

## EMERGING TECHNOLOGIES AND CHALLENGES IN HYBRID UNMANNED AERIAL VEHICLE OPERATIONS IN THE METAVERSE ERA

Florina Ghindescu COSTAŞ, PhD Student

University of Petroşani

Professor Roland Iosif MORARU, PhD, Habil, BEng

University of Petroşani

Lecturer Ioana-Raluca ADOCHIEI, PhD, BEng

“Ferdinand I” Military Technical Academy, Bucharest

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*With the maturity of UAV technologies and the expansion of the Internet of Things (IoT), unmanned aerial vehicles (UAVs) have become an essential component in multiple industries, representing a crucial tool for addressing current and future challenges. Integrating emerging technologies and advanced training methodologies for unmanned aerial vehicle operators is essential to ensure the efficient and safe use of these technologies. This research investigates critical gaps in understanding the emerging risks associated with human-machine interaction, from the perspective of occupational safety and health (OSH). While automation contributes to simplifying processes, extended reality (XR) facilitates the development of interactive educational resources, and augmented artificial intelligence (AAI) amplifies human cognitive capabilities through the use of advanced artificial intelligence (AI) algorithms. In the context of the industrial metaverse, these technologies offer significant opportunities for optimizing operational efficiency, supporting the training of drone operators in successfully managing the complexities of modern airspace.*

*Keywords: UAV operator training; industrial metaverse (AI, AAI); emerging technological risks; occupational safety and health (OSH); UAV;*

## INTRODUCTION

There is growing recognition that the professional environment is evolving rapidly due to technological advances and globalization. According to a report by PriceWaterhouseCoopers (PwC), headquartered in London, UK, AI could contribute up to 15.7 trillion USD to global economic growth by 2030 (Rao, 2017, p. 3). While AI focuses on task automation, augmented intelligence aims to integrate into the human experience rather than fully replace it, being designed to enhance our cognitive abilities and help us achieve higher levels of performance (Kim, 2022, p. 1). At the same time, intelligent automation technologies offer increasing opportunities, including for human resource management, but also present feasible technological and ethical challenges (Christenko, 2022, p. 6).

The impact of these technologies is evident both at the individual level, through the transformation of roles and required skills, and at the organizational level, through the need to reconfigure work processes and cultivate an organizational culture that fosters *human-machine collaboration*. The effects of technological changes on occupational health and safety (OHS) opportunities and challenges have always accompanied technological evolution (Rosen, 2022, p. 1). In this context, a rapidly evolving sector with significant potential, including within the European Union, is unmanned aerial vehicles (UAVs). Currently, UAVs are referred to by various terms, such as drones, remotely piloted vehicles (RPVs), remotely piloted aircraft (RPA), unmanned aircraft systems (UAS), and remotely piloted aircraft systems (RPAS). These terms have emerged at different stages of technological development or in various application scenarios but do not create ambiguity in context (Fan, 2020, p. 199). UAVs represent a class of devices that include multi rotor drones, as well as single-rotor and fixed-wing devices, hybrid versions, and potentially alternative propulsion systems essentially, robots capable of flight. Although the number of commercial drones has grown significantly, military applications still dominate the market.

In terms of autonomy, research presents a taxonomy with six levels (Eibin, 2021, p. 1) or ten levels of autonomy for UAVs (Sequeira, 2023, p. 2). While this taxonomy primarily targets military contexts, it also applies to UAVs operating in other scenarios. UAVs have brought significant changes to how we work and interact

with the environment, opening new opportunities for innovation and economic growth while offering advantages over conventional technologies (Gaurav, 2018, p. 12).

The key sectors benefiting from UAV technology include military, civil, and commercial domains, such as agriculture, construction and infrastructure, logistics and transportation, healthcare, environmental monitoring, defence, mapping and surveying, and scientific research missions. The diversity of UAS applications requires a tailored approach to operator training. Given that each industry and organization has specific requirements, a single certification may be insufficient. Therefore, more nuanced and use-case-specific training requirements are essential, as the lack of such training could lead to incidents (Williams, 2023, p. 1). The Federal Aviation Administration (FAA) highlights significant demand for UAV operators in the military and maritime sectors, providing valuable insights into the challenges faced by the US industry and emphasizing the need for clear standards for drone operation safety and operator training (Ib.).

