

Using SORA Principles to Assess The Safety of Unmanned Traffic Management (UTM) Services

Sara Rachid

Thales Air Mobility Solutions (AMS)
Land and Air Systems (LAS),
Rungis, France
e-mail: sara.rachid@fr.thalesgroup.com

Fateh Kaakai

Thales Research and Technology (TRT),
Palaiseau, France
e-mail: fateh.kaakai@thalesgroup.com

Abstract—This paper presents a methodology to assess the safety of Unmanned Traffic Management (UTM) systems, not sufficiently addressed in the current state-of-the-art, using the concepts of the Specific Operations Risk Assessment methodology (i.e., SORA). This enables a smooth transition from traditional safety assessment frameworks to the new Unmanned Aircraft Systems (UAS) paradigms.

Keywords- UTM; UAS; Safety; FHA; SORA.

I. INTRODUCTION

Operations executed with UAS are gaining more ground recently, with more complex airborne and ground systems and more diversified operational scenarios. This important growth of the UAS traffic implies, among other consequences, a growing safety risk that should be assessed and mitigated appropriately. For this purpose, several regulations were released around the world to define the rules and procedures required to ensure the safety of UAS operations. In addition, the SORA methodology was issued by JARUS (Joint Authorities for Rulemaking on Unmanned Systems) to provide UAS operators with a methodical framework to assess the safety of their operations. It can be observed, on the other hand, that the current state-of-the-art does not address sufficiently the safety of UTM services used to plan, deconflict, validate UAS flight requests prior to their execution, and also to launch the UA and ensure its safety during the flight. UTM services can be identified today as a real source of risk for UAS operations. In fact, such systems have a criticality proportionate to the safety risks of the UAS operations they support, as their malfunctioning can affect the safety of those operations. Consequently, the manufacturers of such systems should perform safety risk assessments in order to ensure the management of these risks. Yet, no adapted guidance is provided today to support this need. Concretely, UTM system manufacturers need to:

- determine the level of safety risk for their system,
- determine the level of development assurance (i.e., the level of industrial development rigor) for their system,
- and ensure a proportionality between the level of development assurance and the level of safety risk, in order to avoid oversized or undersized objectives of development assurance.

This can be challenging considering the operational specificities brought by the context of UAS operations, compared to traditional manned air traffic and other safety-related industries. Hence, traditional safety assessment methods (including non-specific methods) cannot be used directly and should be adapted to this new operational context.

To respond to this need, this paper proposes a methodology to assess the safety of UTM services and allocate commensurate safety risk levels according to the safety risks of the UAS operations they support. To achieve this goal, this paper integrates traditional safety assessment principles (e.g., Functional Hazard Analysis FHA) with the concepts of the SORA.

In the detail, the first contribution of this paper is the establishment of a severity matrix that defines the relevant operational aspects to evaluate (i.e., effect on people on the ground, manned aircraft and UAS crew), and the severity levels to consider for each of them. This step contributes to the specification of the operational environment of the system.

The second contribution of this paper consists of the development of transfer functions that associate the risks of UAS operations (represented by the SORA V2.5 risk metrics ARC, GRC and SAIL) to the commensurate severity levels. The resulting transfer functions will be used as part of the safety risk assessment of the system.

Finally, the last contribution of this paper consists of the validation of this methodology through its application on a real industrial use case.

As described, the proposed methodology is intended to enable a smooth transition from traditional safety risk assessment frameworks to the new UAS paradigms introduced by the SORA. In addition, this methodology helps UTM system constructors in fulfilling the regulatory requirement of demonstrating the safety of UTM systems, as in the regulation (EU) 2021/664 for instance.

In the following, the paper analyses first the state-of-the-art on the methods applicable to the context of UAS operations (in Section II), then describes the proposed methodology to assess the safety of UTM services (in Sections III and IV). An application of the methodology on an industrial case is presented after that (in Section V), in

addition to a discussion of its benefits and limitations (in Section VI).

II. STATE-OF-THE-ART ANALYSIS

Considering the various profiles of stakeholders related to UAS operations, various methods are available in the literature and regulations to answer their needs in terms of safety assessment. This section presents those methods and exposes their different intents and perspectives, in addition to discussing their potential applicability to the safety assessment of a UTM system.

A. SORA and Other Operation-Centred Risk Assessment Methods

The current regulations in The European Union (EU), The United States of America (USA) and other countries allocate to UAS operators the responsibility of demonstrating the safety of their operations, with the conduct of safety risk assessments that can be described as operation-centred for their scope and vision. The SORA is one of the few methodologies available currently in the literature that fill this need.

The SORA methodology is developed by JARUS, providing guidance for the UAS operator on how to evaluate and conduct a UAS operation in a safe manner. The European regulation (EU) 2019/947 presents the SORA as an acceptable means of compliance with Article 11 of the UAS Regulation (EU) 2019/947, which requires the conduct of safety risk assessments on UAS operations.

In accordance with its operation-centred perspective, the SORA aims at assessing the safety risks to which the UAS operation is exposed. For this, the SORA introduces the hazard of losing control over the UAS operation to represent its safety risk. The outcome of this hazard is related to the risk of a mid-air collision with a manned aircraft, the risk of a person struck on the ground and the risk of causing damage to critical infrastructure. While the risk of damage to critical infrastructure is not addressed by the SORA, the air and ground risks are represented respectively by The Air Risk Class (ARC) and The Ground Risk Class (GRC). The SORA starts with assessing the air and ground risks, in the case of a loss of control over the UAS operation using the ARC and GRC. When these are considered as unacceptable, the SORA defines a set of requirements to reduce the probability of losing control over the UAS operation. This is achieved by reducing the probability of malfunctions of a UAS operation that can cause this hazard. The design of the UA, human errors of the remote crew, operational procedures or external systems supporting the UAS operation are identified in the SORA as possible sources of this hazard and can be consequently subject to a set of requirements to robustify them.

