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29 November 2026

A Risk-Aware Mission Planning and Monitoring Methodology for UAS Operations

Stefano Primatesta[1]

Abstract— **The increasing use of Unmanned Aircraft Systems (UAS) in critical scenarios raises the need for efficient mission planning and risk assessment methodologies. One of the main challenges in UAS operations is the regulatory approval process, which requires operators to prepare comprehensive and compliant documentation. In this paper, we propose a mission planning methodology designed to assist UAS operators in conducting a risk assessment aligned with SORA 2.5 and generating documentation that meets European regulatory requirements. Additionally, our methodology integrates a risk-aware path planning approach to compute low-risk flight routes.**

Another key aspect of our approach is a situational awareness module, which enables real-time monitoring of risk and operational constraints during mission execution. If the initially planned route becomes unsafe, a re-planning algorithm dynamically adjusts the route, ensuring an adequate level of safety.

Although the proposed methodology is still under development, this paper presents the essential requirements and features, as well as preliminary results on risk map generation and risk-based route planning and re-planning algorithms.

I. Introduction

In the last few decades, Unmanned Aircraft Systems (UAS) have experienced a significant increase in popularity and usage due to their flexibility in conducting a wide range of applications in both the civil and military fields. In particular, UAS have recently seen further diffusion thanks to the emerging concepts of Advanced Air Mobility (AAM) and Urban Air Mobility (UAM). UAS are aerial platforms capable of carrying different types of payloads, and, therefore, suitable for a wide variety of applications: logistics, monitoring, surveillance, and mapping, to name a few [1].

Nowadays, UAS are already widely used for professional and research activities. However, most of the flight operations are performed with several operational limitations, e.g., with the Pilot in Command in Visual Line-Of-Sight (VLOS) and in non-populated or, if not possible, controlled ground areas. Indeed, for safety reasons, the use of UAS is strictly regulated by National Aviation Authorities (NAA) [2]. For example, in Europe, EASA (European Union Aviation Safety Agency) has adopted a risk-based approach [3] where operational limits are imposed based on the risk of the flight operation, the skills and competence of the UAS operator (and pilot), and the type of aircraft.

The European Regulatory framework classifies UAS operations into three main categories with increasing risk: open, specific, and certified [3]. The Open category is low risk, with numerous operational limitations, and without the requirement to request authorization from the NAA. The specific category is medium risk and, for this reason, requires the performance of a risk assessment and, with some exceptions, requires flight authorization from the NAA. The certified category, on the other hand, is high-risk and requires certification of the aircraft and the operator with an approach similar to general aviation. While the Open and Specific categories are currently involved in numerous UAS flight operations, the certified category is currently being defined.

While the Open category allows the wide use of UAS with important operational limitations (e.g., operating in VLOS), the Specific category is the most promising for carrying out professional activities with UAS. In this category, the operational constraints and safety requirements are defined following a risk assessment conducted through the Specific Operations Risk Assessment (SORA) methodology proposed by JARUS (Joint Authorities for Rulemaking on Unmanned Systems) [4]. The SORA methodology is a multi-step process that allows ground and air risk assessment, and defines the requirements that must be satisfied by the UAS operator to guarantee an adequate level of safety.

However, performing the SORA requires skills from UAS operators and the authorization times can be long [5]. To facilitate operations in the Specific category, EASA has published pre-defined scenarios that do not require the application from scratch of the SORA, but require compliance with operational constraints and safety requirements [3]: *(i)* STS (Standard Scenario) with medium-low risk. A self-declaration by the UAS operator is sufficient to carry out the flight operation; *(ii)* PDRA (Predefined Risk Assessment) with medium risk. It requires authorization from the NAA, but the UAS operator is facilitated with a pre-filled SORA.

According to EASA data [6], there are approximately 1.8 million registered UAS operators in Europe by 2024. Despite this high number of UAS operators only around 1600 operations have been conducted under STS scenarios, about 400 under PDRA scenarios, and approximately 2600 Specific Category operations using the SORA methodology. The data shows that UAS operators tend to prefer conducting operations within the Open Category, mainly due to the challenges associated with obtaining flight authorizations, often related to inadequate training of the UAS operator, and the long times of the authorization process. However, the current situation highlights a limitation within the UAS ecosystem, as the full potential of UAS lies in enabling automatic (or autonomous) operations without operational constraints, such as in BVLOS (Beyond Visual Line-Of-

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Sight) and in populated areas.

