Applicability of JARUS SORA to state UAS operations in disaster relief

Hristo Stanev
Faculty "Economics of Infrastructure"
University of National and World Economy
Sofia, Bulgaria
hstanev@e-dnrs.org

Stefan Hristozov
Sensors and Measurement Technologies in Robotics & Mechatronics Dept.
Institute of Robotics
Sofia, Bulgaria
st.hristozov@ir.bas.bg

***Abstract.** The use of modern unmanned aviation technologies when conducting search and rescue operations, respectively when overcoming the consequences of disasters is an economically justified approach to increase the effectiveness of operations, reducing the costs of their implementation. The nature of the operations implies working in an environment of high uncertainty with variety of stakeholders, which requires the implementation of additional measures to achieve the target levels of aviation safety. To tackle the risks associated with any Unmanned Aerial Systems (UAS) operations JARUS (Joint Authorities for Rulemaking in Unmanned Systems) has proposed a document called SORA (Specific Operations Risk Assessment) adopted as acceptable means of compliance by many civil aviation authorities.*

Admittedly, SORA was developed with civil use of UAS in mind. However, considering its comprehensiveness in risk assessment it is a good starting point to evaluate its applicability at disaster relief operations and adaptability to state aircraft operations. As a rule, activities to overcome the consequences of disasters are the responsibility of the state, therefore it is normal to expect that the capabilities to use UAS will be created and predetermines the relevance of the presented topic.

In the current article the team analyses SORA applicability from the perspective of emergency services as state aircraft operations. Thus, the purpose of this article is to explore the possibilities and to justify the need of implementing a timely procedure and to show an example risk analysis performed for this type of operations, when operating with state unmanned aircraft. Of course, some of the conclusions drawn here for emergency services can be easily transposed to other state UAS operations.

Keywords: JARUS SORA, state UAS, applicability, disaster relief.

I. Introduction

The use of Unmanned Aerial Systems (UAS) to conduct operations in the event of disasters, accidents and catastrophes has established itself as a standard approach to reduce the costs of their conduct, as well as to increase the speed of response while ensuring high levels of aviation safety. There are already many studies in the literature on their application in this field – aerial surveillance for forest fires [1] and firefighting [2], search and rescue missions [3], [4], prevention of disasters [5] and disaster management [6], [7]. Almost all reviews do not take into account the fact that UAS can be used in either their civilian or state capacity. In most cases, civil regulations for UA flights are assumed to be followed, which explains the lack of publications regarding the applicability of JARUS SORA in state UAS operations [8].

On the other hand, it is observed that the International Civil Aviation Organization (ICAO) policy of non-interference in the internal affairs of member states continues to be implemented, not developing the problems of state aviation in ICAO documents, as they are of own responsibility. In the Convention on International Civil Aviation [8], the general understanding of state aircraft is adopted, without speaking of state aviation. In fact, the combination of state aircraft, specialized infrastructure (airports, communication and navigation equipment) and rules for their use predetermines the presence of state aviation in the country where they were created.

An important clarification to introduce into the issues on the subject is the correct understanding of the concept of state aircraft (SA). In Art. 3 of the ICAO, it is accepted that the convention applies to civil aircraft (CA) and does not apply to SA. Those aircraft used in military, customs and police services are considered as SA. From here comes the understanding that the registration of the aircraft is irrelevant - whether it is in a registry of civil aircraft or in a registry of military aircraft (MA), it is only important that they work in the interest of one of the three state services. The same approach should be applied to UAS. Therefore, there may be cases where military, customs or police special operations use civil aircraft flying according to operational flight rules."

