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Unmanned aerial systems: Status and Forthcoming challenges for Safety Risk Management

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Abstract

Urban Air Mobility (UAM) promises a revolution in urban transportation: for the first time ever, cities will be able to use the third dimension for their mobility needs. The traditional aviation industry and high-tech newcomers alike are making huge investments to make this - still unproven - technology a reality. Although Unmanned Aerial Systems (UAS) have now for some time been used in segregated airspace where separation from other air traffic can be assured, potential users have interests to deploy UAS in non-segregated airspaces. Recent technological and operational improvements give reason to believe that UAS safety and performance capabilities are maturing. However, there is still the need for establishing a systematic agreement between UAS safety policies with commonly accepted UAS Safety Risk Management processes. This agreement is needed to show that the risks related to UAS operations in all the different airspace classes can be adequately controlled in a way that would not jeopardize current safety levels and safety mitigations effectiveness. This study aims to investigate the current status of UAS operations and future concepts of operations with specific interest in the management of safety risk. This manuscript aims to summarize some of regulatory aspects currently available linked to safety investigation and reporting of drone operations and consequently draw some potential lines for future research.

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Keywords: Aviation safety; drones; aviation management; Unmanned aviation; air mobility

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1. Introduction

Recent times have seen the rapid emergence of Unmanned Aerial Systems (UAS) as a viable form of commercial civil aviation, as well as a major recreational pursuit. In the US, the majority of the registered drones are recreational, with 1,256,336 in number, while the rest are for commercial purposes reaching 522,645 as of January 2021 (FAA, 2020). The FAA drone statistics also reported there are 208,010 remote pilots certified. If current aviation safety levels are to be preserved and enhanced, both these forms of operation need to co-exist with all sectors of current and future manned aviation in a safe and visible way. UAS traffic represents a fast-emerging sector of civil aviation but can also present additional risks in the provision of safe and efficient Air Navigation Services (ANS).

In particular, the types and sizes of UAS operations are far more diverse compared to current manned civil aviation. The differences in vehicle size, traffic densities and volumes, and the forms of operation are far greater in the unmanned domain. The initial driver for numerical growth is at the small UAS end of the market, for applications including survey and delivery work, where usage is forecast to be huge. In view of the rapid expansion of that traffic sector and the types of operation, their management requires a new approach parallel to, and with connection to, the one in place for manned aviation.

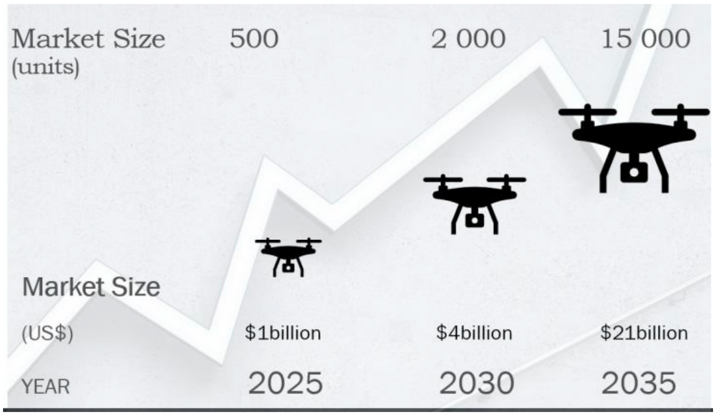


Fig. 1. Growth of the vertical take-off and landing (VTOL) market, Interpreted from: (Porsche Consulting, 2018).

In the past decades, UASs were limited to defense applications. However, drones have proven to be an important tool for numerous applications across both commercial and non-commercial operators. In the last decade, technology has improved significantly, and, as their size has reduced, their numbers and capabilities have increased. Today, UASs emerged as an economical solution for commercial applications such as surveying, mapping, and aerial photography, among others. The growing importance of "drone-as-a-service," as well as the exemptions provided by government and regulatory authorities to operate commercial UASs, has been a driving force for applications in agriculture, construction, and oil rig inspections, among others.