Following this analysis, it is evident that there is a need to develop tools that facilitate UAS operators to perform UAS mission planning, conduct SORA-based risk assessment, and produce adequate documentation for submission to the NAA.

This need is well-recognized in the literature, and several solutions have already been proposed to support UAS operators. Some of these focus on providing a tool for guided SORA execution. In [7], a tool is presented to assist operators in completing each step of the SORA process. A similar approach has been adopted in various Web-app already available for use [8], [9], [10]. Of particular interest is the SORA Tool [11], which implements each individual step of the SORA methodology and guides UAS operators in preparing the documentation required for submission to the NAA. Other studies propose tools to support risk assessment. The work in [12] presents an interactive tool for visualizing operational parameters, while [13] introduces a tool capable of performing a probabilistic risk assessment for fixed-wing drones to support the SORA process.

However, none of the previously described tools provide a comprehensive solution for UAS operators. Some simply translate the SORA process into a digital format, while others only offer specific functionality. Moreover, only [11] presents a solution for generating the documentation required for SORA, but it needs to be updated to SORA 2.5 and is limited to mission preparation.

In this context, this paper aims to identify the requirements and functionalities of a methodology for developing a tool that assists UAS operators in mission planning while also providing situational awareness capabilities during flight operations.

The proposed methodology consists of two main components: mission planning and mission monitoring. Mission planning defines the operational details and performs risk assessment through both the SORA 2.5 framework and a high-fidelity risk assessment approach. This process leverages risk maps to enhance UAS operators' awareness of risk distribution across the operational area. Additionally, when route definition is required, a risk-aware path planning algorithm is employed to compute safe trajectories within the risk map. The output of the mission planner is a SORA 2.5-compliant documentation package, ready for submission to the NAA.

Mission monitoring, on the other hand, focuses on providing situational awareness by tracking the dynamic risk through the risk map. Furthermore, when a minimum-risk route is used, a re-planning algorithm continuously adapts the trajectory in response to real-time changes in the risk distribution.

The proposed methodology builds upon extensive research previously conducted by the research group. In [14], [15], the use of risk maps for estimating both ground and air risks was introduced, also addressing privacy and data protection concerns [16]. Meanwhile, in [17], [18], risk-aware path planning methodologies were proposed. However, these approaches differ from the one adopted in the preliminary results of this paper.

The development of this methodology is part of a larger project entitled 5G4LIVES (5G for a Better Tomorrow: Protecting Lives and the Environment in Riga and Turin). The main objective of 5G4LIVES is the development of innovative solutions based on UAS and 5G technology to enhance public safety. Among the various contributions, there is the development of a Web-app that integrates the methodology proposed in this paper to facilitate mission planning and BVLOS route execution.

The rest of the paper is organized as follows. Section II briefly describes the SORA 2.5 methodology. Section III introduces the proposed methodology by defining requirements, functionalities, and the workflow adopted. Some preliminary results are presented in Section IV. Our conclusions are drawn in Section V.

II. SORA 2.5

The SORA methodology was developed and proposed by JARUS with the aim of providing a standardized risk-based approach for evaluating the safety of UAS operations within the Specific Category. The first version adopted by EASA is SORA 2.0, released in 2019 [4]. This version is the result of an extensive collaboration between regulatory bodies, industry stakeholders, and technical experts.

During the first few years of using SORA, a lot of feedback was collected from real-world applications, as well as the evolution of the UAS ecosystem. This led to the development of a revised version, called SORA 2.5, which includes refinements in risk classification, more detailed guidance for complex operations, and improvement aligned with the evolution of the EU regulatory framework. The SORA 2.5 was released by JARUS in the mid-2024 [19] and, presumably, it will be adopted by EASA before the end of 2025. For this reason, in this paper, we mainly refer to the SORA 2.5.

SORA 2.5 consists of several documents: a main body and 11 annexes, of which two are in preparation. The main structure is very similar to the one proposed in version 2.0. It consists of 10 steps, which are briefly summarized below.

Step #1: **Documentation of the proposed operation(s).** This step aims to provide all the information required to conduct the other steps of the SORA. It includes not only the details of the flight operation (flight location, flight mode, type of UAS, etc.), but also information on pilot training, interaction with other bodies/organizations, and, in practice, all the information required to carry out a risk assessment.