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol4.8195

Here JARUS has the vision to provide timely consensus recommendations for UAS that meet the common needs of JARUS members and stakeholders, including ICAO [9] and comes with a document called SORA – Specific Operations Risk Assessment, developed by Working Group 6 Safety and Risk Management, which now has it's 2.0 version (by the time the article is prepared 2.5 is under public consultation). The SORA is meant to help operators and competent authorities and highlight the benefits of a harmonized risk assessment methodology. [10]

II. ANALYSIS OF SORA METHODOLOGY

The SORA Methodology 2.0 [10] in Fig. 1 comprises of ten systematic steps, each crucial for evaluating the safety aspects of Unmanned Aircraft Systems (UAS) operations. Herein, we delineate each step along with its significance within the framework:

1. **Documentation of Proposed Operations**: This initial step serves as a foundational tool for communication between the applicant and the Competent Authority. It involves the creation of comprehensive documentation encompassing operator manuals, compliance evidence, and risk assessments. These documents elucidate the nature of the UAS operation, including flight path details, airspace type, and population density overflown.

2. **Intrinsic Ground Risk Class (iGRC)**: The determination of iGRC, scaled from 1 to 11, is pivotal and hinges upon UA characteristics and population density. This assessment is conducted for both the area at risk and its adjacent region.

3. **Final Ground Risk Class**: Considering strategic mitigations, this step calculates the Final Ground Risk Class, crucial for evaluating the potential fatality risks associated with the operation.

4. **Initial Air Risk Class (ARC)**: Assessment of ARC, conducted qualitatively, involves evaluating airspace characteristics identified in Step #1. Parameters defining ARC categories include airspace type, altitude, and urbanization levels.

5. **Residual Air Risk Class**: Following strategic mitigations, this step determines the Residual Air Risk Class, aiming to reduce the initial risk level associated with mid-air collisions.

6. **Tactical Mitigation Performance Requirement (TMPR) and Robustness Levels**: Tactical mitigations are implemented during operations to mitigate residual risks. TMPRs address various functional aspects crucial for risk mitigation.

7. **Specific Assurance and Integrity Level (SAIL) Determination**: Utilizing outputs from previous steps, SAIL is determined to gauge the operational integrity and assurance level required for the UAS operation.

8. **Identification of Containment Requirements**: This step focuses on assessing risks posed by operational loss of control, necessitating containment design features and operational procedures to mitigate potential hazards.

9. **Identification of Operational Safety Objectives (OSO)**: Based on the assigned SAIL, OSOs are identified, specifying integrity and assurance levels required for various operational aspects, including UAS technical functionalities and human factors.

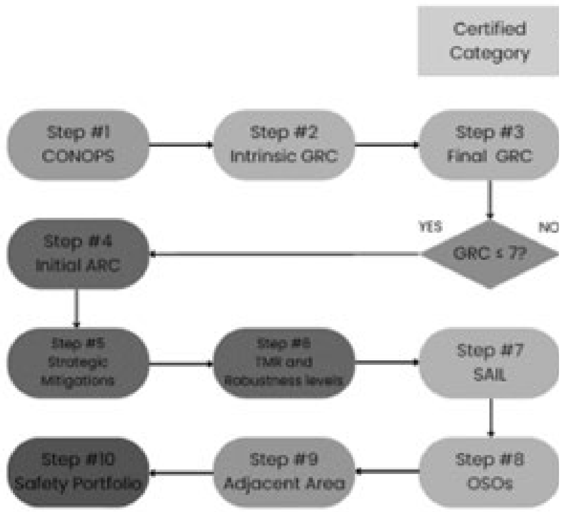

Fig. 1 SORA Methodology (source UAV Navigation-Grupo Oesía)

10. **Comprehensive Safety Portfolio**: This final step involves compiling a comprehensive safety portfolio comprising all necessary documents and compliance evidence, ensuring alignment with SORA requirements. Any discrepancies may necessitate adjustments to the proposed operation or additional evidence for compliance.

By adhering to these systematic steps, the SORA methodology facilitates a rigorous assessment of UAS operations, ensuring safety and regulatory compliance.