The initial introduction of UAS to airspaces, especially in the commercial world, has been limited to visual line of sight (VLOS) operations. Australia, Canada, China, Denmark, New Zealand, Poland, South Africa, Switzerland, and some states in US have taken measures to incorporate UAVs into airspace far beyond visual line of sight (BVLOS) operations, opening opportunities for ever more innovative applications and expansion (Deloitte, 2018).

The UAS market continues to grow, and consumer-centric innovation is one of the most prominent factors for that growth (CANSO, 2011). One of the most vibrant areas—the global vertical take-off and landing vehicle (VTOL) or the passenger drone market—is likely to be worth US$21 billion by 2035 (Deloitte, 2018). Automotive and aerospace manufacturers have been experimenting with concepts in recent years, and it is not unreasonable to expect autonomous flying taxis in the skies within the next ten years. In more recent times, the Urban Air Mobility sector, including unmanned air taxi operations, has been added to the equation. At the same time, there is significant commercial interest in the use of larger unmanned aircraft within non-segregated airspace – the airspace and air routes used for commercial aviation. In practice this means that, when it comes to assessing the safety risks, there is not one form of UAS operation but many, each having differing characteristics.

This manuscript aims to investigate current status of UAS operations and future concepts of operation with specific interest in management of safety risk. The manuscript goal is to summarize some of the currently available regulatory aspects linked to safety investigation and reporting of drone operations and outline what could be meaningful lines for future research in the area.

2. Background

UASs have been represented by the terms "drones," "unmanned aerial vehicles" (UAV), remotely piloted aircraft systems" (RPAS) and small UAS (sUAS) that will all be used interchangeably in this research paper. Additionally, the current COVID-19 pandemic accelerated the use of many types of operations outside of the military, with fast-paced changes in regulation and usages. Some of these areas include delivery of goods (both medical and non-medical), search and rescue, agriculture, and hobbyist activities (Simonsen, et al., 2019). UNICEF believes that drones could be used medically and confirm that drones have been used in 18 countries for delivery and transportation purposes during the COVID-19 pandemic (United Nations International Children's Emergency Fund, 2020). This growth in use of drones for many applications has led to both possibilities and challenges. Manufacturers worldwide can offer diversity in UAS platforms due to significant increases in research and innovation in technologies in the field (Simonsen et al., 2019). Enabling successful safe operations beyond visual line of sight are the core of commercial and government market potential (EC Implementing Reg. 2020/639 – Amending European Commission IR (EU) 2019/947 as regards Standard Scenarios for Operations executed in or Beyond Visual Line of Sight: May 2020); this will require the availability of a variety of aspects (SESAR, 2016):

- **Detect and avoid (D&A)** capabilities are seen as a key enabler for drone operations in all classes airspace and are expected to have a positive impact on safety and social acceptance.
- **Datacom and spectrum issues** are critical to enable BVLOS and long endurance surveying missions to happen in safe conditions. Appropriate datalinks are necessary for command and control (C2) as well as potentially for communication with air traffic control (ATC) or future forms of VLL drone management.
- **Security and cyber resilience** are a priority area of development to mitigate the risk that drones could be subjected to malicious or accidental takeovers of datalinks leading to accidents, theft or deliberate use of the aircraft to damage infrastructure or hurt civilians.
- **Human factors and training** will need additional R&D efforts to ensure that the situation awareness for pilots of drones matches that of pilots in cockpits. Additionally, there will be a requirement to manage the transition from remotely piloted drones to more automated drones that are only monitored. In order to achieve those goals, effective solutions regarding contingency, failure management etc. will need to be put in place.
- **Validation and demonstration** will be important to increase public acceptance of drone operations and will support the regulatory work.
- **The critical area of air traffic management** requires further research and development. All previously mentioned R&D topics depend on how ATM will integrate drones in all classes of airspace. The basic principles of drone traffic management as defined by the concepts of operations will lead to precise requirements on which industry standards will be developed, thereby assuring a strong basis for future investments and partnerships across private industry players and public member states and stakeholders.

