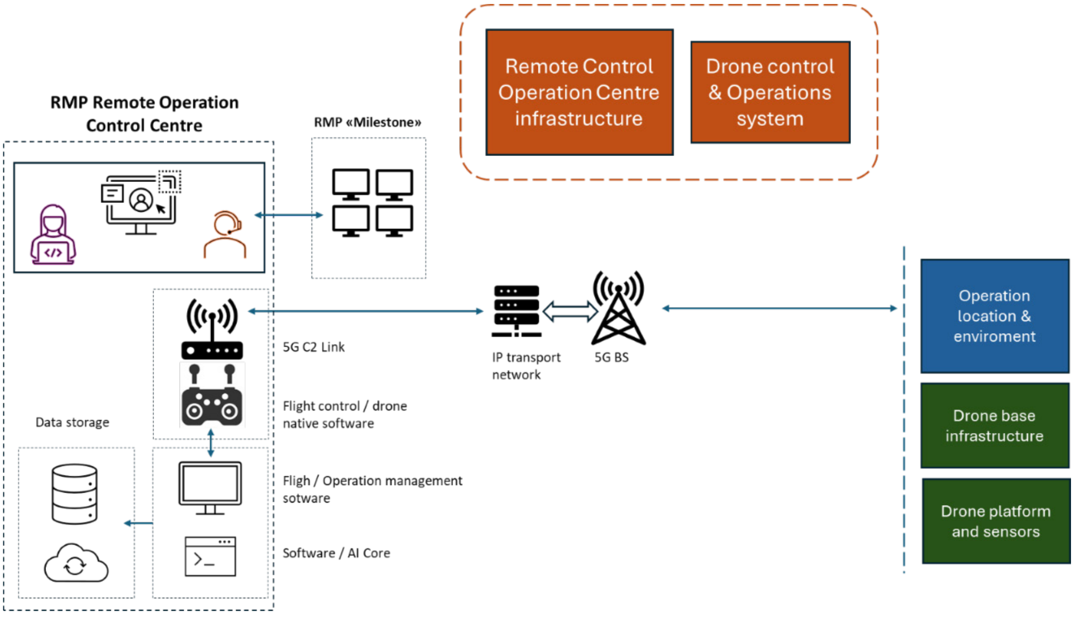

Fig. 1. Remote Operation Control Centre connectivity architecture.

Figure 1 also describes the Remote Operation Control Centre, the central hub for UAV mission planning, Scenario management, UAV operation, and cross-platform real-time monitoring. This facility has the UAV Control & Operations System, which enables remote operators to manage UAV missions using 5G connectivity. The control centre infrastructure is linked to field operations through 5G networks, ensuring almost real-time communication, control, and data exchange. The connectivity extends to other video-based monitoring infrastructure and systems, allowing seamless coordination with emergency services / S&R, or municipal police. The 5G network capabilities ensure that UAV commands, telemetry data, and high-resolution video streams are transmitted in almost real time, allowing immediate situational awareness and decision-making.

Several steps are required before the testing phase to understand the social challenges achieved by implementing 5G UAVs: a roundtable involving rescue department officers, Operation and Control department officers, and Innovative group officers responsible for the technical support of UAVs and collected existing societal information (incident response time, consumed petrol, and working hours on water). Additionally, to the cooperative activities with the Civil Aviation Agency and the implementation of flight restriction zones, several preparation steps were made to reassess and validate scenario design and testing for warm and cold weather operations, ensuring alignment with real-world challenges; the conduction of in vitro trial runs to identify potential obstacles and optimise workflows.

The UAV's telemetry must be transmitted in almost real time with high accuracy and precision to meet these requirements throughout the flight. Leveraging 5G technology, which offers features such as network slicing and mobile edge computing (MEC), holds promise in meeting these connectivity needs. Additional requirements have to be considered: adapting existing UAV operations to seamlessly integrate with 5G networks across various stages of a mission is essential; planning and route definition considering mobile network coverage and performance requirements from the 5G network; validation by assessment of the feasibility of meeting UAV operator needs concerning coverage, infrastructure, functionality, and capacity; execution activities, including proactive monitoring of ongoing missions, ensure adherence to plans and effective management of emergencies, including temporary or permanent loss of radio connection with the serving 5G base station and post-flight analysis, with continuous refinement of procedures and systems based on insights gathered from mission outcomes. The scenario directly addresses the following: reduction in response time, UAV deployment rate, operation success rate, and decision-making time.