Regarding the operations with state UAS, when participating in the disaster relief operations, the applicability of the entire SORA methodology should be assessed in view of the need for a rapid response in the absence of basic information about the area of operations [11], [12]. The assumptions are that SORA can only be applied if there are risk mitigation measures in place beforehand. Regarding the ground risk assessment, there is no doubt that it should be complete in both cases (use of UAS as civil or state), but the risk reduction measures allow to minimize the air risk to allow operations to take place with state UAS in disasters by uncertified personnel according to the requirements of civil aviation. The purpose of the proposed preliminary steps is to minimize the air risk to reasonable limits.

III. EXAMPLE SCENARIO

As of 2011, wildfires around Bansko and Simitli, located in Bulgaria, were a significant concern due to their potential impact on the environment, economy, and public safety. Bansko is a popular ski resort town situated in the Pirin Mountains, while Simitli is a municipality located in the Blagoevgrad Province, also in the southwestern part of Bulgaria.

Wildfires such regions, particularly during dry and hot periods, pose a threat to the surrounding forests, biodiversity, and nearby communities. The Pirin Mountains, where Bansko is located, are known for their diverse ecosystems, including old-growth forests and unique plant species. Fires in these areas can lead to habitat destruction, soil erosion, and loss of biodiversity.

Simitli, being situated in a region with a mix of forests and agricultural lands, is also susceptible to wildfires. In addition to the ecological impact, wildfires in this area can pose risks to agricultural crops, livestock, and rural communities.

UAS can play a crucial role in various aspects of wildfire management and prevention efforts in regions like Bansko and Simitli. Utilizing UAS for forest fire monitoring offers several advantages, including enhanced situational awareness, rapid response capabilities, and reduced risk to human personnel. During wildfire incidents, UAS equipped with infrared cameras and smoke-penetrating sensors can provide real-time data on fire behaviour, smoke dispersion, and hotspots to incident commanders and firefighting crews. This information can help optimize resource allocation, tactical decision-making, and deployment of ground and aerial firefighting assets. UAS can also serve as aerial scouts, providing reconnaissance of fire lines, access routes, and safety zones for firefighting personnel.

IV. SORA Preparations & Application

Considering the Example Scenario as a basis for the ConOps, a progress can be made towards SORA 2.0 methodology.

Step #1

For Step #1 of SORA, ConOps description, we consider the following UA and type of mission for the current operation:

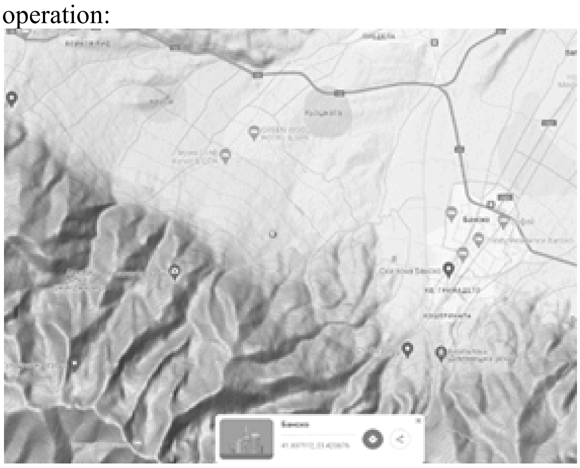

Fig. 2 Area of Operations

- Size of UA 2.5m
- Speed of UA 30 m/s
- ~ K.E. of UA 6750J
- Max Pop Density 660 ppl/km2
- VLOS/BVLOS? BVLOS
- Altitude 4000 feet AGL
- Adjacent Area Not considered
- Average Pop Density 42 ppl/km2

The area of operation is located on the West of the town of Bansko, in the Pirin National Park, with coordinates 41.8368562615972, 23.422988726663785 – Fig. 2

Step #2 & #3

SORA requires pretty straightforward determination of iGRC. Step #3 defines means to mitigate it.