In recognition of this bottleneck, the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) in the United States (FAA, 2020), European Aviation Safety Agency (EASA) (SESAR, 2019), China's Civil Aviation Administration (CAAC) (among others) issued measures for the management of Unmanned Civil Aviation. Many similar organizations around the world have initiatives underway to identify, respond to, and ensure the safety and integrity of the current ATM operation when dealing with UASs.

Managing the airspace and establishing standards for all stakeholders is critical to the long-term success of UAV. UTM (Unmanned Traffic Management) development will ultimately identify services, roles and responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements for enabling the management of UAS operations. Integrating UAS into existing air traffic management operations will present a variety of issues and challenges. It will require bringing together a diverse system of stakeholders that includes operators, communication system service providers, and data service providers, as well as regulating authorities.

3. UAS situation in Europe and in US

Proposals and concepts for UAS operations are appearing all over the world. Two major areas of activity are located into Europe and in the US. The concepts being planned, developed, and implemented in these regions are not only similar in many respects, but are defining the blueprint for UAS systems development by the many industry actors wishing to participate in this growing aviation sector. The following sub-paragraphs therefore examine these two contexts.

3.1. Forms of UAS Operation – the European Context

EASA has defined three categories of UAS which are now embodied in EU legislation (EU Reg. 2019/945 - Unmanned Aircraft Systems and on Third-Country Operators of Unmanned Aircraft Systems: March 2019). In all three categories, i.e., Open, Specific and Certified, the UAS (including its control agency, procedures, and other technical constituents) is required to comply with the operating rules of the airspace with which it operates.

To include all forms of UAS operations within the above airspace volumes, it has been necessary to define seven classes of UAS traffic. Figure 2 summarizes these classes showing the way in which the differing types of UAS operation inter-relate with the UAS categories and the new range of airspace definitions that is necessary to both encompass all UAS traffic.

Airspace Type	UAS Traffic Class	UAS Category	Traffic Type	Airspace Limits	Operations	Purpose
VLL	I	Open	Recreation	Ground to 120m/400 ft	VLOS	Recreational
	II	Specific/ Certified	Specific/ Certified	Ground to 500 ft	VLOS/ BVLOS	Surveys, filming, search and rescue, and similar
	III	Specific/ Certified	Medium/ Long Haul Traffic	Ground to 500 ft	BVLOS, Free flight or route structure	Mainly transport
	IV	Specific/ Certified	Special Operations	Ground to 500 ft	VLOS/ BVLOS	Special Operations
IFR/ VFR	V	Certified	UAS not meeting pan-European performance requirements	500 ft to FL600 including uncontrolled aerodromes	IFR/VFR outside the pan-European network. Not flying SIDs and STARs	Mainly transport or military
	VI	Certified	UAS meeting pan-European performance requirements	500 ft to FL600 including aerodromes	IFR/VFR within the pan-European network, including SIDs and STARs	Any
HFR	VII	Certified	Very High Level IFR operations transiting non-segregated airspace	Above FL600 with transition through lower airspace	IFR/VFR	Stratospheric commercial operations

Fig. 2. UAS Traffic Classes in all Airspace Types and Volumes (EUROCONTROL, 2018).

These connections provide a basis on which manned and unmanned traffic may be integrated (EUROCONTROL, 2018). In the European context, the operation of UAS is encompassed within the European Community's U-Space concept, which coordinates the UAS vehicular requirements and specifications and the airspace structures which facilitate UAS operation and integration.

3.2. Forms of UAS Operation – US concept

In the US, the same development challenges exist, but applied to an airspace system which is different in some respects to that in Europe. Nevertheless, the commercial demands are broadly the same as the principal actors pushing for the introduction and use of UAS are global entities. The Federal Aviation Administration (FAA) has been working with the National Aeronautics and Space Administration (NASA) and US Industry to develop a Concept of Operations (ConOps) and Implementation Programme to enable the use of UAS, including their integration into the National Airspace System (NAS) (FAA, 2020).