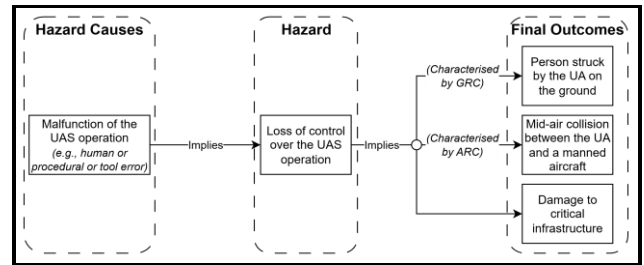


Figure 1. Risk Model for UAS Operations in The SORA

Figure 1. presents how these elements constitute the risk model for UAS operations of the SORA.

B. Airspace Risk Assessment Methods

The METHoDology for the U-Space Safety Assessment (MEDUSA) is a method provided by the CORUS team (Concept of Operation for EuROpean UTM Systems) to address the need of assessing the safety of U-space airspaces. The MEDUSA relies on the SESAR Safety Reference Material (SRM) where safety assessment includes both a failure approach and a success one. In the context of U-space, this enables the assessment of U-Space's negative effect on the risk of an accident (failure approach), but also the positive contribution of U-Space to aviation safety (success approach).

The MEDUSA uses a holistic approach for the U-space safety assessment, incorporating both the operator and the airspace perspectives of U-space service provision, and the interoperability of these with manned Air Traffic Management (ATM). For this, the MEDUSA takes into account the outputs of the SORAs performed on the UAS operations expected in the U-space. These elements are integrated as a result in a single U-space safety assessment to obtain a unified airspace viewpoint.

The MEDUSA can also, on the other hand, recommend or require changes to be applied on the UAS operations expected in the assessed U-space, which results in changes in the SORAs.

More information on the MEDUSA is provided in [14] and [15].

C. Generic Risk Assessment Methods

To assess safety risks in more generic contexts, several methods are described in the literature and have been used traditionally for this purpose. Considering that the method presented in this article is applicable mainly to safety assessment methods that evaluate hazard severities, this section focuses on this type. As its title may indicate, this type of methods identifies failures at the level of the analysed scope and analyses their propagation and their potential effects and severities on the next higher level(s). Based on the targeted objectives of the analysis, these

methods can be employed on different levels of a system (e.g., piece-parts, functions, black-box, etc.).

In opposition to the MEDUSA and the SORA, traditional risk assessment methods are designed to be generic and applicable to different operational contexts.

In the context of safety assessments that evaluate hazard severities, the literature today contains mainly the Failure Mode and Effect Criticality Analysis (FMECA) proposed by the National Aeronautics and Space Administration (NASA) for space program hardware reliability [44], and the Functional Hazard Analysis (FHA) presented in the aeronautical safety process in ARP4761 [12].

D. Applicability of Risk Assessment Methods for UTM Systems

As afore explained, the intent of the SORA does not cover demonstrating the safety of UTM systems. It cannot therefore be used alone to fulfil this need, and a generic safety risk assessment should hence be conducted for this purpose. However, the SORA prescribes, when needed, a set of requirements on those systems and any other elements of the UAS operation to prevent a potential loss of control. Accordingly, to prevent the failures of UTM systems that may cause a loss of control, the SORA provides the Operational Safety Objective OSO#13: “External services supporting UAS operations are adequate for the operation”. This OSO should be met with a level of integrity (i.e., safety gain) and a level of assurance (i.e., method of proof), which both must be proportional to the risk of the UAS operation. Therefore, this OSO with its required levels of integrity and assurance are provided as inputs for the UAS operator to determine the need to perform a safety risk assessment on UTM systems.

On another level, the SORA presents an interesting method to assess the final outcomes of unsafe UAS operations in the air and ground, through the metrics ARC and GRC. These ones can be provided as inputs for the safety risk assessment of a UTM system. This use is possible assuming that the safety impact of such systems can vary based on the intrinsic risk of the UAS operations they manage.

In addition, it is important in the safety risk assessment of a UTM system to consider the operational assumptions and the mitigation means used in the SORAs of the UAS operations it manages. On one hand, this enables to retain the same ConOps studied in the operation SORAs and avoid thus inconsistencies between the SORAs and the safety risk assessments of UTM systems. On the other hand, the mitigation measures taken by the UAS operators (in their SORAs) can have a potential mitigation gain in the safety risk assessments of those systems.

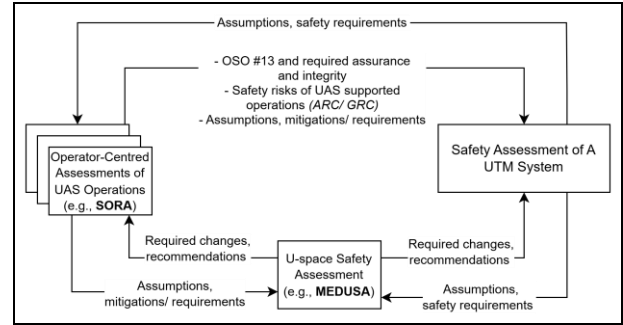


Figure 2. Link between The SORA and Safety Assessments of UTM Systems

As far as MEDUSA (and potentially other airspace safety assessment methods) is concerned, this assessment uses the outputs of SORAs to incorporate the operator perspective. In addition, if safety assessments of UTM systems in the assessed U-space are available, the MEDUSA is expected to take into account the results of those assessments. In fact, this enables to retain the operational use assumed for those systems, but also take advantage of the used mitigation measures. In the other way around, the MEDUSA may allocate requirements or recommendations to some UTM systems and/or to other operation elements. These would therefore result in potential changes to be considered in the SORAs and the safety assessments of the concerned systems.

Figure 2. represents the interfaces between the risk assessment methods, when applied in a context of UTM.

E. Summary of the State-of-The-Art

The UAS-related risk assessment methods available in the current state-of-the-art present little work on the safety assessment of UTM systems. Even less work is provided on methods that employ the concepts of SORA for assessing the safety risks of UTM systems. To address this need, this paper defines a safety methodology with the purpose of using the SORA concepts in the context of traditional safety risk assessment methods like FHA and FMECA.