The area of the example scenario is located West of the town of Bansko with the folloing characteristics of population (Fig. 3):

- Density 12,348 ppl/km²
- Count 660 People

Table 1 is taken directly from SORA 2.0 and depicts the iGRC utilized in determining the GRC. It shows the GRC determined based on the operational scenario and the maximum characteristic dimension of the UA, which determines the lethal area of the UAS. If there is a discrepancy between the maximum UA characteristic dimension and the anticipated kinetic energy, the applicant must justify the selected column.

Table 1 Intrinsic UAS Ground Risk Class Determination Table

Max UAS characteristics dimension	1 m / approx. 3ft	3 m / approx. 10ft	8 m / approx. 25ft
Typical kinetic energy expected	< 700 J (approx. 529 Ft Lb)	< 34 KJ (approx. 25000 Ft Lb)	< 1084 KJ (approx. 800000 Ft Lb)
Operational scenarios			
VLOS/BVLOS over controlled ground area	1	2	3
VLOS in sparsely populated environment	2	3	4
BVLOS in sparsely populated environment	3	4	5
VLOS in populated environment	4	5	6
BVLOS in populated environment	5	6	8

Fig. 3 Population Density Heat Map

The Final GRC determination (Step #3) is based on the availability of these mitigations to the operation. TABLE 2 provides a list of potential mitigations and the associated relative correction factor. A positive number denotes an increase of the GRC, while a negative number results in a decrease of the GRC.

The claims available in Annex B of SORA, that are made, are:

For M1:

- Integrity – the applicant evaluates the area of operations by means of on-site inspections/appraisals to justify lowering the density of people at risk (e.g. residential area during daytime when some people may not be present or an industrial area at night time for the same reason).
- Assurance – the applicant declares that the required level of integrity has been achieved

TABLE 2 LIST OF POTENTIAL MITIGATION FACTORS (ANNEX B)

Mitigation Sequence	Mitigations for ground risk	Robustness		
		Low/None	Medium	High
1	M1 – Strategic mitigations for ground risk	0: None -1: Low	-2	-4
2	M2 – Effects of ground impact are reduced	0	-1	-2
3	M3 – An Emergency Response Plan (ERP) is in place, operator validated and effective	1	0	-1

For M2:

- Integrity – Any equipment used to reduce the effect of the UA impact dynamics are installed and maintained in accordance with manufacturer instructions
- Assurance – 1. Procedures are validated against standards considered adequate by the competent authority and/or in accordance with means of compliance acceptable to that authority.
  2. The adequacy of the procedures is proved through:
    - Dedicated flight tests, or
    - Simulation, provided that the representativeness of the simulation means is proven for the intended purpose with positive results.

For M3:

- Integrity – the ERP:
    - is suitable for the situation;
    - limits the escalating effects;
    - defines criteria to identify an emergency situation;
    - is practical to use;
    - clearly delineates Remote Crew member(s) duties.
- Assurance – 1. An ERP training syllabus is available.
  2. A record of the ERP training completed by the relevant staff is established and kept up to date

Determination of Initial Air Risk Class (iARC) (Step #4 & #5):

The ARC is a qualitative categorization representing the likelihood of a UAS encountering a manned aircraft within typical generalized civil airspace. It serves as an initial assessment of the

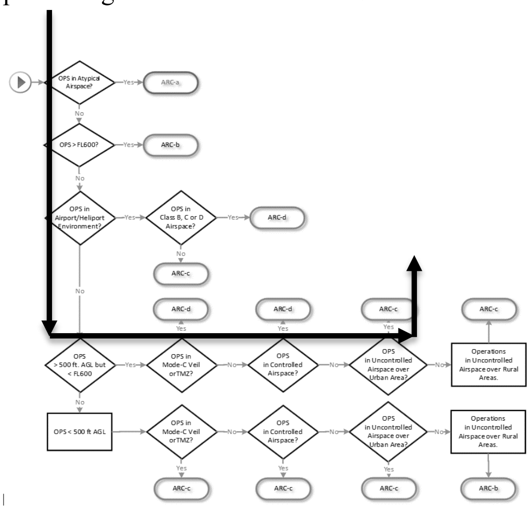

Fig. 4 ARC assignment process from JARUS guidelines on Specific Operations Risk Assessment (SORA)

combined collision risk for the airspace, before any mitigating measures are implemented.