UAVs are stored at special dock stations in specially organised areas. Docking stations support the ability to monitor the condition of UAVs and batteries and provide battery replacement. Information about the UAV's condition and readiness for operation is remotely available for operator checking at the Flight Control Centre (FCC). Docking stations are located directly at the locations, on the territory of rescue stations, have protection against weather conditions and damage, as well as lighting (signalling), and are fenced to restrict access to unauthorised persons. Docking stations support using green energy sources for recharging UAV batteries, such as solar panels and hydrogen power elements. FCC controls and manages operations at the locations. FCC has two operators: 1 Main Remote Pilot, who manages UAVs and related systems, and 1 Remote Pilot, who monitors and coordinates UAV information. An Operation Supervisor may also be involved – a person coordinating management at the FCC, making decisions on engaging related bodies in case of the need for response in the locations and coordinating all involved parties who are users of the information. Depending on the situation and the ability to meet the requirements, Remote Pilots can perform this role, provided they have the appropriate clearances. All operations in FCC are conducted in accordance with the Operations Manual (OM), which outlines all the necessary procedures for operation.

Basic operating scenarios are stored, and according to the schedule or specific operation call, the Remote Pilot selects a scenario, ensures the possibility of operation according to the checklists and OM, and activates the scenario. Special tools supporting BVLOS capability components check operational-specific parameters when activating the scenario. Based on the responses received from the tools, tactical corrections to the saved operating route and other flight parameters can be made. Thanks to automation and special tools, checking, tuning, and activating scenarios take minutes. All UAV operations are entirely within specially reserved airspace. Therefore, no intervention from other Stakeholders or Actors, except the FCC, is required. All UAVs meet specified operating requirements and are fully connected to all the necessary services and network components. Monitoring is carried out during daylight and night hours, with a specified number of operations per period. The scenario is activated according to the schedule or on demand, and the following components are activated: UAV GCS, BVLOS capability support tools, UAV dock station systems, network UAV ID broadcasting, operations management software platform, and tools and components with AI and automation capabilities. The remote pilot acts according to the OM procedures.

The scenario's saved settings include a flight plan, including take-off, exit after take-off to the operating area, flight along the specified route covering the specific mission area, orientation of UAV monitoring systems for effective coverage of the observation area, specified speed and altitude of flight, return to the docking station, and landing. Critical procedures and activities at all operational phases are digitised, including using a digital checklist, information provision services in a centralised user interface, UAV fleet and Remote Pilots management, post-flight information services, etc.

In the FCC, all data from all connected and operating devices and systems (air, ground, and marine levels) are transmitted via the 5G network. According to the activated specified scenario, platform automation components process the received data in real time (determining the number of people and other parameters included in the specific scenario) and output the processed information to the corresponding user interface. By the centralised information flow in the FCC, obtained from UAV sensors and other sources (ground and marine, mobile, and stationary), the operator can assess the situation at the location from various parameters at any given moment. This, along with automated data processing, allows for quick decision-making. The platform ensures connectivity such that users acting directly on the location (municipal police and rescuers) also receive real-time visual and other necessary information on mobile devices. This synchronises situational awareness across all platform users, ensuring coordinated and consistent actions during relevant operations and services.

After the implementation, the methodology will be tested in the use case. It will be used to evaluate the risk in the operational area and design a flight mission that follows the regulatory framework and has an adequate level of risk.

Industrially manufactured UAVs are designed for operation in multiple countries worldwide. Depending on their configuration and the specific requirements of various drone applications, drones may be equipped with different transmitting devices that operate in one or more RF bands. Since RF allocation and usage rules can differ from country to country, it is essential to ensure that the RF bands used on UAVs comply with the regulations of the country in which they operate. In many cases, UAVs are fitted with multiple transmitting devices supporting alternative RF bands, making it necessary to select the appropriate band for the given location.

RF spectrum is required to operate UAVs for various purposes, including allowing the remote pilot to control the UAVs and send navigation commands, facilitating the transmission of data and video from the UAVs to the remote pilot/operator, and implementing technology to notify other airspace users of the UAV position and flight trajectory; providing the UAVs with the ability to identify and evade obstacles or other aircraft; depending on the airspace in which the UAVs is being flown and on the capability of other systems on the UAVs, Air Traffic Controllers may need to maintain oversight and control of the flight [17].

Cellular connectivity, particularly 5G, will be the crucial communication channel to control the UAVs and send/receive live video/data feed to achieve this goal. The use of UAVs is intended for the BVLOS flight mode. The main safe operation component of UAV BVLOS is the ability of the UAV operator to control UAVs and to send commands to them in any phase of flight when they are out of sight. When piloting a UAV using a cellular network (LTE/5G), the cellular network provides the essential communication channel in this situation. It is important to note that the use of RF bands for mobile communications in public land mobile networks, including 4G and 5G, is subject to regulation. Before such spectrum can be used for commercial services, the operator must obtain both RF usage rights (normally awarded through a spectrum auction) and an RF assignment licence specifying the technical and geographical conditions of use. This requirement applies regardless of the service type, unless the operation takes place in specific frequency bands that are designated for licence-exempt or shared use under national regulations. Licence-exempt RF bands for UAVS control and command commonly use 2.4 GHz and 5.8 GHz. Licence-exempt bands, also known as shared RF bands, are frequency ranges where radio equipment can operate without obtaining an individual RF licence from the regulatory authority, and no separate paper or electronic licence is issued. Nevertheless, the use of radio equipment in these bands is still subject to specific rules and regulations.