III. METHODOLOGY RATIONALE

A. Impact of UTM Systems on UAS Operations

Various types of UTM systems can be distinguished, based on the operational phase of the UAS operation where they interfere. Some examples of such systems can be used in the pre-flight phase, i.e., before the execution of a UAS operation, notably for verifying the safety of that planned execution, authorising and preparing it. On the other hand, other systems can support UAS operations during their execution, i.e., in their in-flight phase, to ensure their safety.

Independently from the operational phase where such systems may interfere, the performed activities that rely on

them can have a potential impact on the execution of the concerned UAS operations. Consequently, the failures of those systems, while used to support UAS operations, can potentially have an impact on their execution as well.

In the concrete, if the failure of a UTM system can potentially, by definition, affect the execution of UAS operations and is not mitigated at an early stage, this one can result in an unsafe execution of the UAS operations that use the failing system service. An unsafe execution of a UAS operation takes place in the form of a direct exposition to its air and ground risks, with a compromised or annulled mitigating effect of the mitigation means that could reduce those risks.

In fact, when planning a UAS operation and assessing its safety, the UAS operator may eventually support it with one or many tools (e.g., operational procedures, systems) to reduce its estimated air and ground risks to an acceptable level. When a failure of a UTM system occurs, the efficiency of all the used mitigation means possessing dependencies with this one will be potentially impacted. In addition, if the occurring failure induces the execution of a UAS operation in conditions that are different from its initial plan, this can weaken the efficiency of several mitigation means or even devalue their use as their mitigating effect was assessed in accordance with the initially planned conditions. Therefore, a failure of a UTM system can compromise or annul the efficiency of those mitigation means, which implies that the UAS operations will be exposed to their initially unmitigated air and ground risk levels (see Figure 3.).

Based on that, the air and ground risk levels of a UAS operation are the characteristics to consider when assessing the safety impact of a failing UTM system, as it directly affects the severity of its outcome.

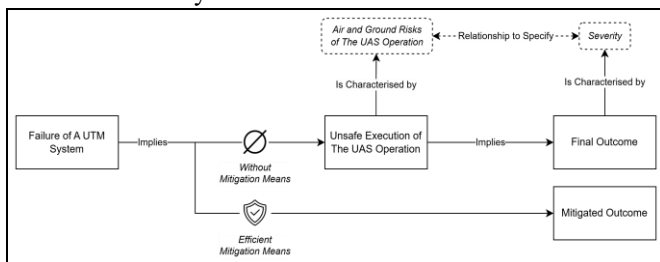


Figure 3. Propagation Scheme of Failures for UTM Systems

The ground risk of a UAS operation is the risk of a person on the ground struck by the UA, while the air risk of a UAS operation can be either the risk of a mid-air collision with a manned aircraft or with another UA. The risk of collision between UAs is excluded from the scope of the presented process. Consequently, the application of this process should be complemented with additional tools to cover this type of risk.

In what follows, the air risk refers to the risk of collision between a UA and a manned aircraft.

B. Use of SORA Concepts for UTM Systems Safety

It is hence clear that, in order to determine the appropriate severity level to associate to a similar scenario, it is first necessary to have an adequate method to define the air and ground risks and to determine their possible levels.

In this perspective, the ARC and GRC, introduced by the SORA, are estimated to provide a suitable representation of the air and ground risks to meet this need. As defined by the SORA, the ARC relates to the risk of a mid-air collision with a manned aircraft, and the GRC relates to the risk of a person on the ground struck by the UA (in the case of a loss of UAS control with a reasonable assumption of safety).

The ARC and GRC metrics and the matrices and procedures that are established to determine their values represent an efficient set of tools to express the variance of the level of risk of a UAS operation. In contrast to risk models based on continuous functions, the proposed ARC and GRC definitions furnish a finite number of risk classes covering the different possible risk degrees (i.e., low, medium and high risks). This discrete level distribution enables a simple association of ARC and GRC classes with severity levels. Furthermore, the ARC and GRC classes are defined using concrete parameters, which induces more facility to evaluate the safety impact represented by each ARC or GRC class and to associate it with the most convenient severity level. In addition, as the SORA is endorsed by the European Union Aviation Safety Agency (EASA) as an acceptable means of compliance with Article 11 of the UAS Regulation (EU) 2019/947, the ARC and GRC metrics are used for UAS risk assessments in different parts of the world, including the European Union (EU) and other countries that choose to follow European UAS regulations. Finally, these metrics are simple to use for they can be used independently from any software tools.

The cited elements make the ARC and GRC metrics a good choice to characterise the risks related to unsafe executions of UAS operations and to contribute to characterising the criticality of systems supporting them as a result.

C. Applicability of Methodology

As designed, the proposed methodology is applicable mainly to safety assessment methods that evaluate hazard severities. This includes methods like the FMECA and the FHA.

In addition, two types of risk related to UA operations will be addressed as part of this paper, in accordance with the SORA methodology. First, the “air risk” of a UAS operation will refer to the risk of a mid-air collision between

the UA and a manned aircraft. Secondly, the “ground risk” of a UAS operation will refer to the risk of causing physical harm to people on the ground, due to a collision with the UA. The risk of collision between UAs will be excluded from the scope of the presented process, and its potential safety consequences in the air and on the ground will not be considered in the assessment of the “air and ground risks” introduced earlier.

On another note, the « ground risk » in this article will not include the risk of a noise impact, privacy concerns or any other societal issues, nor the risk of damage to properties or critical infrastructure.

IV. PRESENTATION OF THE SAFETY ASSESSMENT METHODOLOGY FOR UTM SYSTEMS

A. Definition of The Reference Severity Levels

An unsafe execution of a UAS operation can impact the safety of operations on three levels. First, it can impact the capabilities of the UAS remote crew, by increasing their workload and/or debilitating their efficiency. It can also impact the safety of air traffic by interfering with manned aircraft using the airspace, and potentially causing reduction in safety margins with them which can go up to a mid-air collision. Finally, it can impact the safety of persons on the ground by causing events varying from a physical discomfort to one or multiple fatalities.

As a result, to determine the severity of an unsafe execution of a UAS operation, its final outcomes on the UAS remote crew, in the air and on the ground should be considered. Accordingly, the severity levels to be used in the context of UAS operations should be defined based on these three aspects. In alignment with this framework, the existing literature for the context of UAS operations rely on these safety aspects to provide definitions for severity levels.