In view of the fact that in order to achieve higher efficiency of unmanned aircraft UA flights over natural disaster areas, flights are required to be conducted at altitudes above 500 ft, it is no longer necessary to comply with the requirements for flights up to 500 ft. Take-off and landing are always carried out in visual line of sight (VLOS), which is within this altitude, and an ad-hoc danger zone may not be designated as long as the responsibility for avoiding collision with other aircraft rests with the UAS operator and he is able to provide it.

As previously mentioned, ARC serves as a generalized qualitative assessment of the likelihood of a UAS encountering a manned aircraft within a specific airspace environment. However, it's acknowledged that the collision risk within the UAS Operational Volume may differ from the initially assigned ARC.

Strategic mitigations are implemented by controlling the airspace infrastructure through physical characteristics, procedures, and techniques aimed at reducing conflicts or facilitating conflict resolution.

Looking ahead, as Unmanned Traffic Management (UTM) and U-Space become more defined and widely adopted, they will offer a framework for UAS operators to apply strategic mitigations based on common procedures and rules in the airspace. This will enable more effective management of collision risk in UAS operations.

For the current scenario if the Flowchart from SORA 2.0 is used the iARC ends up in ARC-c. This might not be true for state operator with predefined procedures to deploy an ad-hoc danger zone and convert the area of operations into Atypical Airspace.

Step #6: Tactical Mitigation Performance Requirement (TMPR)

Operation Requirements:

Modifications to the initial and subsequent approvals may be necessary as safety and operational issues arise, as determined by the competent authority or Air Navigation Service Provider (ANSP).

It is essential for both the operator and competent authority to recognize that the Air Risk Classes (ARCs) provide a generalized qualitative classification of collision risk. Local circumstances, such as special events, may invalidate the assumptions regarding aircraft density made in the SORA.

Therefore, it is imperative for both parties to have a comprehensive understanding of the local airspace and air traffic flows. Developing a system that can promptly alert operators to changes in the airspace on a local level is crucial. This will enable operators to effectively address the increased risks associated with such events and ensure safe operations. Such discussion is outside of the current research.

Step #7: Specific Assurance and Integrity Level (SAIL) Determination

The SAIL parameter integrates ground and air risk analyses, guiding necessary actions to be taken. It signifies the level of confidence in the UAS operation's ability to remain under control.

Following the determination of the Final GRC and Residual ARC, the SAIL associated with the proposed ConOps can be derived.

The SAIL is qualitative and reflects:

- Operational Safety Objectives (OSO) to be adhered to,
- Description of activities facilitating compliance with these objectives, and
- Evidence demonstrating the fulfilment of these objectives.

The assignment of SAIL to a specific ConOps is determined using TABLE 3.

TABLE 3 SAIL DETERMINATION

	Residual ARC			
Final GRC	a	b	c	d
≤2	**I**	**II**	**IV**	**VI**
3	**II**	**II**	**IV**	**VI**
4	**III**	**III**	**IV**	**VI**
5	**IV**	**IV**	**IV**	**VI**
6	**V**	**V**	**V**	**VI**
7	**VI**	**VI**	**VI**	**VI**
>7	Certified operation			

Step #8: Identification of Operational Safety Objectives (OSO)

In the final step of the SORA process, the Specific Assurance and Integrity Level (SAIL) is utilized to assess the defenses within the operation by defining Operational Safety Objectives (OSO) and determining their corresponding level of robustness.

TABLE 4 below is an extract of Table 6 from SORA 2.0 and offers a qualitative methodology for making this determination. In the table, the designation "O" indicates an optional objective, "L" denotes a recommendation with low robustness, "M" suggests a recommendation with medium robustness, and "H" signifies a recommendation with high robustness.