In addition to the RF bands commonly used for UAV operations, it is important to consider GNSS RF bands. Global Navigation Satellite System (GNSS) constellations provide signals that enable precise navigation and geolocation worldwide, making them essential for UAV positioning. GNSS signals are also critical in mobile communication networks, particularly for time synchronization. GNSS operates in the RF bands allocated for the Radio Navigation Satellite Service (RNSS) by the International Telecommunication Union (ITU). These GNSS RF bands include:

- 1559–1610 MHz – referred to as L1, E1, B1, G1;
- 1215–1300 MHz – referred to as L2, E6, B3, G2;
- 1164–1215 MHz – referred to as L5, E5, B2, G3.

Multiple global satellite systems operate within these GNSS bands, managed by the USA (GPS), the EU (Galileo), the Russian Federation (GLONASS), and the People's Republic of China (BeiDou). The use of different signalling methods allows several GNSS systems to function simultaneously without causing mutual interference. Using multiple GNSS systems in parallel improves positioning accuracy, extends coverage, and increases resistance to interference [18].

BVLOS flights are currently limited to controlled ground areas to ensure that no uninvolved people are present in the event of an accident. This restriction is based on the SORA methodology, which is mainly qualitative and assesses overall scenarios without detailed analysis of the operational area. For instance, SORA restricts operations in urban areas due to population density, although safe zones with reduced risk can sometimes be identified. To overcome this, the project seeks to develop a methodology for planning and validating BVLOS flights using high-fidelity, quantitative ground risk assessment. By applying population density data, it can estimate how many people might be affected by an uncontrolled crash. The methodology will include risk maps for large-area risk quantification (usable offline for mission planning and online during flight), risk-aware path planning to minimise risk and flight time, and mission validation to determine route acceptability. It will also integrate 5G technology for real-time position transmission, dynamic route updates, and 5G coverage maps to design missions that ensure ground safety and continuous network connectivity for communication with the ground segment.

The main requirement is full compatibility with SORA 2.5, the latest update of SORA 2.0. JARUS published SORA 2.5 in mid-2024, and EASA is expected to adopt it before the end of 2025. The tool must perform each step of SORA 2.5, structured as a guided procedure offering UAV operators contextual suggestions for input data, risk assessment best practices, and mitigation strategies. The demonstration phase focuses on Step 10 of SORA 2.5, which includes compiling the Comprehensive Safety Portfolio and uploading supporting documents (manuals, test reports, mitigation measures, and robustness evidence). The tool will provide templates and checklists to ensure completeness. The submission phase will initially involve downloading documentation compliant with NAA submission requirements. Future updates may enable integration with NAA platforms for automated submission handling.

UAV operators often lack access to comprehensive data for risk assessment. Therefore, the tool integrates multiple data layers visible on a planning map:

- Geo-Zones: No-fly zones, restricted and controlled airspace, and sensitive areas. Data is sourced from platforms like D-Flight (Italy);
- Population Density: Critical for assessing ground risk;
- Weather Data: Includes wind speed/direction, temperature, precipitation, and visibility; Sourced from OpenWeather, offering real-time and up to one-week forecasts;
- Buildings Data: Extracted from OpenStreetMap to determine obstacles and sheltering effects;
- Mobile Network Coverage: Used to evaluate and ensure communication performance throughout the mission.

SORA's standard methodology uses predefined population density classes, but this lacks fine resolution. High-fidelity risk assessment integrates detailed data such as dynamic population distribution, terrain, and urban structure to improve ground risk accuracy. Dynamic risk maps based on mobile network-derived population data visualise realistic risk distribution. These maps can be used as mitigation measures in SORA 2.5 to support sheltering and demonstrate that operational restrictions are implemented. An acceptable Equivalent Level of Safety (ELOS) is defined as 1·10^ (-6) h^1. The robustness level of this mitigation depends on data quality and compliance with SORA standards.

The use of risk maps also facilitates risk-based situational awareness. Though primarily intended for mission planning, dynamic application during flight operations supports real-time decision-making. When constructed using continuously updated data, these maps offer online risk estimation and can be used as a tactical mitigation measure to validate real-time mission safety. This requires continuous UAV tracking and real-time visualisation of risk on the map. The DROMT platform provides this capability.

Risk-aware path planning is a predefined functionality. It optimises routes based on risk and flight time, especially for transit-type delivery missions. Minimising flight time is crucial, as risk exposure is time dependent. During execution, replanning algorithms can dynamically adapt routes based on updated risk maps, improving mission safety and flexibility. Advanced simulations will validate the feasibility of transmitting updated routes to UAVs in real time, within operational safety constraints.