TABLE I. TABLE OF REFERENCE SEVERITY LEVELS

Severity Category	Effect on People on The Ground	Effect on Manned Aircraft	Effect on UAS Crew
S5	No Safety Effect	Discomfort to persons	No safety effect
S4	Minor	Physical distress or minimal injuries to persons	Potential contingency manoeuvre to anticipate a reduction in safety separation, with no safety effect on the manned aircraft crew.
S3	Major	Non-serious injuries to persons	Significant reduction in safety separation between unmanned and manned aircraft
S2	Hazardous	Serious injuries to one or many persons, with no fatalities	Large reduction in safety separation between unmanned and manned aircraft
S1	Catastrophic	Fatality or fatal injury to one or many persons	A collision with a manned aircraft

To define the table of severity levels as part of the method presented in this article, two documents from the literature were chosen to be used as references: JARUS AMC RPAS.1309 Issue 2 and ATO Safety Management System Manual (SMS), December 2022. The consolidation

of both severity tables results in TABLE I. , which will be used in the rest of the article.

B. Association between SORA GRC and Severity Levels

1) Definition of The SORA GRC Metric

The GRC metric is defined in the SORA Step #2 “Determination of the UAS intrinsic ground risk class (GRC)” and the SORA Step #3 Final GRC determination. It relates to the risk of a person struck by the UA (in the case of a loss of UAS control with a reasonable assumption of safety). Its value is determined based on the maximum UA characteristic dimensions and/or its maximum speed, and the population density in the overflowed ground area (see GRC table in the next section). The consideration of one or many external mitigation means could result in a reduced GRC value.

2) Strategy of GRC and Severity Association

To associate the GRC values to the appropriate severity levels, it is important to determine the safety impact presented by GRC values. In the literature, the fatality of striking a person on the ground by a UA (due to a loss of control over the operation) is represented in several existing workpapers as a function that varies based on the kinetic energy of the strike. Some proposed models may also involve the impacted regions of the human body (e.g., head, thorax, limb) as a second influencing parameter in this context.

In most of the existing studies, the event of striking a person on the ground, caused by an uncontrolled UA or other types of falling debris or fragments, causes a fatal untreatable injury (i.e., Abbreviated Injury Scale AIS = 6) and a probability of fatality of 90% when the kinetic energy absorbed by the human body surpasses 150 Joules (cf. Figure 4.). The curve providing this conclusion does not consider the variability of the fatality based on the impacted regions of the human body, as it is based on the *Average Body Position* data described in **Erreur ! Source du renvoi introuvable.** In addition, the analysed events concern blunt force traumas caused by falling objects and excludes penetrating ones.

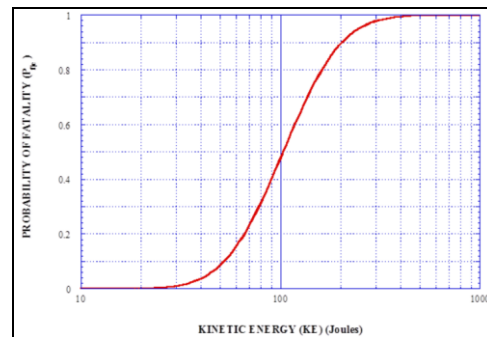


Figure 4. Kinetic Energy versus Probability of Fatality (Extract from [2])

The strike of a UA with a 25 m/s speed can generate a kinetic energy of 150 J if the UA weighs at least 480 grams. Several consumer UA models on the market with a 25 m/s speed exceed this weight and thus are expected to release more than 150 J, considered here as fatal. Based on that, it is considered that the first column of the table of GRC values (representing UAs with a 25 m/s speed, cf. TABLE II.) includes the risk of causing fatalities on the ground. Therefore, the GRC values contained in this column are representative of all the possible degrees of ground risk (i.e., low, medium, high). Consequently, the association between the GRC values and the appropriate severity levels can be done on this column first, before being extrapolated to the rest of the table. With this strategy, the associations will be based on a single variable: the population density on the ground.

In this sense, the first and second cells of the first column (i.e., GRC=1 and GRC=2) are considered to represent a negligible risk of having a person struck by the UA, as the probability of this event in controlled and remote ground areas is considered as negligible.

The third and fourth cells of the same column (i.e., GRC=3 and GRC=4), with a lightly and sparsely population density, are associated to a minor risk level. The fifth cell of the same column (i.e., GRC=5), related to suburban/ low density metropolitans, is related to a major risk level. The sixth cell of the same column (i.e., GRC=6), related to high density metropolitans, is related to a hazardous risk level. The last cell of this column (i.e., GRC=7), related to assemblies of people, is associated to the highest risk class, as it represents a high number of persons exposed to the UA and a limited ability of the persons to avoid it. The other values of GRC higher than 7 are all related to the highest risk level as well.

3) Transfer Function between GRC and Severity Levels:

Based on the ground risk division explained above, the GRC values are associated with the reference severity levels, which results in the transfer function provided by the following table:

TABLE II. TRANSFER FUNCTION BETWEEN GRC AND SEVERITY LEVELS

Max UAS Characteristics Dimension		1 m ≈ 3 ft	3 m ≈ 10 ft	8 m ≈ 25 ft	20 m ≈ 65 ft	40 m ≈ 130 ft
Maximum Speed		25 m/s	35 m/s	75 m/s	120 m/s	200 m/s
Maximum Population Density (people/ km ²)	Controlled Ground Area	1 (S5)	1 (S5)	2 (S5)	3 (S4)	3 (S4)
	< 5 (Remote)	2 (S5)	3 (S4)	4 (S4)	5 (S3)	6 (S2)
	< 50 (Lightly populated)	3 (S4)	4 (S4)	5 (S3)	6 (S2)	7 (S1)
	< 500 (Sparsely populated/ Residential lightly populated)	4 (S4)	5 (S3)	6 (S2)	7 (S1)	8 (S1)

< 5,000 (Suburban/ Low density metropolitan)	5 (S3)	6 (S2)	7 (S1)	8 (S1)	9 (S1)
< 50,000 (High density metropolitan)	6 (S2)	7 (S1)	8 (S1)	9 (S1)	10 (S1)
> 50,000 (Assemblies of people)	7 (S1)	8 (S1)	Not part of SORA v2.5		

C. Association between SORA ARC and Severity Levels

1) Definition of The SORA ARC Metric

As defined by the SORA V2.5, the ARC relates to the risk of a mid-air collision with a manned aircraft (in the case of a loss of UAS control with a reasonable assumption of safety). Its value is determined based the intrinsic characteristics of the used airspace (e.g., altitude, controlled versus uncontrolled airspace, etc.), in addition to the risk reduction potential of one or many strategic mitigation means.