The OSOs are categorized based on the threats they help mitigate, which may result in some objectives being repeated in the table.

Step #9 – Adjacent Area/Airspace Considerations

In the specific case, the depicted airspace is located in a Class G airspace and to ensure the safety of other airspace users who are not involved in a disaster operation, it should be done through the definition of ad-hoc danger zones. The zone thus defined can be estimated to be from some lower limit to some upper limit, depending on the opto-electronic equipment used on board the UAS, with safety buffers included in the horizontal and vertical planes. Appropriate safety buffers are 500 ft in the vertical plane and up to 1 NM in the horizontal plane (unless in an urban environment where smaller values may apply depending on terrain and urban infrastructure acting as a natural separation

TABLE 4 OPERATIONAL SAFETY OBJECTIVES

OSO Number (in line with Annex E)		SAIL					
		I	**II**	**III**	**IV**	**V**	**VI**
	Technical issue with the UAS						
OSO#01	Ensure the operator is competent and/or proven	O	L	M	H	H	H
OSO#02	UAS manufactured by competent and/or proven entity	O	O	L	M	H	H
OSO#05	UAS is designed considering system safety and reliability	O	O	L	M	H	H
	Human Error						
OSO#18	Automatic protection of the flight envelope from Human Error	O	O	L	M	H	H
	Adverse operating conditions						
OSO#24	UAS designed and qualified for adverse environmental conditions	O	O	M	H	H	H

boundary of operations between manned and unmanned aircraft Take-off and landing in all cases are carried out in conditions of direct visibility, therefore there is no need to define an ad-hoc danger zone.

The SORA process equips the applicant, competent authority, ANSP and the Operator with a comprehensive methodology aimed at ensuring the safe conduct of UAS operations. This methodology includes a series of mitigations and safety objectives to be considered, which are as follows:

- Mitigations utilized to adjust the intrinsic Ground Risk Class (GRC).
- Strategic mitigations addressing the Initial Air Risk Class (ARC).
- Tactical mitigations addressing the Residual Air Risk Class (ARC).
- Considerations for the Adjacent Area/Airspace.
- Operational Safety Objectives.

The satisfactory substantiation of these mitigations and objectives, as required by the SORA process, provides a sufficient level of confidence that the proposed operation can be conducted safely.

V. DISCUSIONS

With the application of preliminary measures to reduce aerial risk according to the specific unmanned platforms used in disasters, the possibility of a quick response by drone operators is also achieved. Shortening the time for the preparation of the assessment (write here which final assessment is important from TABLE 4 and what are the differences before and after the application of preliminary measures) also allows increasing the efficiency of operations with unmanned aircraft, while maintaining high levels of aviation safety. A common understanding of prioritizing search and rescue operations over other operations is of utmost importance for timely provision of safe working conditions in the disaster area. Informational awareness of other airspace users, whether manned or unmanned, is the other key factor without which aviation safety cannot be guaranteed when conducting drone operations in the disaster area.

CONCLUSION

Overall, effective wildfire management (e.g. Bansko and Simitli) requires a comprehensive and integrated approach that addresses both the immediate response needs and the underlying factors contributing to wildfire risk in the region. Collaboration between government agencies, local communities, and stakeholders is essential for reducing the threat of wildfires and safeguarding the region's natural and cultural resources. Integrating UAS into wildfire management efforts can enhance operational efficiency, improve situational awareness, and contribute to more effective wildfire prevention, detection, and response strategies. However, it's essential to ensure compliance with aviation regulations, privacy considerations, and coordination with existing wildfire management protocols when deploying UAS in fire-prone environments.

The capabilities created by the states to use UAS (state or civil aircraft) in conducting operations in the event of disasters, accidents and catastrophes should be supported in the possibility of being used in short terms. As seen from the results of applying SORA 2.0 to the full scenario and pre-created scenarios, it is quite possible to apply JARUS SORA 2.0 to state UAS disaster relief operations.