The FAA ConOps is referred to as UTM, even though this title is now in wider use to refer generically to a number of other traffic management applications being marketed worldwide. Most of the information presented will apply to UTM operations in any airspace under 400 ft, but operational and technical requirements may vary due to unique characteristics and implications of the airspace class in which UASs are operating. In this Version 1.0 (FAA, 2020), the use cases presented are mostly specific to Class G operations. Class G airspace is the portion of airspace in the NAS that has not been designated as controlled airspace (i.e., not Class A, B, C, D, or E). It is therefore designated uncontrolled airspace (see Figure 3). ATC has no responsibility to provide separation services in Class G airspace, rather, manned aircraft cooperatively manage their operations based on specified principles of operations.

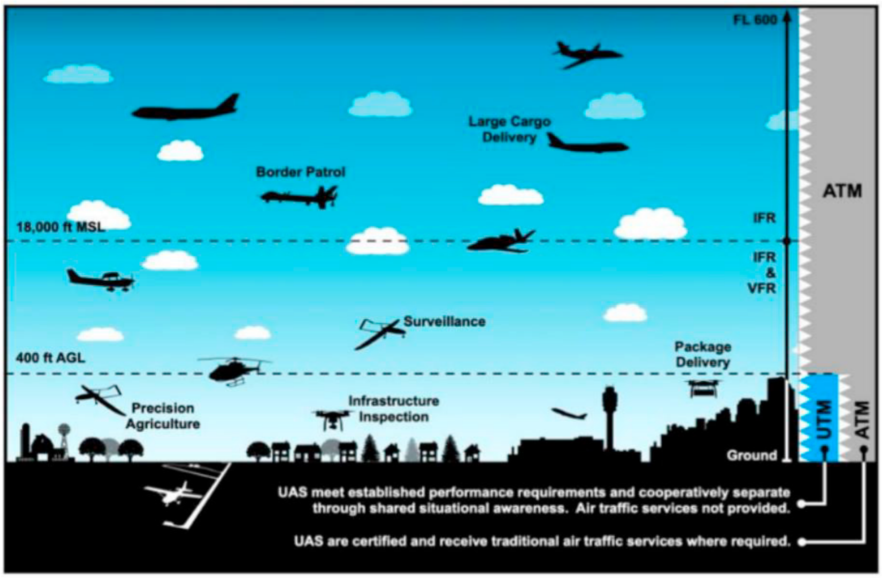


Fig. 3. UTM Operations in the Context of Airspace Classes, adapted from (FAA, 2020)

To provide UAS with the same access as manned aircraft, UTM is designed to provide a similar means of cooperative traffic management for UAS and other participating aircraft in this airspace (FAA, 2020)

A particular feature of the US approach is the need to define roles and responsibilities between the various actors foreseen to be involved in the provision and regulation of UAS services. This is an especially important aspect of defining safety regulations and requirements for the continued protection of aviation safety.

3.3. UAS Management Systems

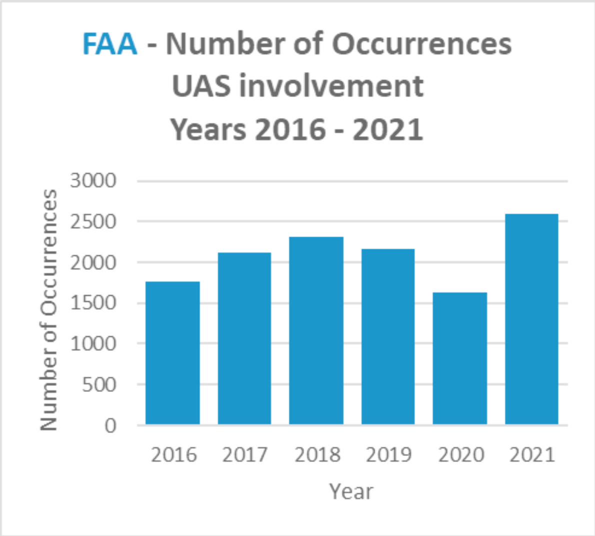
U-Space and UTM are two specific implementations of UAS management systems. The assessment of the above operating contexts and concepts shows considerable similarities between the approaches – as might be expected when faced with broadly the same direction of industry development. A number of further generic issues fundamental in assessing future safety needs can be revealed:

- The need for *formal systems of traffic management* – based on the traffic levels forecast it is clear that UAS traffic will hit current airspace by a large number, and this traffic cannot be accommodated under present day ATM and airspace arrangements. Therefore, to properly organise the airspace with implemented UAS will require proper organisation and it can also be expected that new approach to airspace design will be needed.
- The high level of *Automation*, automated safety nets on board of UAS and in UTM as well.
- *UAS flight related services*, to have a precise picture of the UAS operation in the airspace a range of automated pre-flight and in-flight services will be required to provide smooth UAS operation, such as:
  - Initial vehicle registration
  - Flight planning, including Flight Plan composition and submission
  - Flight approvals and authorisations
  - NOTAMs and Weather information
  - Air situation notification
  - Infrastructure status reporting (CNS)
- The need for *UAS Air Traffic Flow Management* – to use maximum potential airspace capacity for UAS operation while keeping in mind the predicted increase in UAS traffic. All relevant air traffic flow services have the main goal to optimise airspace use in the high safety levels (Kovacova, 2018). These services include Airspace management, Potential conflict prediction and alert, Dynamic re-routing and Strategic de-confliction.

For manned aviation, all these functions are provided within the scope of ATM. Many involve human intervention and decision-making which will not be present largely for unmanned aviation involving U-Space/UTM concepts. While UAS traffic management will be "ATM-like" to some extent, it seems to involve traffic volumes, technologies and levels of automation not currently used in ATM. Where UAS are integrated into non-segregated airspace, within ATM-controlled operations, some of the services will be provided within the ATM system while a proportion will be automated. Whatever the specific arrangement of flight services, or the type of UAS operation being considered, the UAS Traffic Management System will need to have an important interface with the ATM system within which the operations take place and, specifically, with the relevant ATM providers (Stevenson, 2017).

4. UAS and Aviation Safety

Clearly, all forms of unmanned aviation need to operate, and be seen to operate, in a manner that does not create risk at a level beyond the safety limits that are viewed as tolerable today. This implies, among other measures, a system of UAS traffic management where safe and orderly operation can be assured, and levels of safety can be both measured and regulated. Accident investigation authorities have already published final reports on accidents or serious incidents involving UAS, and certain statistics have also been made available. Nevertheless, when comparing the available data, it should be remembered that there are no harmonized rules on when to report and investigate an accident or serious incident involving collect data on such occurrences, the sharing of data and the standardization of accident reporting and investigation processes are still in their primary stages of maturity (Kasprzyk et al., 2021; Patriarca et al., 2018). Figure 4 synthetizes the numerosity of occurrences in US and EU where UASs were involved.



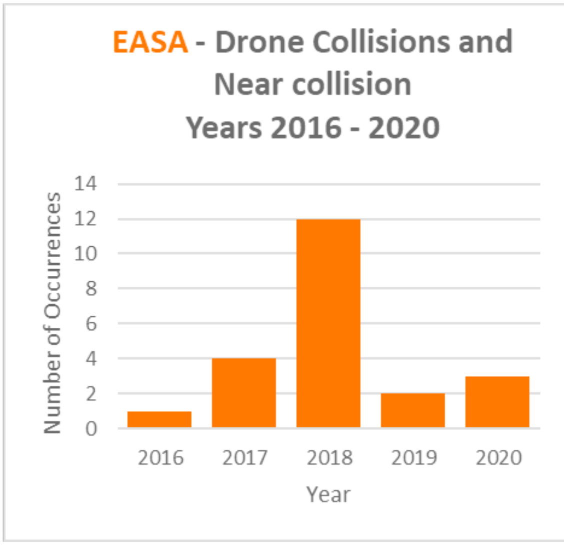


Fig. 4. Overview of reported occurrences in US (left) and EASA (right). Note the different variables in the count and the different scale.