Step #2: **Determination of the intrinsic Ground Risk Class (iGRC).** The intrinsic Ground Risk Class is defined on a scale from 1 to 10 considering the aircraft characteristics and the population density in the operational area and ground risk buffer. This step has been revised compared with SORA 2.0 and, in particular, the iGRC is defined with some qualitative criteria to define ground risk more objectively.

Step #3: **Final Ground Risk Class determination.** The Final Ground Risk Class is determined by considering the mitigations applied to reduce the likelihood of a fatality after loss of control in the operation. Three mitigation types are assumed: *(i)* strategic mitigations to reduce the risk before flight; *(ii)* tactical mitigations to reduce the risk during flight; and, *(iii)* mitigations to reduce the effect of a ground impact.

Step #4: **Determination of the initial Air Risk Class.** The initial Air Risk Class (ARC) is defined considering the airspace type, altitude, and other parameters. The risk defined by ARC-a to ARC-d is defined based on the expected generalized encounter rate in the airspace.

Step #5: **Application of strategic mitigations to determine residual Air Risk Class.** The residual ARC is defined by applying any strategic mitigation to reduce the initial ARC. Mitigations can be both operational limitations, and/or specific rules of the airspace (e.g. UTM, U-Space).

Step #6: **Tactical Mitigation Performance Requirement (TMPR) and Robustness Levels.** This step defines the tactical mitigation requirements to reduce any unacceptable residual air risk.

Step #7: **Specific Assurance and Integrity Level (SAIL) determination.** This step defines the resulting SAIL assigned to the operation. This step is essential, as it determines the final risk based on the Final GRC and residual ARC. The SAIL level plays an important role in all subsequent steps.

Step #8: **Determination of Containment requirements.** Containment requirements are designed to ensure that the target level of safety is achieved for both ground and air risks in adjacent areas.

Step #9: **Identification of Operational Safety Objectives (OSO).** The SAIL defines Integrity and Assurance levels (Low, Medium, High) for each OSO. Operators must demonstrate compliance with 17 OSOs at the required robustness level. These OSOs address areas such as UAS design, operations, maintenance, related services, training, technical aspects, external system reliability, human-machine interface, human error, and adverse conditions.

Step #10: **Comprehensive Safety Portfolio** The Comprehensive Safety Portfolio (CSP) is a set of documents demonstrating compliance with SORA requirements for the proposed operation. If the CSP lacks sufficient evidence for the assigned SAIL, adjustments such as risk reduction measures, design changes, or additional analyses may be required by the NAA.

While the above steps may appear simple, UAS operators often face challenges in assessing the required aspects. These difficulties are due to limited operator expertise or the unavailability of critical data, such as population density, airspace structure, and environmental constraints.

III. Mission planning and monitoring methodology

A. Requirements and Functionalities

The requirements and functionalities described here are the result of an in-depth analysis considering several factors. The first aspect concerns regulatory constraints, which must be addressed to develop a tool aligned with EASA regulations. The second aspect focuses on the needs and requirements of UAS operators. Several interviews were conducted to understand how a support tool should be structured. These needs go beyond regulatory compliance, encompassing geographic and risk awareness during mission planning, as well as access to hard-to-find data, such as population density. The third aspect relates to compatibility with the objectives of the 5G4LIVES project, in which the tool presented in this paper will be employed. Specifically, since the 5G4LIVES project involves unmanned aircraft connected to the 5G mobile network, having real-time awareness of the connection quality is essential to ensure continuous communication with the UAS. Below, each requirement and feature grouped by topic is analyzed and discussed.

Compatibility with SORA 2.5

The main requirement is full compatibility with SORA 2.5. In particular, the tool must be able to perform each step of SORA 2.5. Each step should be presented as a guided procedure, offering UAS operators contextual suggestions for input data, best practices for risk assessment, and recommendations for selecting appropriate mitigation strategies.