A key output of the methodology is the generation of regulatory-compliant documentation. This includes the full SORA 2.5 assessment, the Operations Manual, mitigation evidence, and OSO compliance documentation. Depending on the mission and applied mitigations, the package may also require Means of Compliance (MoC) for critical systems such as parachutes or flight termination modules. Proper structuring and completeness of this documentation are essential for facilitating regulatory approval.

3. IMPLEMENTATION WORKFLOW

The first step is mission definition, which aims to define the details of the mission. The UAV operator must input geographic information regarding the location, aircraft type and characteristics, flight mode (VLOS, BVLOS, or EVLOS), flight height, and mission type (route or definition of a flight area). This step will also require operational information to help contextualise the mission type, such as whether a controlled ground area is to be used or if hazardous goods are to be transported.

The information provided is essential for suggesting and verifying whether a SORA is needed or whether the operation can be classified under simpler operational categories, such as those defined for Open or Certified categories.

The tool may also suggest adopting Standard Scenarios (STS) or Predefined Risk Assessment (PDRA) scenarios, simplifying risk assessment and authorization management. In such cases, the tool could guide the operator in completing the required documentation, although this aspect is not currently addressed in this paper.

In the Ground Risk Assessment step, the operator can refer to the risk map to observe the population density and the risk distribution on the map. The display of the iGRC accompanies this visualisation. The operator can adjust the map's operational area or previously defined points of interest to modify the resulting risk. This step also includes the Risk-Aware Path Planning functionality. Suppose an automatically defined route is in place. In that case, the user can observe the low-risk flight plan and, if necessary, modify the starting and destination points to minimise the risk further.

The UAV operator must include and demonstrate mitigations. In some cases, demonstrations will be suggested (such as when using the risk map and risk-aware path planning). In contrast, in other cases, it will be the operator's responsibility to justify and, if necessary, attach supporting documentation. The demonstration of mitigations does not need to be fully detailed at this step; instead, the UAV operator can include preliminary comments or outlines.

Following the determination of the Final GRC, the UAV operator checks whether the resulting level is acceptable (Final GRC < 8). If not, the operator can adjust the information defined in the previous steps to reduce the GRC.

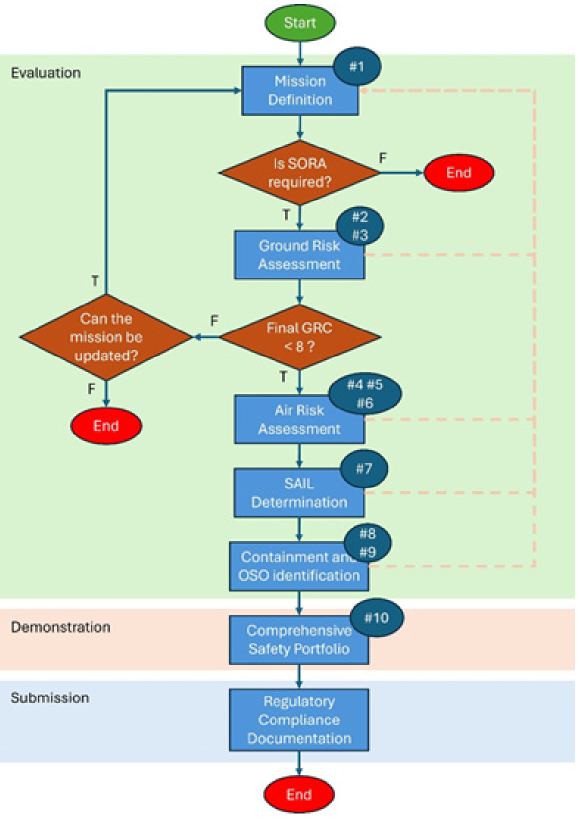

Fig. 2. Workflow of the mission planning phase.

The Air Risk Assessment step defines the type of airspace. The UAV operator will view supporting information on the map regarding the airspace classification, which may include the possibility of issuing a NOTAM. This step will also include the definition of strategic mitigations to establish the Residual ARC and the Tactical Mitigation Performance Requirements (TMPR). Once the Final GRC and Residual ARC are determined, the SAIL is defined.

Next, the Containment Requirement step is determined based on the characteristics of the operational space. The UAV operator can select and view the requirements related to the type of containment: base or enhanced. Thus, the OSOs identification step follows.

All the previously described steps are part of the evaluation phase, which aims to assess the risks and requirements for the planned mission easily. The evaluation phase allows the user to modify any information at any step easily. This feature is advantageous for a UAV operator, as they often lack awareness of the resulting risks and requirements. Therefore, the user can adjust mission details to achieve the desired mission profile, even in terms of the ability to meet the various requirements set by the OSOs.

After the evaluation phase, the UAV operator can complete the Comprehensive Safety Portfolio. In this step, the user must demonstrate compliance with the SORA requirements by providing supporting documentation and including justifications for the mitigations selected during the evaluation phase. This step is essential for gathering all necessary documentation.