Recent studies in AI and remotely piloted aircraft systems show that a fully autonomous system could significantly improve decision-making and the overall efficiency of missions (Eibin, ib.). These exponential advances are driven by both algorithmic innovations (sensorimotor learning in simulation) and system engineering improvements, covering the entire navigation flow: perception, planning, and control (Hanover, 2024, p. 17). Currently, drones that offer a balance between autonomy and human control remain relevant (Presamil, 2024, p. 1). Until fully autonomous systems can reliably manage the vast amount of data generated during flight in real time, human operators will remain essential to ensure the safety and performance of UAVs.

As AI becomes more robust, safety algorithms are becoming critical for UAV operations in complex and uncertain environments (Hanover, p. 18). Alongside technological progress, the global regulatory framework must be modernized to enable fully autonomous RPAS operations (Eibin, p. 2).

A recent study (Rahmani, 2023, p. 57) highlights that drone operators working in the gig economy have been overlooked in terms of occupational health and safety (OHS). The study explores human-UAV interaction, the dynamics of operator training through the adoption of new AI and XR technologies, and how OHS risks are affected by these changes. Digital technologies offer more efficient and flexible possibilities for military training, adapting to the complexity of modern operations (Jungck, 2023, p. 1). Recent findings show that human factors, rather

than technological defects, are the primary cause of most drone accidents, such as a lack of situational awareness and poor decision-making (Rahmani, pp. 63-64).

The human-machine interface is an emerging risk in occupational health and safety (OHS), but it also offers a pathway to improving safety, highlighting the importance of proper design as UAV autonomy levels increase (Sequeira, 2023, p. 7). In the era of the metaverse, digital technologies such as AI and XR have a significant impact on the training process, providing personalized learning experiences. While the integration of these technologies enhances operational efficiency, it also introduces new occupational health risks.

This new paradigm requires a holistic approach that considers both the technological complexity and the impact on the occupational health of UAV operators, within a dynamic and ever-changing regulatory framework. The lack of empirical data on associated risks complicates the development of effective risk mitigation strategies. Identifying research gaps is essential for developing informed policies that ensure operator safety and address unaddressed risks.

This study employs the PRISMA methodology for the selection and critical analysis of relevant literature from academic and industrial sources. The sources presented below have been filtered based on the irrelevance to the following areas: unmanned aerial vehicles (UAVs), occupational health and safety (OHS), and the use of XR technologies in UAV operator training.

## THEMATIC ANALYSIS

### *UAV Integration, Digital Surveillance, Ethics, and Space*

Research conducted within European Commission projects – ranging from the improvement of flight standards (aw-drones.eu, 2021) and the coordination of UAV fleets and their integration into air traffic (labyrinth2020.eu) to the development of solutions for countering threats, including neutralizing UAVs operating in restricted areas (alladin2020.eu) and exploring the potential of 5G technology (5gdrones.eu) – has marked significant progress in drone integration. However, these initiatives have also identified potential safety threats posed by UAVs. It is not surprising that technological issues no longer dominate research concerns. Instead, organizational, managerial, and operational impacts on performance and safety are becoming the primary focus (Sequeira, p. 4).

Despite the clear benefits of UAV usage, their rapid proliferation in various work environments raises social and ethical dilemmas, particularly regarding privacy

invasion and public safety risks (Rahmani, p. 63). Initiatives led by organizations such as NATO, along with discussions at international forums, play a critical role in shaping a collective response to these emerging challenges. These initiatives emphasize the importance of collaboration in securing airspace, especially within the context of contemporary digital conflicts. The significance of cooperation is further highlighted by ongoing efforts to develop a comprehensive legal and ethical framework for digital space operations, ensuring a balanced approach that accounts for both military and civilian interests (Botezatu, 2024, p. 6).