Inspired by what is already proposed in SORA Tool [11], three phases can be identified: evaluation, demonstration, and submission. The evaluation phase is the most substantial, as it involves the execution of steps 1-9. This phase aims to guide the operator through the risk analysis, supporting them in data collection and preliminary safety assessments. The demonstration phase primarily concerns step 10, i.e., the demonstration of compliance. It includes the completion of the Comprehensive Safety Portfolio, and the uploading of supporting documents (e.g., manuals, test reports, mitigations, and robustness evidence). The tool can assist in this phase by providing templates for documentation and checklists to ensure that all required evidence is present. Finally, the submission phase involves the formal submission of the documentation to the competent authority. In the first version of the tool, this phase consists of downloading documentation compliant with submission requirements for the NAA. However, future integration with NAA platforms for automated submission management is also possible.

Data provision

A common challenge faced by UAS operators is the difficulty in accessing the data required for a thorough evaluation of the operational area. Currently, the NAAs of many European and non-European countries provide publicly available maps that allow operators to identify and verify so-called geo-zones, i.e., predefined areas where specific operational constraints apply, such as restricted airspace or no-fly zones. These maps serve as essential tools for mission planning and risk assessment, but they often lack data on other critical factors, such as population density and weather conditions. For this reason, the proposed tool

includes different types of data, available and viewable on the map during mission planning.

Geo-zones: visualization of specific areas in which the flight is restricted or prohibited. It includes no-fly zones, restricted airspace, controlled airspace near airports, and sensitive environments such as nature reserves. In our project, information about geo-zones is extracted from D-Fligth [20], the Italian UTM service provider.

Population Density: the visualization of population density and distribution is crucial for assessing the ground risk. Depending on the source, population density data can be static (e.g., derived from census data), or dynamic (e.g., based on mobile network data analysis). While static census data provides information about where people live, it does not reflect the actual presence of people at a specific time of the day. In contrast, population distribution estimates from mobile network companies offer more accurate data, providing both historical trends and real-time estimations to support a more realistic ground risk assessment.

Population density data for this project are provided by Wind Tre S.p.a., a 5G4LIVES partner, based on historical mobile network data analysis. The estimates, available for different times of day and days of the week, are essential for estimating ground risk.

Weather Data: weather data is a critical factor in mission planning, as it influences both flight safety and operational feasibility. Key parameters include wind speed and direction, temperature, precipitation, and visibility. Weather data is useful both for mission planning using weather forecasts and during the flight mission by analyzing real-time data to support dynamic decision-making. Weather data are obtained from OpenWeather [21], which provides access to both real-time weather data and forecasts up to one week in advance.

Sensitive Areas: visualization of specific zones that may raise privacy, security, and safety concerns. Examples include schools, hospitals, and other critical infrastructure. This data is crucial to enhance the operator's situational awareness, helping to identify infrastructures within the operational areas that could pose potential risks or require specific considerations. As presented in [16], sensitive areas are extracted from OpenStreetmap [22].

Mobile Network Coverage: with UAS connected to the mobile network—such as in the 5G4LIVES project—it is crucial to have a representation of mobile network coverage. This information can be used to determine suitable flight areas based on the required data transmission capabilities. This data is provided by Wind Tre, as the 5G4LIVES project will utilize the Wind Tre mobile network across the Italian territory.

High-Fidelity Risk Assessment

The SORA methodology provides a multi-step approach for assessing ground risk. However, this approach determines the risk based on predefined population density classes without a highly detailed spatial and temporal resolution. In some scenarios, a more refined ground risk estimation can enhance operational safety and flexibility. High-fidelity risk assessment methodologies can integrate additional data sources, such as dynamic population distribution, terrain and urban area characteristics, and other factors, to provide a more granular assessment of the ground risk associated with a given flight operation.

The high-fidelity risk assessment can be provided by using a probabilistic methodology widely used in the literature [23]. Specifically, in the proposed tool, we adopt the methodology defined in our previous work [14] to compute the ground risk

The ground risk is defined as the expected frequency of fatalities ($f_{\mathbf{fatality}}$) expressed in fatalities per flight hour (h^{-1}) computed as

$$f_{\mathbf{fatality}} = f_{\mathbf{GIA}} \cdot N_{\mathbf{impact}} \cdot P_{\mathbf{fatality}} \tag{1}$$

with $f_{\mathbf{GIA}}$ is the rate of a ground impact accident, $N_{\mathbf{impact}}$ is the number of people exposed to the ground impact accident, and $P_{\mathbf{fatality}}$ is the probability that impacted people suffer of fatal injuries. Refer to [14] for details on the definition of each term in the equation.