2) Strategy of ARC and Severity Association

The ARC metric is defined in the SORA Step #4 “Determination of the initial air risk class (ARC)” and the SORA Step #5 Application of strategic mitigations to determine the final ARC. However, for the sake of simplification, the definitions of ARC classes used in this section are taken from the SORA Step #6 “TMPR and robustness levels” (see [5]). This SORA Step #6 provides generic and concise definitions of the ARC classes, involving both the airspace intrinsic characteristics and the impact of strategic mitigation means. In truth, the used definitions describe the ARC classes (i.e., ARC-a, ARC-b, ARC-c and ARC-d) based on two parameters: the probability of encountering manned A/C acquired from the intrinsic airspace characteristics, and the efficiency of the strategic mitigation means available.

To enable the transfer from the ARC classes to the reference severity levels as intended, a fifth ARC class needs to be added to this list. Considering the provided ARC definitions, the definition of the class ARC-c was estimated to be potentially dividable into two risk classes, to meet this need. The differentiation between the obtained risk classes, ARC-c and ARC-c’, was set based on the same parameters used to define the other ARC classes.

3) Transfer Function between ARC and Severity Levels:

In the light of this, the resulting transfer function between the ARC classes and the severity levels is provided in TABLE III. and TABLE IV.

The association here between ARC-d and the catastrophic severity level (i.e., mid-air collision with a manned aircraft) assumes that no mitigations are available on the manned aircraft side to avoid a collision with a UA out of control. Therefore, the severity related to ARC-d can be reduced if we consider that manned aircraft can detect and avoid collisions with UAs.

TABLE III. TRANSFER FUNCTION BETWEEN ARC AND SEVERITY LEVELS

ARC-a (S5)	- Airspace where the manned aircraft encounter rate is expected to be extremely low.
ARC-b (S4)	- Airspace where the likelihood of encountering another manned aircraft is low but not negligible and/or where strategic mitigations address most of the risk and the resulting residual collision risk is low.
ARC-c (S3)	- Airspace with a moderate likelihood of encounter with manned aircraft, and/or where the strategic mitigations available are medium robustness.
ARC-d (S1)	The manned aircraft encounter rate is high, and/or the available strategic mitigations are low. Therefore, the resulting residual collision risk is high.

TABLE IV. MATRIX REPRESENTATION OF ARC CLASSES

Manned A/C Encounter Probability (Based on Intrinsic Airspace Characteristics)	Efficiency of Available Strategic Mitigation Means		
	Low	Medium	High
Extremely low	ARC-a (S5)	ARC-a (S5)	ARC-a (S5)
Low	ARC-b (S4)	ARC-b (S4)	ARC-b (S4)
Moderate	ARC-c (S2)	ARC-c (S3)	ARC-b (S4)
High	ARC-d (S1)	ARC-c (S2)	ARC-c (S3)

D. Association between SORA SAIL and Severity Levels

A Specific Assurance and Integrity Level (SAIL) is a parameter defined in the SORA as combination of the ARC and GRC levels of a UAS operation. This way, a SAIL is intended to reflect the level of confidence that the operation will remain under control, and to determine, when needed, the Operational Safety Objectives (OSOs) with their adequate levels of robustness to bring that level of confidence to an acceptable degree.

Having established earlier transfer functions to associate both ARC and GRC values to the appropriate severity levels, a transition from SAIL levels to severity levels can be defined as follows:

TABLE V. TRANSFER FUNCTION BETWEEN SAIL AND SEVERITY LEVELS

Final GRC	Residual ARC				
	a	b	c	c'	d
≤2	I (S5)	II (S4)	IV (S3)	IV' (S2)	VI (S1)
3	II (S4)	II (S4)	IV (S3)	IV' (S2)	VI (S1)
4	III (S4)	III (S4)	IV (S3)	IV' (S2)	VI (S1)
5	IV (S3)	IV (S3)	IV (S3)	IV' (S2)	VI (S1)
6	V (S2)	V (S2)	V (S2)	V (S2)	VI (S1)
7	VI (S1)	VI (S1)	VI (S1)	VI (S1)	VI (S1)
>7	Category C operation				

V. METHODOLOGY VALIDATION THROUGH INDUSTRIAL USE CASE

A. Presentation of The Industrial Use Case

The example used in this section is taken from a system that provides UA remote crews with the positions of manned aircraft in the vicinity of their UAs. The provided

service is intended to support UA remote crews while operating their UAs, by contributing to their situational awareness and enabling them to detect and avoid potential mid-air collisions between their UAs and manned aircraft.

In the case of losing this service, the UA remote crew loses their ability to monitor manned traffic in proximity to their UA. Consequently, their ability to detect and avoid manned aircraft, which is considered as a main protection against the air risk, becomes impaired and/or completely inefficient. This is particularly impacting when the UAS operation is conducted in a BVLOS mode (i.e., Beyond Visual Line Of Sight). The described failure results hence in a direct exposition of the UA to the risk of a mid-air collision with manned aircraft.

To assess the safety impact of this failure on the operational environment, three independent propagation scenarios were analysed as shown in Figure 5.

The first scenario considers the case of UAS operations conducted in a VLOS mode. In this type of operations, the avoidance of mid-air collisions with manned aircraft is assumed to be fully achievable by the UA remote crew using their human vision only. Consequently, the safety of operations is not expected to be impacted by the loss of manned aircraft positions in the vicinity of their UAs.