Finally, the output of the mission planning tool is the documentation that can be downloaded in an editable format. The resulting documentation must comply with the NAA's requirements.

The mission monitoring phase implements situational awareness functionalities during the flight operations. The flowchart of this phase is shown in Fig. 3.

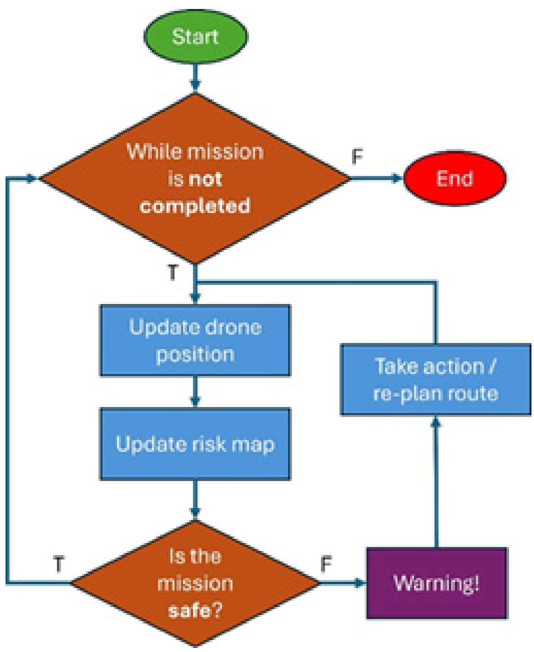

Fig. 3. Workflow of the mission monitoring phase.

Once the mission is started, the tool continuously updates the UAV's position, and the Pilot in Command can monitor it in real time on the map, overlaying various available layers, such as the risk map and population density. During the mission execution, the risk map is continually updated, considering dynamic data. If any undesirable situations arise, the tool will warn the operator. Common causes for warnings include high-risk areas (exceeding the ELOS), an invalid or unsafe risk-aware path, the UAV deviating from its route or moving outside the

Flight Geography, or updates to the geo-zone that affect the operational volume.

Suppose the unmanned aircraft follows a route calculated with the risk-aware path planning algorithm. In that case, the methodology will re-plan the route, providing an updated flight path based on the dynamic map. The pilot must approve the updated path in command before sending it to the UAV for execution. It is important to emphasise that the tool only notifies users of situations where the mission is no longer safe or feasible. The decision to abort the mission, perform emergency manoeuvers (safety landing etc.), or proceed with the flight remains in the hands of the Pilot in command.

4. TECHNOLOGICAL INFRASTRUCTURE

As previously mentioned, the tool implementing the BVLOS mission planning, validation, and monitoring methodology is under implementation. However, the working group has already defined the implementation specifications and implemented the software modules that represent the tool's "core," i.e., the risk map generation and the risk-aware path planning and re-planning.

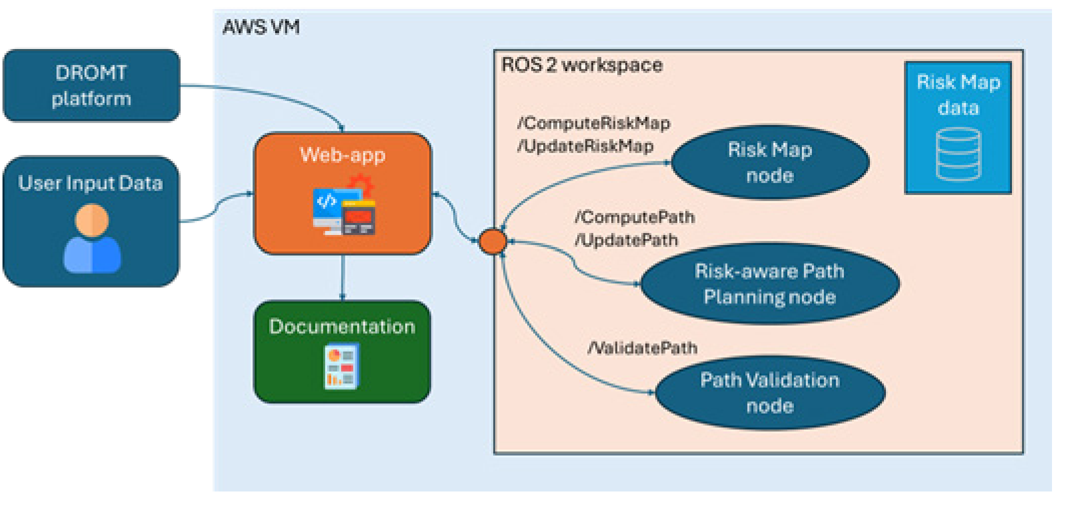

Fig. 4. The main software architecture.