One of the main challenges of high-fidelity risk assessment is the use of realistic and consistent data. The value of $f_{\mathbf{GIA}}$ is generally not provided by manufacturers and varies significantly depending on the type of aircraft, as discussed in [24], as well as other factors such as human error. In Europe, drones with a Class Identification Label meet specific design and safety standards. This classification can help estimate failure rates and the likelihood of ground impact accidents. A precise estimate of $N_{\mathbf{impact}}$ relies on the accuracy and resolution of the population density data. The estimate of $P_{\mathbf{fatality}}$ also depends on various factors, including the sheltering factor, which represents how people can be sheltered by buildings or other structures. To ensure a reliable risk assessment, it is advisable to adopt a conservative approach in such cases.

A crucial feature is the visualization of the risk distribution on the map. This can be useful in the mission planning phase to have an awareness about the risk in the area of interest. In this regard, the use of risk maps is particularly suitable. Risk maps were previously introduced in [14] and allow to quantify the ground risk over large areas. Specifically, a risk map is a two-dimensional location-based map, in which each element of the map has a risk value defined with a high-fidelity risk assessment approach.

Risk maps can also be employed as a strategic mitigation measure (M1) in SORA with a medium-high level of robustness, both to support the sheltering criterion and to demonstrate that operational restrictions have been implemented to reduce risk. In particular, the mitigation is effective if it can be shown that the resulting risk remains within acceptable limits. As specified in SORA and the relevant literature [23], an adequate Equivalent Level of Safety (ELOS) is defined as $1 \cdot 10^{-6}\ \mathrm{h}^{-1}$. The applicable level of robustness depends on the quality of the data used and the compliance with the requirements in SORA.

Risk-based Situational Awareness

The adoption of risk maps already supports risk-based situational awareness. While risk maps are primarily utilized for risk assessment during mission planning, their dynamic application offers an additional advantage by providing real-time situational awareness during flight operations, supporting decision-making. When constructed with dynamic data and continuously updated, risk maps can provide an online risk estimate, enabling UAS operators to adapt to evolving conditions. This capability can also serve as a Tactical Mitigation (M1), as it provides real-time evidence of the risk level throughout the mission, enhancing overall operational safety. This feature requires real-time drone tracking, with its position continuously shared and displayed on the dynamic risk map.

Risk-aware Path Planning and Re-Planning

Another functionality is the integration of risk-aware path planning. In [18], we introduced a risk-aware path planning approach that optimizes both risk minimization and flight time. This optimization is particularly relevant because risk is typically expressed as an hourly frequency, so it is directly proportional to the duration of flight operations. However, this approach is not applicable to all mission types. It is particularly beneficial for operations requiring transit between a starting point and one or more destination points, such as logistics and delivery services, where reducing exposure time and optimizing the route are critical factors.

Risk-aware path planning offers advantages not only during mission planning but also in supporting decision-making during mission execution. When combined with the ”Risk-based Situational Awareness” functionality, a re-planning algorithm can dynamically adjust the flight path in response to real-time variations in the risk map, ensuring that the operation maintains an acceptable risk level throughout its execution. This capability enhances operational flexibility and safety, particularly in dynamic environments where risk factors may change unexpectedly.

Regulatory Compliance Documentation

Finally, a crucial functionality is the generation of regulatory-compliant documentation. The tool’s output should be a complete set of documents ready for submission to the NAA as part of the flight authorization request. The documentation must include the SORA 2.5 assessment along with all supporting materials required from the UAS operator. This includes the Operations Manual, evidence of implemented mitigations, and documentation demonstrating compliance with the OSOs. Additionally, depending on the specific risk assessment and mitigations applied, further documentation may be required, such as Means of Compliance (MoC) for safety-critical systems like parachutes or flight termination systems. Ensuring that all necessary evidence is properly compiled and structured is essential to facilitate regulatory approval and streamline the authorization process.