The second scenario concerns BVLOS operations, where the use of external services for the provision of manned traffic positions has a significantly higher impact on the situational awareness of the remote crew. In this scenario, it is assumed that emergency recovery procedures (e.g., immediate landing procedures, Return To Home procedures, procedures for controlled crash, etc.) are available and can be applied by UAS remote crews to mitigate such cases. These procedures are generally defined by UAS operators and are intended to be used in “emergency” situations to ensure a safe termination of UAS operations. Based on that, this scenario will lead to protecting the UA against its operation air risk. However, the occurrence of this unexpected emergency situation may result in a physical discomfort of the UAS remote crew, which is related to a severity S4 in the table of reference severities.

The third scenario, also addressing BVLOS UAS operations, represents the case where no efficient emergency recovery procedures are available. This may be related to the absence of defined emergency recovery procedures to apply, the existence of defined emergency recovery procedures that are not efficient at ending safely UAS operations, or even the existence of defined emergency recovery procedures that have safety-impacting dependencies with the failing external service. In all the mentioned cases, the emergency recovery procedures are considered to have no mitigating effect on the air risk of the UAS operations. As a consequence, the UA will be exposed

directly to its operation ARC and the final outcome of this scenario will vary accordingly.

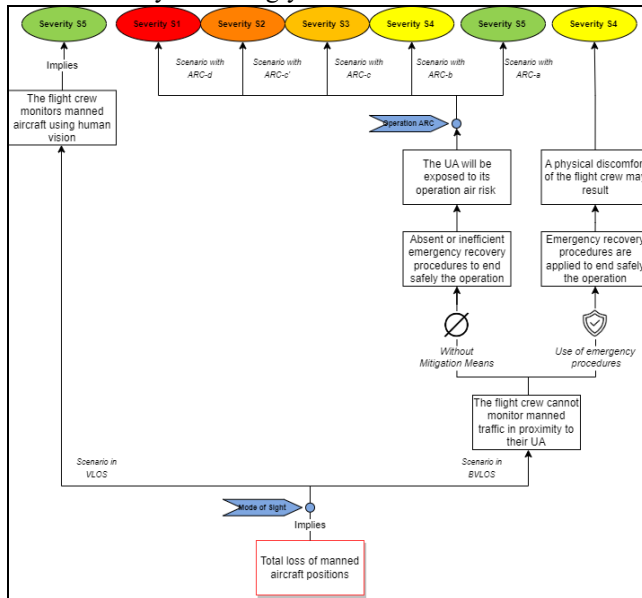


Figure 5. Graphical Representation of The Application Case

B. Assumptions of The Analysis

To illustrate efficiently the method presented in this paper, it is important to present a readable application case, that furnishes simple yet expressive scenarios, without including details that are irrelevant to this context. To achieve this vision, a set of assumptions were established to simplify the presented scenarios:

- It is assumed that a VLOS mode of sight is considered to be an acceptable tactical mitigation for collision risk for all ARC levels. This is supported by AMC 1, Article 11, Section 2.4.4.1 (a) in [5], applicable in the European context.
- It is assumed that the operational procedures and/or technical tools used by the UAS remote crew to mitigate the residual ground risk of their operation and to avoid collision with other UAs, do not rely on the failing service or have any other safety-impacting dependencies with this one that can affect their usability or efficiency.
- It is assumed that the operational procedures and/or technical tools used by the UAS remote crew to mitigate the residual ground risk of their operation and to avoid collision with other UAs, continue to be used to mitigate these risks during the execution of an emergency recovery procedure.
- It is assumed that the execution of an efficient or inefficient emergency recovery procedure cannot induce an increase of the ground risk.

- It is assumed that the execution of an inefficient emergency recovery procedure cannot induce an increase of the air risk.

VI. CONCLUSION AND FUTURE WORK

As detailed above, this paper presents a methodology that uses the principles of the SORA to assess the safety of UTM systems. This is achieved through:

- the establishment of a severity matrix which defines a list of possible severity levels that can be achieved in the case of an unsafe execution of a UAS operation.
- The development of transfer functions that associates the risks of UAS operations (i.e., ground and air risks) to the commensurate severity levels.

This methodology is intended to help UTM system manufacturers in fulfilling the regulatory requirement of demonstrating the safety of UTM systems, as in the regulation (EU) 2021/664 for instance.

In fact, the provided transfer functions, associating ARC/GRC/SAIL metrics to severity levels, enable a straightforward conversion of these metrics into adequate final outcomes with determined severities. This represents a smooth integration of the SORA outputs into traditional safety risk assessment methods (e.g., Functional Hazard Analysis FHA). In addition, the employment of the SORA concepts here is intended to provide more harmonisation between the practices of system manufacturers and those of UAS operators, as the proposed methodology recalls the same concepts used on the UAS operator side. This will enable more interoperability between safety assessments produced on both sides. Also, the SORA brings the advantage of being a methodology already recognised and integrated as a UAS-specific safety risk assessment tool in several regions of the world.

It is important to note, when using the transfer functions, that the ARC/ GRC/ SAIL values used in the safety assessment of a UTM system shall have no safety-impacting dependencies with that UTM system. In fact, the SORA methodology enables the consideration of potential mitigations means for risk reduction, which influences the values of ARC/ GRC/ SAIL. On the other hand, the methodology proposed in this article uses the ARC/ GRC/ SAIL metrics to evaluate the safety risk related to a UTM system. Therefore, for a correct risk evaluation within the proposed method here, the ARC/ GRC / SAIL values shall not consider the UTM system as a risk reduction means.

On another level, the transfer functions between the SORA metrics (i.e., ARC, GRC, SAIL) and the end severities are established using expert-informed heuristics derived from domain expertise and the current state-of-the-art. This deliberate choice is considered as more compatible with the

operation-centric nature of the SORA. It also enables an easier understanding by safety practitioners and a simpler integration into their safety assessments. Iterative hardening is undoubtedly necessary in future enhancements of the methodology to move toward full industrial maturity. The growing industrial experience on UTM is also expected to help align the methodology with variables like the overall target level of safety for UAS operations, the assumptions made on the operational environment and the weight of operational parameters in the estimation of the end severities. These variables may be impacted due to the evolution of the operational framework of UTM, but also as a result of the growing return on experience on UTM operations.