The main software architecture is depicted in Fig. 4, as Risk Map and Risk-Aware Path Planning and Re-Planning functionalities are implemented within the ROS 2 framework. ROS 2 (Robot Operating System v2) is an open-source framework widely used to develop robotics applications. This framework has been chosen because it offers several tools suitable for managing the communication between different software modules (ROS nodes) and for the compatible libraries useful for generating the maps and implementing the path planning algorithm. The Risk Map and Risk-aware Path Planning module have been developed in C++ as ROS nodes. The Risk Map node uses several data sources, including OpenStreetMap, WeatherMap, and some raster data provided by the project partner from Italy Wind Tre, including the population density and the Coverage Network data.

The Risk Map is managed using a multi-layer structure and exploiting the GridMap library. The Risk-Aware Path Planning implements a dynamic path planning algorithm called D-RRT#, a sampling-based algorithm based on the well-known Rapidly Exploring Random Tree developed by the Politecnico di Torino research group. This algorithm uses the OMPL (Open Motion Planning Library) library. These ROS nodes exchange data with the Web App using Service-based communication. Several services have been created to generate and update the Risk Map (/ComputeRiskMap and /UpdateRiskMap) and plan and re-plan safe routes (/ComputePath and /UpdatePath). The web app represents the tool for implementing the BVLOS mission planning, validation, and monitoring methodology. This web app is under implementation and will be executed on the Cloud, exploiting some AWS Cloud-based services. The web app will include all the functions exposed in the previous sections and will follow the workflow previously described. Most of the input data will be inserted manually by the UAV operator in each step of the SORA. Some data are sent from the DROMT platform, such as the real-time position of the UAV and its status.

The output is the documentation that includes the mission planning details, as detailed in the previous paragraphs.

UA specifications include:

- Type: rotorcraft without parachute;
- Altimetry: barometric altimetry;
- Maximum speed: Up to 20 m/s (in case of the Vecaku beach, it should be limited to 10 m/s by software);
- Maximum wind speed: 8.0 m/s;
- Dimensions: 0.5 m (diagonal, including propellers);
- Maximum pitch angle: 25.0 degrees.

Flight parameters are the following:

- Height of flight geography: 50 m (take-off/landing zones must be reduced approx. up to 20 m);
- Ground risk buffer manoeuver: Ballistic.

Assumptions are the following:

- GPS inaccuracy: 3 m;
- Position holding error: 3 m;
- Reaction time: 3 s (minimal allowed);
- Altitude error (barometric): 1 m;
- Altitude error (GPS): 4 m;
- Additional errors: 0 (could become known after UAV (including software) launch).

Calculated results are the following:

- Horizontal contingency volume: 80 m;
- Vertical contingency volume: 94 m;
- Ground risk buffer: 66 m;
- Height of flight geography: 50 m.

5. LAKESIDE RESCUE AND SURVEILLANCE

There is a reserved airspace zone secured by the NOTAM for monitoring using UAVs, which excludes the possibility of operating manned aircraft and UAVs.

In the locations, specially reserved zones are designated for operations, prohibiting manned aviation flights. In each location, two UAVs operate; they are centralised and managed by the FCC. FCC operators maintain communication with municipal police and rescue officers, both mobile and radio, which provides them with the proper situational awareness to fulfil their tasks. All operation phases are performed in BVLOS conditions.

Two flight plans will undergo testing at the lake. During mild weather (April to October), the initial flight will be directed towards destination A, followed by the second trip to destination B. Every flight will occur parallel to the coastline to identify individuals and vessels engaged in swimming activities. The testing will determine the ideal flight distance to the shoreline for optimal identification of a boat and a swimming individual. The test should yield accurate data regarding the actual battery life, which may impact future flight plans. The tests will be conducted during the daytime and nighttime, and the rescue officers will be available at the rescue station around the clock. Flight plans are prepared for the approximate characteristics of the possible UAV options.

UAV Monitoring is automatically carried out according to a predetermined schedule during daylight and nighttime hours. Figure 5 shows the detailed flight plans.