The main difference in data pictured above is how they are categorized and analyzed. FAA runs short analysis of each occurrence report, but data are not put in the occurrence categories in the same way as occurrences involving traditional air traffic. Contrarily, EASA started to apply same methodology for data collected from occurrences where UAS was involved as for all incidents in aviation regarding current EU regulations (EASA, 2021). This dichotomy makes difficult to compare data unambiguously and to highlight main risks connected to UAS operations.

From recent experience at the beginning of UAS use, the main safety risk was associated to operations near airports. One of the important findings was that most of the occurrences where not reported by pilot/operator of UAS but by the aircraft involved in occurrence or by third independent party. This also brings the question about the maturity of UAS operators in safety occurrence reporting culture and just culture as well (Kovacova, 2019).

During evolving years both FAA and EASA implemented regulations whose main goal is to start proper collection of occurrences with UAS involvement, and which also bring mitigations in the place to prevent any safety risks brought by UAS operations near airports.

For the future, it is necessary to consider working environments in which UAS operate alongside manned aviation, either through UAS operation integrated within non-segregated airspace – i.e., together with manned aviation, or for small UAS operations, within segregated airspace under the control of a UTM system. In both these cases, risks to be mitigated result both from the UAS itself and from the airspace (and its management system) within which the UAS operates. Out of the many forms of risk that are potentially introduced by UAS operations, the assessments in the following paragraphs focus solely on safety risks.

The major concern is the capability of the UAS to meet the operating requirements of the types of airspace in which they may operate. This requires UAS, as a minimum, to replicate the performance of manned aircraft in that same airspace in respect of its ability to 'detect and avoid' increased-risk situations – including collisions with other aircraft, and with the ground (with the potential to cause collateral injuries on the ground). The ability of UAS to operate to this level of performance is determined by their technical capabilities (Speijer, 2018) in respect of:

- *Communications* – the ability of the UASs to inform the agencies controlling the airspace of its status, and to respond to any changes necessary to its flight path. This may include communication with an external agency (such as a remote pilot).
- *Navigation* – the ability of the UASs to position itself with required accuracy, respond as required to fluctuating navigational demands and to comply with applicable navigational performance criteria (such as RNP specifications).

- *Surveillance* – the need for UASs to see and be seen. This includes the ability to remain electronically visible, to sense the surrounding operational environment adequately and fully as well as to comply with surveillance criteria applicable to the airspace of operation.

On the same area, current airspace arrangements require an ANSP to manage - i.e., to identify and mitigate - safety risks through use of a Safety Management System (SMS). In turn, the ANSP's operation of the SMS is subject to safety oversight by the National Supervisory Authority (NSA). The key risk-related issue is therefore how these service-provision arrangements are affected by the advent of UAS, which can be referred to three critically important areas:

- For Safety Oversight
  - The need to introduce appropriate standardised processes for the safety oversight of UTM operators
  - The need to introduced safety culture into the UAS and UTM service providers
  - The need for formal establishment of the cooperation between ATM, UTM and UAS service provider with the main goal - sharing experience and knowledge related to safety risk management in the airspace
  - The need for adjustments in the safety oversight arrangements by the NSA of the ANSP to address the additional risks posed by UAS operations.
- For UTM:
  - The need for establishment of a formal SMS of UAS operators
  - The need for understanding and formal implementation of Safety Culture and Just Culture
  - The interface and consistency between the safety requirements and safety occurrences reporting system and analysis for both UTM and ATM.
- For ATM:
  - The allocation of safety responsibilities between ANSP and UTM operator(s)
  - The interface and consistency between the safety arrangements for ATM and UTM
  - The integration of a proportion of UAS traffic into non-segregated airspace
  - The operation of UTM volume(s) of airspace within national airspace
  - Safety oversight arrangements by the NSA to cater for the addition of UAS operations.