As for the safety objectives that could be allocated to UTM systems based on each severity level, these are considered outside the scope of the proposed method. This choice is retained as the establishment of safety objectives for severity levels is difficult to generalise for all UTM systems. In fact, this relationship depends on several factors, including but not limited to: the Target Levels of Safety (also TLS), the contribution of UTM systems to the occurrence of undesired events and the complexity of UTM systems.

Moreover, this methodology does not address the risk of collision between UAs. Consequently, to perform an exhaustive safety assessment of a UTM system, the application of this methodology should be complemented with additional tools to cover this type of risk. One avenue for future work is to integrate the risk of collisions between UAs. This would allow UTM system manufacturers to cover the most significant safety risks associated with their systems through a single consistent methodology.

Ultimately, the deployment of the presented methodology in an industrial context is expected to be a gainful use on several aspects, when used within its applicability conditions.

REFERENCES

- [1] Secretariat Range Commanders Council U.S. Army White Sands Missile Range, "RCC 321-00," Risk and Lethality Commonality Team Range Safety Group Range Commanders Council, NM, April 2000 Surname A and Surname B 2009 *Journal Name* **23** 544.
- [2] Department of Defense Explosives Safety Board, "Procedures for the Collection, Analysis, and Interpretation of Explosion-Produced Debris", DDESB TP 21, Dec. 2007.
- [3] Z. Svatý, L. Nouzovský, T. Micunek and M. Frydrýn, "Evaluation of The Drone-human Collision Consequences," *Heliyon*, vol. 8, issue 11, Nov. 2022, doi:10.1016/j.heliyon.2022.e11677.
- [4] Í. de Oliveira, J. Fregnani, G. Balvedi, M. Ulrey and J. Musiak, "Safety Analysis Methods for Complex Systems in Aviation," The fifteenth Air Transportation Symposium (XV SITRAER 2016), Nov. 2016, arXiv:2208.02018.
- [5] EASA. "Easy Access Rules for Unmanned Aircraft Systems," Jul. 2024. [Online]. Available from <https://www.easa.europa.eu/>.
- [6] P. Stastny and A. Stoica, "Safety Management for Unmanned Aviation," *INCAS BULLETIN*, vol. 13, issue 2021, pp. 213 – 228, doi:10.13111/2066-8201.2021.13.4.18.
- [7] JARUS. "JARUS Guidelines on Specific Operations Risk Assessment (SORA)," ed. 2.5, May. 2024. [Online]. Available from: <http://jarus-rpas.org/>.
- [8] Anamta Khan, "Risk Assessment, Prediction, and Avoidance of Collision in Autonomous Drones," The 17th European Dependable Computing Conference (EDCC 2021), Sep. 2021, arXiv:2108.12770.
- [9] EASA. "Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft," May. 2019. [Online]. Available from: <https://eur-lex.europa.eu/>.
- [10] EASA. "Commission Implementing Regulation (EU) 2021/664 of 22 April 2021 on a regulatory framework for the U-space," Apr. 2021. [Online]. Available from: <https://eur-lex.europa.eu/>.
- [11] EASA. "Acceptable Means of Compliance and Guidance Material to Regulation (EU) 2021/664 on a regulatory framework for the U-space," May 2024. [Online]. Available from <https://www.easa.europa.eu/>.
- [12] SAE International. "ARP4761, Guidelines and Methods for Conducting The Safety Assessment Process on Civil Airborne Systems and Equipment," issue 1996-12, 1996.
- [13] J. Qin, Y. Xi and W. Pedrycz, "Failure mode and effects analysis (FMEA) for risk assessment based on interval type-2 fuzzy evidential reasoning method," *Applied Soft Computing*, Volume 89, April 2020, 106134.
- [14] SESAR Joint Undertaking, "Intermediate ConOps Annex D MethoDology for the U-Space Safety Assessment (MEDUSA)," CORUS consortium, Ed. 01.00.00, 2019.
- [15] SESAR Joint Undertaking, "U-space Concept of Operations," CORUS consortium, Ed. 03.00.02, 2019.
- [16] K. ZAŁĘSKI, "Unmanned Aircraft as A Growing Hazard for Aviation Safety," *Modern Management Review*, vol. 13, 25 (2/2018), p. 99-111, Apr. 2018.
- [17] L. Sedov, V. Polishchuk, T. Maury, M. Ulloa and D. Lykova, "Qualitative and Quantitative Risk Assessment of Urban Airspace Operations," *Proc. The 11th SESAR Innovation Days*, Dec. 2021.
- [18] R.V. Melnyk, D.P. Schrage, V.Volovoi, and H. Jimenez, "Develop Sense and Avoid Requirements for Unmanned Aircraft Systems Using a Target Level of Safety Approach," *Risk Analysis*, Oct. 2014, doi:10.1111/risa.12200.
- [19] J. Stevenson, S. O'Young and L. Rolland, "Estimated levels of safety for small unmanned aerial vehicles and risk mitigation strategies," *Journal of Unmanned Vehicle Systems*, vol. 3, issue 4, pp. 205-221, Sep. 2015.
- [20] SESAR Joint Undertaking and Eurocontrol, "Guidance to Apply SESAR Safety Reference Material," 2018.
- [21] A. La Cour-Harbo, H. Schiøler, "Probability of Low-Altitude Midair Collision Between General Aviation and