Another important aspect is the growing role of artificial intelligence (AI) and augmented artificial intelligence (AAI) in UAV surveillance and control. These technologies facilitate efficient risk management and enhance operational efficiency. AI enables the automation of complex processes, while AAI improves human capabilities by integrating automated analysis with human decision-making, offering safe and effective solutions for UAV operations in both civilian and military contexts.

Emerging technologies such as 5G networks and the Internet of Things (IoT) also play a crucial role in managing air traffic and communication networks. However, these advancements bring additional risks, including cybersecurity vulnerabilities, which require appropriate security measures and standardization efforts.

To ensure the safe and efficient integration of UAVs into airspace, an integrated regulatory framework is essential – one that balances both military and civilian interests. Strict regulations supported by a solid ethical framework will prevent the misuse of surveillance technologies and contribute to public safety and privacy protection.

Drones have significantly transformed the strategic conduct of warfare, offering substantial advantages in power projection, operational efficiency, reduction of political and humanitarian risks, and adaptability to asymmetric and cyberwarfare (Barbu, 2024, pp. 11–13). The use of unmanned aerial vehicles (UAVs) in military missions not only reduces the risk of human casualties, thereby enhancing operational safety in conflict zones, but also generates significant cost savings compared to manned aircraft operations (Fan, 2020, p. 204). Additionally, UAVs can access confined or inaccessible spaces, as well as flammable or toxic environments, making them essential for high-risk operations (Rahmani, p. 53).

The National Institute for Occupational Safety and Health (NIOSH), in an integrated approach to workplace safety, classifies UAVs as “*professional service robots*”, highlighting their role in performing dangerous or repetitive tasks, thereby

reducing the risk of accidents and incidents at work (NIOSH, 2024, p. 1). Consequently, the application of UAV systems in the military domain has become increasingly common and will continue to shape new military capabilities. Since the emergence of the first UAV in the United Kingdom in 1917, drone technology has evolved from target drones and reconnaissance aircraft to sophisticated, multifunctional systems capable of executing a wide range of complex military operations (Fan, p. 204).

Since the early 1990s, next-generation UAVs have been widely deployed in conflicts and wars, performing various missions, including reconnaissance, firepower engagement, electronic countermeasures, communication support, and logistics transport. The “*unmanned*” characteristic of these systems is gradually becoming a core component in the development of modern weaponry and their practical use on the battlefield (Ib.).

To ensure that military forces possess the capabilities necessary to successfully complete missions and address future challenges, decades of military research have focused on improving team and equipment efficiency. The military, alongside the aviation community, has been a leader in advancing research on team dynamics and performance, shaping the development of “*team science*” (Goodwin, 2018, p. 331).

Defining events, such as the 2001 terrorist attacks, catalysed the development of combat capabilities for unconventional, dynamic, and unpredictable environments. These efforts have ranged from developing specific tools for assembling military support teams to substantial investments in team training technologies (Ib., p. 328). Technological advancements have created new arenas for military competition, such as cyberspace, fostered a reliance on information superiority as a strategic advantage, and introduced robots and AI-based software systems into decision-making and combat environments.

A relevant example is the TADMUS (Tactical Decision Making Under Stress) program, which systematically explored the dynamics of decision-making teams under stress, driving research in both military and non-military domains (Ib.). Today, the use of drones in military conflicts, such as the war in Ukraine, has redefined warfare tactics, offering critical advantages in surveillance, precision strikes, rapid response, and integration into complex information networks, while also reducing the risks and costs associated with traditional military operations (Barbu, 2024, p. 10).

While the commercial sector explores the concept of the metaverse, synthetic environments used by military forces worldwide allow for complex military training

in a controlled setting. These environments, integrated with technologies such as artificial intelligence (AI), augmented reality (AR), and simulation, provide realistic and effective training for armed forces. Additionally, secure cloud infrastructure ensures the protection of sensitive data and information, which is essential in the context of military training (Jungck, 2023, p. 1).