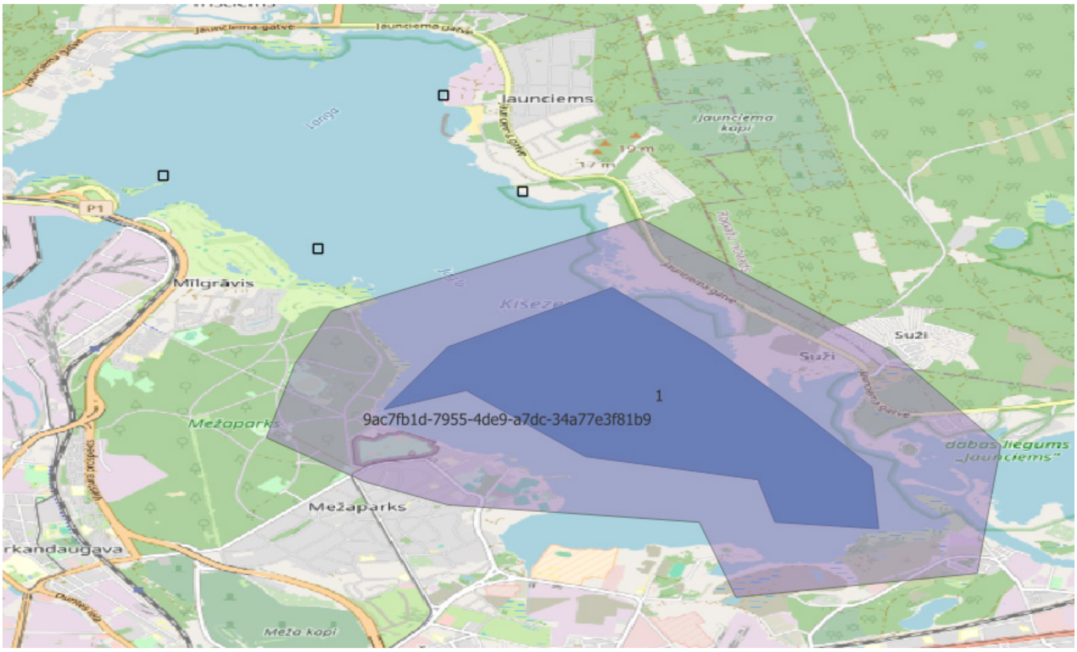

Fig. 5. The flight plan.

The operations environment and platform are fully integrated at the location. The special reserved operating zone limits the operating zones vertically by the maximum specified operating altitude in the specific geozone. 5G network coverage is provided in the operating area, with stable necessary parameters, performance, and appropriate coverage.

The existing rescue station will be used as a UAV base station, where UAV “dock stations” will be installed. Hence, the operator will act as the owner of the UAV operation zone and have the authority to coordinate UAV flights. The use case flight demonstrations are planned during cold and warm seasons, with subsequent verification and evaluation. From all the scenarios and described opportunities, we followed the stakeholders’ opinions to select the best possible solutions that might bring the most benefits, such as improving emergency response and increasing public safety.

Location will be equipped with 5G technology. At least four UAVs will be purchased since the weather conditions in winter and summer vary significantly, from frozen water to a full-fledged bathing season. There will be embankment observation (search and rescue in landscaped areas and beach observation). It is important to consider several scenarios, such as developing safety protocols for BVLOS flights, Notice to Air Missions (NOTAM) procedures, balancing between police purposes and airport Control Zone (CTR) restrictions, and inspecting landscaped and abandoned areas to prevent arson or other incidents. Surveillance and rescue operations will be carried out using modern and intelligent technologies, which will help reduce the load on necessary personnel, speed up rescue time, and benefit all members of society, including visitors, families with children, deaf or blind people, persons with reduced mobility, athletes, and lovers of various recreational activities, guests of the city, and even pets.

UAV flights will be tested in the lake aquarium during the active bathing period, which spans from 15 May to 15 September. These flights will occur between 07:00 and 23:00. Outside of this time frame, the UAV will only be used for specific observations when necessary. The rescue officers are at the location from 10:00 to 22:00. Outside these hours, the FCC will relay information to nearby patrols. The tests will provide insight into 1) the utilisation of various operations within a single flight; 2) the flight's distance and signal strength; and 3) the integration of artificial intelligence. Modifications to the flight plan will be made after the testing procedure. During the summer, the number of beach users increases, including at unregistered beaches, while shore fishing intensifies in the off-season of spring and autumn. We must rely on reports or patrol the area with a boat and thermal camera to identify shore fishermen. This is particularly relevant during the night in autumn, summer, and spring. It is desirable to equip UAVs with a thermal camera. Suppose the optics and thermal imaging are powerful. In that case, there is no need to fly along the shores while circling the lake's perimeter, as a powerful thermal camera will "see" the water part of the lake along the shore and the shore section from the middle of the lake.

In the nature reserve, people and vessels are forbidden to be present during the bird nesting period from 15 March to 1 July, and vehicle entry is restricted all year round. From 1 March to 30 April, fishing from boats is prohibited. During this period, any boat is suspicious at night. Individuals or vessels can disappear over water. For instance, a child may be blown deeper into a lake on a mattress, an athlete may be unable to reach the shore of the lake on their own, or a motorboat's engine may fail in the middle of the lake, necessitating the boat and its passengers to be brought ashore. In such cases, an aerial UAV is used to determine the location of the person or vessel. The area of flight zone restrictions is depicted in Fig. 6.

To reduce the potential for human error and help with situation awareness, the lifeguards use UAVs manually piloted by one of the lifeguards. However, this approach still involves significant human involvement, which will be critical in emergencies where every lifeguard needs to be available for rescue operations. To address this issue, a UAV solution will be implemented to reduce human involvement in public beach area surveillance. The use case description derived from interviews with stakeholders and actors allows us to identify areas for improvement, processes associated with UAV use, and specific technological improvements that are viable with better cellular connectivity and user-specific programming. This is shown in Table 1 below.