- Unmanned Aircraft,” *Risk Analysis*, vol. 2019, issue 39, pp. 2499–2513.
- [22] The MITRE Corporation, “Modeling Risk-Based Approach for Small Unmanned Aircraft Systems,” 2018. [Online]. Available from: <https://www.mitre.org/>.
- [23] A. La Cour-Harbo, “Quantifying risk of ground impact fatalities of power line inspection BVLOS flight with small unmanned aircraft,” *International Conference on Unmanned Aircraft Systems (ICUAS)*, IEEE, Jun. 2017, pp. 1352-1360, ISBN: 978-1-5090-4495-5.
- [24] S. Oh, Y. Yoon and S. Kim, “Risk Analysis of Unmanned Aerial System Operations in Urban Airspace Considering Spatiotemporal Population Dynamics,” 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), IEEE, Nov. 2022, pp. 428-433, ISBN: 978-1-6654-6880-0.
- [25] A. Allouch, A. Koubâa, M. Khalgui and T. Abbes, “Qualitative and Quantitative Risk Analysis and Safety Assessment of Unmanned Aerial Vehicles Missions Over the Internet,” in *IEEE Access*, May 2019, vol. 7, pp. 53392-53410, doi: 10.1109/ACCESS.2019.2911980.
- [26] H. E. Roland and B. Moriarty, “System Safety Engineering and Management”, 2nd Ed., John Wiley & Sons, Inc., 1990.
- [27] R. Clothier and R. Walker, “The Safety Risk Management of Unmanned Aircraft Systems”, *Handbook of Unmanned Aerial Vehicles*, pp 2229–2275, Jan. 2014.
- [28] L. Speijker, D. Ozuncer, J.A. Stoop and R. Curran, “Development of a Safety Assessment Methodology for the Risk of Collision of an Unmanned Aircraft System with the Ground”, *SAE Technical Papers*, Oct. 2011, doi:10.4271/2011-01-2684.
- [29] JARUS, “AMC RPAS.1309 Issue 2, Safety Assessment of Remotely Piloted Aircraft Systems”, Nov. 2015. [Online]. Available from: Available from: <http://jarus-rpas.org/>.
- [30] EUROCAE, “ED-279, Generic Functional Hazard Assessment (FHA) for UAS and RPAS”, Oct. 2020.
- [31] FAA, “49 USC 44809, Exception for limited recreational operations of unmanned aircraft”, Oct. 2018.
- [32] FAA, “14 CFR Part 107, Small Unmanned Aircraft Systems”, Jun. 2016.
- [33] FAA, “14 CFR Part 91, General Operating and Flight Rules”.
- [34] FAA, “FAA Order 8040.6, Unmanned Aircraft Systems Safety Risk Management Policy”, Apr. 2019.
- [35] EASA, “Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes (CS-25), Amendment 27”, Nov. 2021.
- [36] FAA ATO, “ATO Safety Management System Manual (SMS)”, December 2022.
- [37] IEC, “IEC 61508, Functional Safety of Electrical/ Electronic/ Programmable Electronic Safety-related Systems”.
- [38] N. Leveson, “Engineering a safer world: Systems thinking applied to safety”, in MIT Press, 2012, ISBN: 9780262298247.
- [39] S. Du, G. Zhong, F. Wang, B. Pang, H. Zhang and Q. Jiao, “Safety risk modelling and assessment of civil unmanned aircraft system operations: A comprehensive review”, in *Drones*, vol. 8, issue 8, May 2024. Retrieved from <https://www.mdpi.com/2504-446X/8/8/354>.
- [40] J. Stádník, Š. Hulínská and J. Kraus, “Comparison of methods for the safety evaluation of UAS operation”, *Transportation Research Procedia*, vol. 65, pp. 621-628, Nov. 2022. Retrieved from <https://www.sciencedirect.com/science/article/pii/S2352146522006779/pdf>.
- [41] L. Meyer, C. Carlsson, Å. Svensson and M; Peukert, “Stressing safety assessment methods by higher levels of automation”, *Proc. The 33rd International Congress of the Aeronautical Sciences (ICAS)*, Sep. 2022. Retrieved from https://www.icas.org/ICAS_ARCHIVE/ICAS2022/data/papers/ICAS2022_0903_paper.pdf.
- [42] F. Bonfante, “Safety Management System for Light RPAS”, in *CORE*, 2020. Retrieved from <https://core.ac.uk/download/pdf/234931050.pdf>.
- [43] E. Stefana, G. Di Gravio, R. Patriarca and F. Costantino, “Adopting the specific operations risk assessment methodology for drone inspections at industrial sites”, “7th International Conference on System Reliability and Safety (ICSRS 2023)”, IEEE. Retrieved from <https://ieeexplore.ieee.org/abstract/document/10381275/>.
- [44] R. Borgovini, S. Pemberton and M. Rossi, “Failure Modes, Effects and Criticality Analysis (FMECA)”, *Reliability Analysis Center*, 1993.
- [45] A. Shoufan, R. Alkadi, “Integrating Counter-UAS Systems into the UTM System for Reliable Decision Making”, Nov. 2021, arXiv:2111.07291.
- [46] K. Spalas, “Towards the Unmanned Aerial Vehicle Traffic Management Systems (UTMs): Security Risks and Challenges”, Aug. 2024, arXiv:2408.11125.
- [47] M. Rubagotti, I. Tusseyeva, S. Baltabayeva, D. Summers and A. Sandygulova, “Perceived Safety in Physical Human Robot Interaction - A Survey”, May 2021, arXiv:2105.14499v1.
- [48] J. Xiang, J. Xie and J. Chen, “Learning-accelerated A* Search for Risk-aware Path Planning”, Sep. 2024, arXiv:2409.11634v1.
- [49] S. Pohland and C. Tomlin, (2024). “PaRCE: Probabilistic and Reconstruction-Based Competency Estimation for Safe Navigation Under Perception Uncertainty”, Sep. 2024, arXiv:2409.06111v1.
- [50] B. Clement, M. E. Dubromel, P. Santos, K. Sammut, M. Oppert and F. Dayoub, “Hybrid Navigation Acceptability and Safety”, Apr. 2024, arXiv:2404.11882v1.
- [51] T. Savas, “A Risk-Based Analysis of Lightweight Drones: Evaluating the Harmless Threshold Through Human-Centered Safety Criteria”, in *Drones*, vol. 9, issue 8, Jul. 2025, <https://doi.org/10.3390/drones9080517>.
- [52] S. A. H. Mohsan, M. A. Khan, F. Noor, I. Ullah and M. H. Alsharif, “Towards the Unmanned Aerial Vehicles (UAVs): A Comprehensive Review” in *Drones*, vol. 6, issue 6, Jun. 2022, <https://doi.org/10.3390/drones6060147>.