In summarizing the effects of UAS on aviation safety, the introduction of UAS operations, as proposed, presents new areas of threat that must be addressed and mitigated if the future of aviation safety is to be secured. These areas are in the form of new risks which demand enhancements to existing safety management mechanisms to achieve risk mitigation to tolerable levels (Yang et al., 2022).

Joint Authorities for Rulemaking of unmanned systems (JARUS), under the umbrella of EASA introduced in Europe a new methodology called SORA (Specific Operations Risk Assessment) (JARUS, 2019). This new methodology proposes risk assessment of activities for UAS operations, especially for those which are incorporated in the "specific category", where the urban air mobility belongs as well. Although this methodology is already in the place and available to the public, it offers not only the solution for risk management process, but it also raises a lot of practical questions. The methodology combines a qualitative and quantitative approach to safety risk assessment. Its weakness lies in the lack of practical experience with UAS operations (in some cases experiences are coming from simulations), specifically when operational scenarios need to be defined as well as existing risk mitigation barriers. (Sedov et al., 2019).

The analysis of UAS occurrences, reported in USA and in EU, also shows the diversity in the approach to risk identification and its mitigations up to their implementation into the operation. During research, as mentioned above, there is one main aspect which need to be highlighted - the length of SMS evolution and building and promoting the strong safety culture through the recent aviation system. This new challenge should be in the scope of the minimum SMS definition for all UAS providers, in the same manner as the SMS is implemented and applied by all aviation stakeholders, in US and as well in Europe.

5. Conclusion

UASs represent a fast-emerging sector of civil aviation but it can also present additional risks in the provision of ANS. In both Europe and in the US, the major Concepts of Operations for UAS are under advanced development, but the consequential effects on safety management have not yet been fully addressed in legislation and published guidance. This paper therefore seeks to document this gap and to draft proposals for reinforcing SMS effectiveness. The principal means for identifying and controlling risks is indeed the organization's SMS. However, an analysis has been necessary to assess whether an ATM SMS has the capability to adequately address UAS-related risks. This has shown that, while current SMS design encompasses the scope and the major functions needed to achieve this objective, specific enhancements are required to a wide range of these SMS elements to make the control of UAS-derived risks fully effective. A range of risk countermeasures are proposed which, if implemented, would enhance SMS to increase its effectiveness in mitigating risks arising from UAS operations. In addition, the currently proposed concepts of operation for UTM demand a similar, but parallel, approach when specifying safety management requirements applicable to that sector. Lessons are transferrable from ATM, but some adaptation is necessary to fully address the specific features of UTM operations. Accordingly, initial, and indicative SMS requirements for UTM should be proposed to supplement applicable generic regulations and foster UASs safety management.

In EU and US there are already in place many initiatives with focus on UAS operations starting with training of future drone pilots, workshops focused on the current situation and discussions on the potential safety risks, new concept of operations scenarios and studies for the next UTM operations. These actions show a positive approach towards the management of safety risks, even though a harmonized management is still missing.

Here is a huge open area for the near future research, whose starting point needs to be in the collection of safety data, to be based on the same well-defined criteria and classification schemas, so they can be properly analyzed and used for identification of effective mitigation actions. These data are the grounding sources to be used for validating different operational scenarios for future UAS operations and their contributions to safety risks management, enhancing decision-makers' safety intelligence (Patriarca et al., 2019).

The economic and public pressure for the fast implementation of UAS operations is enormous. Nonetheless, we still require to be aware that UAS operations will be operated in a certain environment by specific operators. The flying areas need to be evolved and they are required to achieve the same level of maturity and safety as UAS technology itself. To achieve this goal there is the need for implementing customized SMS elements in UTM, and harmonize them with ATM SMS, especially in line with the regulatory items.

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