It should be noted that in view of the change of the applicable SORA from version 2.0 to version 2.5, this analysis should also be performed according to the requirements of the new methodology. After the adoption of SORA 2.5, it will be possible to analyse the benefits of applying the new methodology compared to the old one, but with regard to the use of state UAS in operations related to crisis management.

ACKNOWLEDGMENTS

This work was supported by the National Scientific Programme “Defence & Security”, which has received funding from the Ministry of Education and Science of the Republic of Bulgaria in execution of Ministry Council Decision No. 731/21.10.2021under the grant agreement No. D01-74/19.05.2022.

REFERENCES

[1] S. Sudhakar, V. Vijayakumar, C. S. Kumar, V. Priya, L. Ravi and V. Subramaniyaswamy, “Unmanned Aerial Vehicle (UAV) based Forest Fire Detection and monitoring for reducing false alarms in forest-fires,” *Computer Communications,* vol. 149, pp. 1-16, 2020.

[2] B. Aydin, E. Selvi, J. Tao and M. J. Starek, “Use of Fire-Extinguishing Balls for a Conceptual System of Drone-Assisted Wildfire Fighting,” *Drones,* vol. 3, no. 1, p. 17, 2019.

[3] P. T. Thavasi and C. D. Suriyakala, “Sensors and Tracking Methods Used in Wireless Sensor Network Based Unmanned Search and Rescue System -A Review,” *Procedia Engineering,* vol. 38, pp. 1935-1945, 2012.

[4] C. V. Tilburg, “First Report of Using Portable Unmanned Aircraft Systems (Drones) for Search and Rescue,” *Wilderness & Environmental Medicine,* vol. 28, no. 2, pp. 116-118, 2017.

[5] P. Petrides, P. Kolios, C. Kyrkou, T. Theocharides and C. Panayiotou, Disaster Prevention and Emergency Response Using Unmanned Aerial Systems, A. Stratigea, E. Kyriakides and C. Nicolaides, Eds., Springer International Publishing, 2017, pp. 379-403.

[6] L. Apvrille, T. Tanzi and J.-L. Dugelay, “Autonomous Drones for Assisting Rescue Services within the Context of Natural Disasters,” in *2014 XXXIth URSI General Assembly and Scientific Symposium (URSI GASS)*, Beijing, China, 2014.

[7] M. Quaritsch, K. Kruggl, D. Wischounig-Strucl, S. Bhattacharya, M. Shah and B. Rinner, “Networked UAVs as Aerial Sensor Network for Disaster Management Applications,” *e & i Elektrotechnik und Informationstechnik,* vol. 127, no. 3, pp. 56-63, 2010.

[8] P. Janik, M. Zawistowski, R. Fellner and G. Zawistowski, “Unmanned Aircraft Systems Risk Assessment Based on SORA for First Responders and Disaster Management,” *Applied Sciences,* vol. 11, no. 121, pp. 53-64, 2021.

[9] International Civil Aviation Organization, *Convention on International Civil Aviation,* 9 ed., 2006.

[10] JARUS - Joint Authorities for Rulemaking on Unmanned Systems, “JARUS - Joint Authorities for Rulemaking on Unmanned Systems,” [Online]. Available: http://jarus-rpas.org/. [Accessed 26 February 2024].

[11] Joint Authorities for Rulemaking of Unmanned Systems, JARUS guidelines on Specific Operations Risk Assessment (SORA), Joint Authorities for Rulemaking of Unmanned Systems, 2019.

[12] K. H. Terkildsen and K. Jensen, “Towards a Tool for Assessing UAS Compliance with the JARUS SORA Guidelines,” in *International Conference on Unmanned Aircraft Systems (ICUAS)*, Atlanta, 2019.

[13] D. Rothe, “Development of System Architectures on the Basis of SORA in the Specific Category and Qualitative Estimation of the Implementation Efforts,” Institut für Flugsystemtechnik, Braunschweig, 2020.