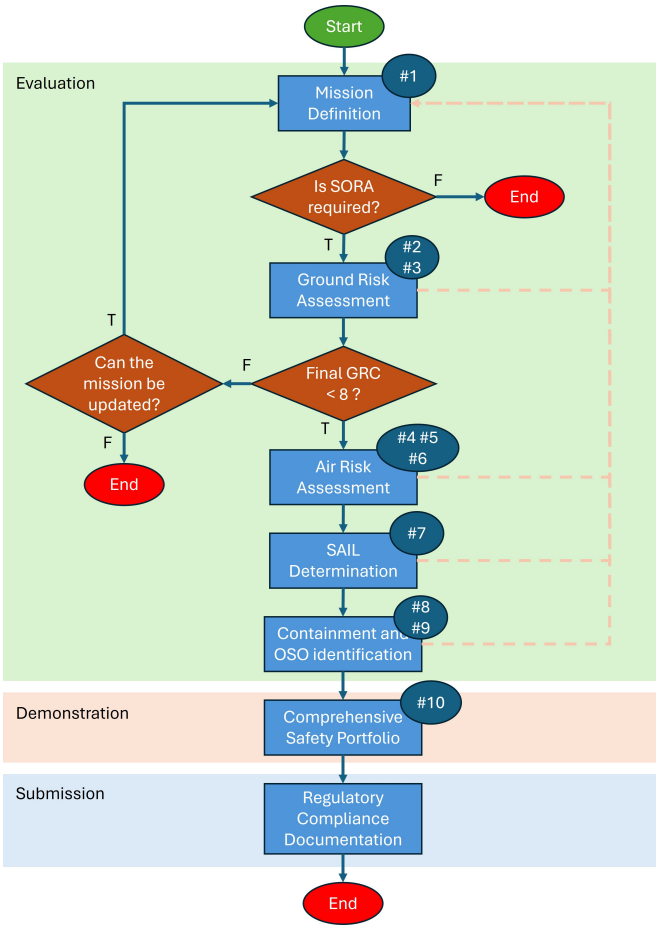


Figure 1. Workflow of the mission planning phase.

B. Methodology Workflow

The high-level workflow is divided into two main phases: mission planning and mission monitoring.

The mission planning phase aims to define the flight mission by conducting a risk analysis incorporating SORA 2.5 and the high-fidelity risk assessment, as well as preparing the necessary documentation for submission to the NAA to request flight authorization.

The mission monitoring phase focuses on providing advanced functionalities to enhance situational awareness during the mission. These include, for example, dynamic risk visualization and real-time flight plan updates to ensure an adequate level of safety.

Mission Planning

The mission planning phase has been defined by incorporating all steps of the SORA 2.5. For this reason, the flowchart in Figure 1 highlights the relevant SORA steps within the various blocks.

The first step is Mission Definition, which aims to define the mission’s details. The UAS operator will need to 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 contextualize the mission type, such as whether a controlled ground area will be used, or if hazardous goods will be transported. The information provided is essential for suggesting and verifying the actual need to perform a SORA, or if the operation can be classified under simpler operational categories, such as those defined for Open or Certified categories. The tool may also suggest adopting STS or PDRA scenarios, which simplify the 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. This visualization is accompanied by the display of the iGRC. The operator has the flexibility to adjust the operational area or the points of interest on the map previously defined in order to modify the resulting risk. This step also includes the Risk-Aware Path Planning functionality. If an automatically defined route is in place, the user can observe the low-risk flight plan and, if necessary, modify the starting and destination points to further minimize the risk.

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

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

The Air Risk Assessment step defines the type of airspace. The UAS operator will view supporting information on the map regarding the airspace classification and 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 UAS 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 easily assess the resulting risk and the requirements for the planned mission. The evaluation phase allows the user to easily modify any information at any step. This feature is advantageous for a UAS 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.

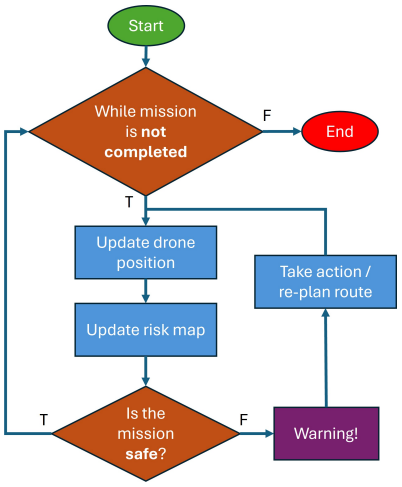


Figure 2. Workflow of the mission monitoring phase.

Following the evaluation phase, the UAS operator can complete the Comprehensive Safety Portfolio. In this step, the user has to 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.