At the national level, research programs aim to develop and implement new standards for interoperability and cybersecurity. In this regard, the lack of technological know-how among developers can have serious implications for the cybersecurity of these systems (Veveřa, 2018, p. 72). In the case of UAVs, addressing cyber risks has led to digital solutions such as platforms that ensure the transmission of critical data through public telecommunications networks, the cloud storage of sensitive information, and segregated data access using immutable Blockchain technologies and military-grade encryption (DIGITALI, 2023, p. 1).

In conclusion, the use of UAVs in military operations is becoming increasingly flexible and dynamic, supported by multidimensional platforms that operate simultaneously across land, sea, air, and space. New tactics and combat methods are emerging, such as the coordinated operation of “manned and unmanned aircraft” and “drone swarms”, enhancing the combat capabilities of entire systems (Fan, 2020, p. 204). For instance, the HADRON project aims to facilitate UAV operations by ensuring scalability and incorporating artificial intelligence algorithms to reduce the workload on operators, allowing them to focus more on supervisory roles (Casado Fauli, 2024, p. 4).

However, military revolutions require more than just the widespread adoption of new technologies. Armed forces must develop new operational concepts, integrate technological capabilities into complex military systems, and adapt their organizational culture and structure to these developments. A true revolution in military affairs involves not only technological innovations but also a doctrinal component tailored to the new realities of the battlefield (Barbu, 2024, p. 10).

### The Metaverse in Industry 5.0: A Human-Centred Approach

The metaverse is currently regarded as an inevitable trend in the process of social informatization and virtualization, representing the final stage of the Internet’s development. Concepts such as virtual reality (VR), augmented reality (AR), mixed reality (MR), and extended reality (XR) together shape the framework for the new era of interactions between the digital and real worlds (Tang, 2024, p. 2). The “Fourth Industrial Revolution”, which began in 2012, and its transition to Industry 5.0, is characterized by the digital transformation of organizations, driven by machine-to-machine collaboration, connectivity, and digital enablers such

as the Internet of Things (IoT), Big Data, intelligent systems, cloud computing, virtualization, collaborative robotics, and artificial intelligence (Moraru, 2024, p. 192).

However, this transition also brings emerging risks, creating opportunities for proactive research in security science. By merging the real and virtual realms, the metaverse offers enormous potential to revolutionize not only the industrial sector but also services, enabling personalized experiences and improving operational efficiency. The seamless synergy between Industry 5.0’s human-centred principles and the metaverse’s ability to deliver personalized value establishes a solid foundation for future technological development (Mourtzis, 2023, p. 1110).

The COVID-19 pandemic accelerated the shift of life and work towards digital spaces, reinforcing the metaverse’s role in reshaping professional and social interactions. These virtual worlds allow users – represented by avatars – to interact with each other, create, and consume content in immersive, scalable, synchronized, and persistent environments (Weinberger, 2022, p. 1). The integration of emerging technologies, such as brain-computer interfaces (BCIs), into the metaverse promises to seamlessly fuse virtual experiences with human cognitive capabilities, enabling far more complex and personalized interactions (Mourtzis, p. 1107).