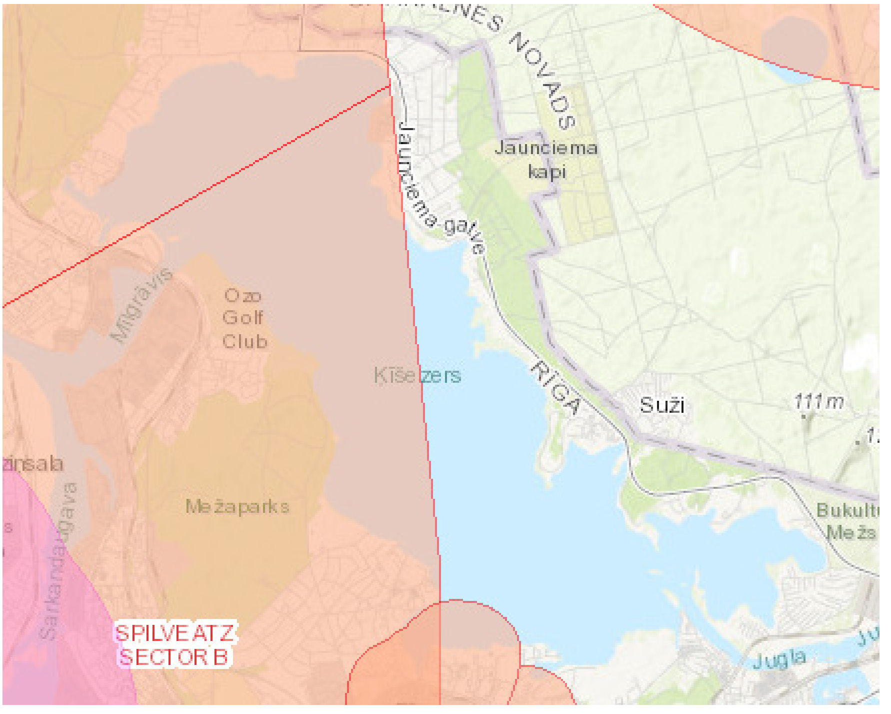

Fig. 6. The area of flight zone restrictions.

Table 1. Improvement Processes Based on Identified Difficulties

Problem/difficulties	**Solution**	**Enabling technologies**
Limited personnel for UAV management	Automation and semi-automation of UAV operation	- 5G network - UTM tools and systems - Mission planning and control software - UAV with 5G and BVLOS capabilities - Software and applications-based procedures and processes - Monitoring hardware with 5G capability - AI-based components for automation of data processing
Need for quick and accurate interpretation of information received from the UAV	Data processing and post-processing with appropriate visualisation	- 5G network - Image processing - Tools for information receiving and processing with 5G capabilities - High-resolution cameras and sensors with 5G network transmission capabilities - Gimbal with the capability to send online axis position data - AI-based components for automation of data processing - User-centric interface
Need for information retrieval during nighttime	Data processing and post-processing with appropriate visualisation	- 5G network - Image processing - Night vision capabilities of the camera

Problem/difficulties	Solution	Enabling technologies
Contactless ice condition measurement	Special payload equipment was installed in the UAV for automated measurement	- 5G network - Radar-based technologies - Sonar-based technologies
Need to provide audio information close to objects	Special payload equipment installed into the UAV for voice command repeated (online / recorded)	- 5G network - Loudspeaker installed in the payload/UAV
Need for geolocation parameters of objects	Special hardware/software integrated into UAV sensors and systems	- Gimbal with the capability to send online axis position data - 5G network
Need for quick deployment of UAVs	Automation and digitalisation of components and processes	- dock station with platform support automation - Digitalisation of procedures and operations - Near real-time data flow and processing
Large surveillance area	UAV performance, UAV operation/management	

6. CONCLUSIONS

This study demonstrates the viability and strategic importance of integrating UAV systems with 5G connectivity for lakeside rescue and surveillance operations in urban environments. Adopting a SORA 2.5-compliant methodology supported by high-fidelity risk assessment tools makes planning and executing safe and operationally effective BVLOS missions possible. Using real-time monitoring and automated docking infrastructure ensures that emergency response units can act faster, with greater situational awareness and reduced human burden.

Furthermore, the ROCC, powered by 5G infrastructure, enables seamless coordination between UAV operators, municipal authorities, and first responders. Automated workflows and standardised operation manuals ensure mission repeatability and compliance with national and EU regulations.

Looking ahead, the approach outlined in this study offers a scalable framework that can be replicated across different geographical and regulatory contexts in the EU. It also sets the stage for further integration with advanced sensor payloads, mobile AI processing, and cross-sector interoperability in public safety, environmental monitoring, and disaster response.

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