Mission Monitoring

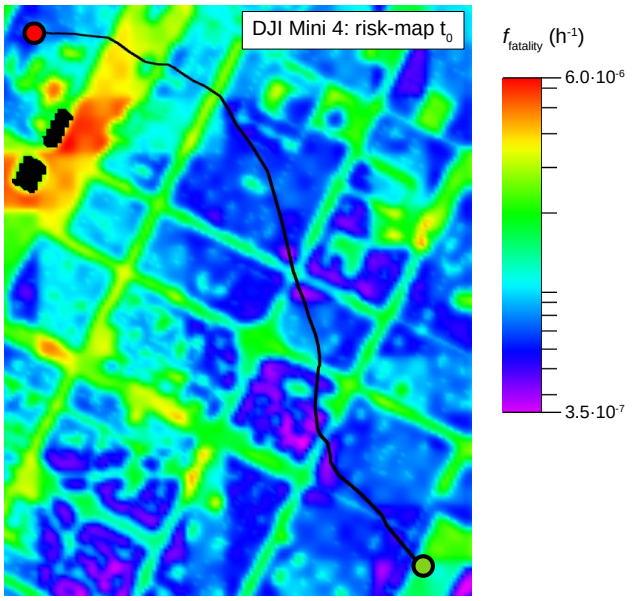
The mission monitoring phase implements situational awareness functionalities during the flight operations. The flowchart of this phase is shown in Figure 2.

Once the mission is started, the tool continuously updates the drone, and the Pilot in Command can monitor the drone's real-time position on the map, overlaying various available layers, such as the risk map and population density.

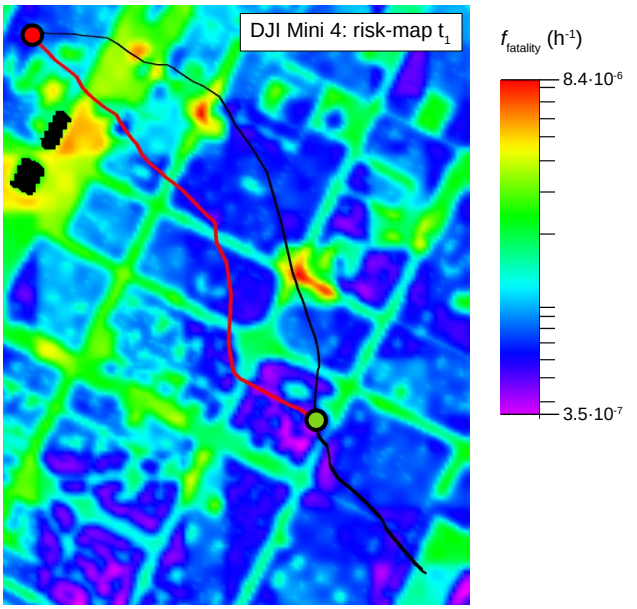
During the mission execution, the risk map is continually updated, considering dynamic data. If any undesirable situations arise, the tool will issue warnings to inform the operator. Common causes for warnings include: high-risk areas (exceeding the ELOS), an invalid or unsafe risk-aware path, the drone deviating from its route or moving outside the Flight Geography, or updates to the geo-zone that affect the operational volume.

In case the unmanned aircraft follows a route calculated with the risk-aware path planning algorithm, the methodology will re-plan the route, providing an updated flight path based on the dynamic map. The updated path must be approved by the pilot in command before being sent to the drone for execution.

It is important to emphasize that the tool only notifies the user of situations where the mission is no longer safe or feasible. The decision to abort the mission, perform emergency maneuvers (e.g., safety landing), or proceed with the flight remains in the hands of the Pilot in command.



(a)



(b)

Figure 3. In (a) is the minimum risk path (black line) computed within the ground risk map considering a DJI Mini 4. In (b) is the result of the re-planning phase (red line) after a dynamic update of the ground risk map.

IV. Preliminary Results

As mentioned in the introduction, the goal of this paper is to present the requirements and functionalities of the mission planning and monitoring tool. The methodology proposed is currently under development by the research group involved in the 5G4LIVES project. In this section, we will provide some implementation details and report on preliminary results regarding the ground risk map and the risk-aware path planning and re-planning algorithm.

The mission planning and execution tool will be developed as a Web-app. The framework will be entirely executed in the Cloud exploiting Amazon AWS, meaning no installation will be required on the device of UAS operator, nor will there be any specific computational requirements.