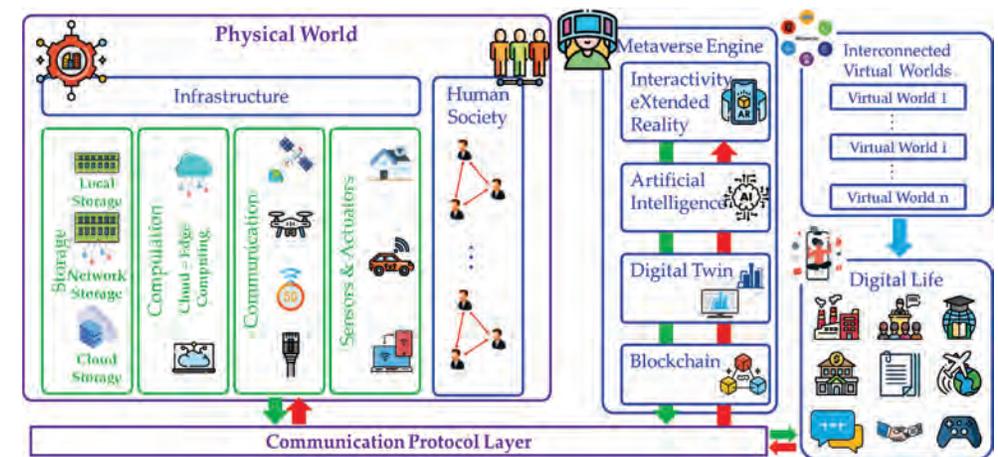


Figure 1: Technical architecture for the Industrial Metaverse (Mourtzis, 2023)

The convergence of the metaverse with advanced brain-computer interfaces (BCIs) promises to seamlessly merge virtual experiences with users’ cognitive abilities. By detecting and translating brain activity into computer-readable commands, brain-computer interfaces have the potential to radically transform how people interact with technology. Although still in its early stages of development, this technology shows promise, offering unlimited opportunities for application in various fields, including healthcare and education (Ib.).

To ensure the sustainable development and widespread adoption of these technologies, the metaverse must consistently prioritize user experience, protect fundamental rights, and proactively address the ethical and security challenges associated with these virtual environments (Ib.). Such an approach will be essential in building a secure and inclusive digital ecosystem capable of improving human interactions and preventing potential risks related to data protection and privacy.

At the same time, the metaverse provides an ideal framework for researching and testing artificial intelligence (AI) algorithms applied to drones, thereby accelerating technological progress and its applicability in the real world. Recent projects, such as DARPA's Fast Lightweight Autonomy (FLA) and the European Research Council's Agile Flight, reflect the accelerated race to develop and integrate artificial intelligence into the construction of fully autonomous drones (Hanover, 2024, p. 17). Despite significant technological advancements, considerable challenges remain, including the gap between the performance of drones in controlled environments and their applications in the real world. Issues such as operational safety, task generalization, and adaptability to various flight environments require innovative solutions and in-depth research to enable a seamless transition of autonomous drones into commercial and military applications (Ib.).

While autonomous drones have demonstrated performance exceeding human capabilities in controlled conditions, developers face the need to find trade-offs between safety and performance, especially in the case of agile flight. In this context, accelerating the development of the production industry for advanced UAV systems will continue to facilitate innovation in emerging technological applications, such as aerospace manufacturing, the widespread use of artificial intelligence, communication networks, and advanced materials (Fan, p. 204).

As these technologies become increasingly integrated into Industry 5.0, they will not only transform manufacturing and logistics but will also open up new opportunities for innovation in the mid and high-value chain, thus facilitating a transition to intelligent, efficient, and human-centred production.

### ***Disruptive Technologies and Emerging Trends in UAV Research***

A recent analysis of UAV research trends from 2020 to 2023 has revealed a significant focus on developing sophisticated artificial intelligence (AI) tools capable of enhancing UAV performance in various domains, such as object detection, optimal trajectory planning, and autonomous mission execution. Emerging technologies identified include the Internet of Things (IoT, 4%), deep learning (DL, 8%), machine learning (ML, 4%), and reinforcement learning (RL, 3%), which open up new possibilities for the development of autonomous and intelligent

systems (Telli, 2023, p. 5). These trends indicate a significant transformative potential of UAV technologies, with applications in numerous fields, but also with significant challenges related to the complexity and security of these systems.

As UAVs become more robust and are used for an ever-wider range of purposes, the airspace is becoming increasingly congested. In this context, artificial intelligence plays a crucial role in integrating manned and unmanned aircraft, facilitating the safe sharing of airspace among users and the advanced implementation of U-space services, in accordance with European standards (EASA, 2024, p. 1). This integration is essential to ensure efficient air traffic management in an increasingly complex and competitive environment.