The core of the framework consists of the software that implements the creation of the ground risk map and the risk-aware path planning and re-planning algorithm. These algorithms, as described in [14], [18], are implemented in C++ within the ROS 2 (Robot Operating System) framework. The results presented below have been validated in a simulation environment based on the ROS2/Gazebo/PX4 framework.

Figure 3 reports a preliminary result of the ground risk map and the risk-aware path planning and re-planning. The ground risk map is computed considering the DJI Mini 4, a small drone with a mass of about 0.250 kg, suitable to fly over populated areas. The ground risk map is computed over a portion of the city of Turin (Italy) with a high population density, and considering a flight altitude of 30 meters. The ground risk map has been computed using source data from OpenStreetMap and a realistic, though synthetic, population density dataset. For more details about the implementation procedure, refer to [14].

The risk map shown in Figure 3(a) demonstrates its potential as a powerful tool for assessing risk distribution across large areas. For example, in urban environments, the risk is significantly higher in exposed areas such as roads, while it is considerably lower over buildings. This reduction is attributed to the sheltering factor provided by the structures. The risk map is, therefore, a graphical tool that UAS operators can use to visualize risk distribution and identify the safest areas.

The risk-aware path planning and re-planning is performed by adopting an algorithm based on RRT^X [25] with the minimization of risk costs in the ground risk map and the flight time, as in [18]. RRT^X is a dynamic and enhanced implementation of the well-known Optimal Rapidly-exploring Random Tree (RRT*). As demonstrated in [18], minimizing risk and flight time is an appropriate strategy since the risk, expressed per flight hours, is proportional to the overflight time of a given area.

Figure 3(a) shows the result of the risk-aware path planning. The risk-aware path planning algorithm takes 3.58 s to compute a near-optimal solution with an average ground risk of $9.43 \cdot 10^{-7}$ h^{-1}, lower than the ELOS of $1 \cdot 10^{-6}$ h^{-1}.

We simulated an update of the ground risk map by applying a variation in population density during the flight execution. As a result, the previously computed path is no longer safe, as the average risk of the remaining path has increased to $1.56 \cdot 10^{-6}$ h^{-1}. The risk-aware re-planning computes the updated path in only 0.49 s, and returning a minimum risk path with an average risk of $9.51 \cdot 10^{-7}$ h^{-1}.

This preliminary result demonstrates how the re-planning algorithm can quickly adapt the flight path, ensuring a safe trajectory even with a dynamic risk map.

V. Conclusions

In this paper, we have proposed a mission planning and monitoring methodology that enables UAS operators to plan

missions, assess risk in compliance with SORA 2.5, and monitor risks during mission execution. Specifically, the paper has provided a detailed analysis of the requirements and functionalities that such a tool should implement.

Although the tool is still under development, we have presented preliminary results regarding the definition of the ground risk map and the risk-aware path planning and re-planning algorithm. As previously discussed in [14], the ground risk map is a promising tool for assessing ground risk variations across large areas. UAS operators can leverage it to define the operational area of their mission. Moreover, when updated in real-time, the risk map serves as a valuable situational awareness tool, alerting operators and pilots to potential hazards and dynamic conditions that may pose risks to the flight operation.

The risk-aware path planning algorithm has demonstrated its ability to compute a minimum-risk trajectory within the map. Additionally, the re-planning algorithm can quickly adapt the flight path in response to a dynamically changing risk map.

The integration of the risk map with the path planning algorithm represents a promising decision-making tool. However, the tool aims to go beyond just mission planning. It is also designed to assist in preparing the necessary documentation for flight authorization requests to be submitted to the NAA.

Finally, this tool is not only beneficial for UAS operators but also for NAAs, which need to evaluate comprehensive and regulation-compliant documentation. Of course, this is only feasible if the tool produces high-quality documentation and is approved by the NAA itself. For this reason, the goal is to present the tool to ENAC (Ente Nazionale per l'Aviazione Civile), the Italian NAA, once its development is complete.

Future works include several activities required to finalize the implementation of the methodology. The highest priority tasks are the development of the Web-app to execute the steps of SORA 2.5 and its integration with the software for generating the risk map and risk-aware path planning. The implemented methodology will then undergo an evaluation phase with both UAS operators and ENAC to ensure its development aligns with their requirements and needs.

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