However, the implementation of new technologies is not without risks and challenges. Machine learning systems raise issues related to operational complexity and cybersecurity, and the ethical implications of using these technologies in military or civilian contexts require special attention. To guarantee the reliability and robustness of AI systems in these domains, a hybrid approach combining machine learning (ML, DL) models with logical and knowledge-based models is recommended. This type of hybrid AI would allow for the exploitation of both data and human expertise, ensuring a better understanding of system behaviour and increasing the level of confidence in the decisions made by these systems (EASA, 2023, pp. 6-19).

In this direction, explainable AI (XAI) has become a critical area of research, addressing the need for transparency and understanding in automated decision-making processes. AI systems that use deep learning (DL) methods rely on multi-layer neural networks to solve complex problems such as object classification or autonomous driving. The role of explainability is to provide clarity on how AI arrives at certain decisions, which improves the integration of these technologies into airborne combat systems, facilitating more informed tactical decisions and progress in combat strategy (Saldiran, 2024, p. 2).

The explainability of these systems is essential to build trust among pilots and UAV operators in the decisions made by autonomous or semi-autonomous drones. This trust is crucial for pilots to be able to focus on more complex tasks and make superior strategic decisions. Explainability allows users to build more detailed mental models of AI operation, thus improving human-AI collaboration and facilitating the use of autonomous drones in complex combat environments (Ib., p. 1).

In the long term, it is estimated that neural networks will replace every stage of the UAV navigation flow, similar to what has been observed in computer vision and natural language processing. This progress will require substantial innovations,

including efficient computing architectures, pre-training strategies, and rapid adaptation to unforeseen conditions (Hanover, 2024, p. 18). In this context, flight simulators have become an essential tool for training UAV pilots and testing autonomous drone control algorithms.

Today, photorealistic simulations, such as AirSim, FlightGoggles, and Flightmare, represent advanced technologies that have accelerated research in the field of autonomous flight and allow for the testing of complex scenarios in a safe and controlled environment (Ib., p. 13). AI-based simulations use techniques such as deep learning (DL) and reinforcement learning (RL), which allow them to accurately model drone behaviour in unforeseen and diverse situations. These technologies play a central role in the development of fully autonomous drones, being essential for optimizing their performance and safety (Amarasooriya, 2024, p. 127).

In an effort to improve control interfaces for UAVs, innovative technologies such as touchscreens, gesture-based control, voice recognition, and augmented reality (AR) have been explored. These solutions contribute to improving user interaction with the drone and increasing situational awareness, thus increasing operational efficiency (Casado Fauli, p. 4).

At the same time, the exponential evolution of the field of artificial intelligence has led to the development of advanced research programs that investigate the applicability of computer vision in controlling autonomous drones. For example, brain-computer interface (BCI) technologies are testing alternative ways of controlling drones, allowing operators to control UAVs through commands generated directly from brain activity. Recent tests have demonstrated an accuracy of 95.5% in controlling a quadcopter, but this technology has not yet been widely adopted (Dumitrescu, 202, p. 1).

Multidisciplinary technologies will continue to be integrated into UAV applications, and disruptive innovations will generate new solutions for current and future challenges. Ultimately, it is essential to establish clear rules for UAV operation, including for swarms of autonomous drones, to ensure operational safety and security (Telli, p. 33). These aspects are fundamental for the safe and responsible use of autonomous drones, as well as for protecting users and airspace.

**Unmanned Aerial Vehicles (UAVs): Occupational Safety and Health Implications, Emerging Risks and Research Gaps**

The continuous introduction of new technologies and work tools generates new risks for the health and safety of workers. Therefore, OSH risk assessment must be a dynamic and adaptive process, in accordance with legislative regulations (EU-OSHA, 2021, p. 1). EU-OSHA's prospective studies play a crucial role in anticipating

these risks and promoting a culture of prevention. Thus, the specific training programs will address the achievement of the different required qualification levels of the drone pilots depending on the type of drone, the autonomy level of the drones, varied and optimized for the use case of the drone (Casado Fauli, p. 1).

Research priorities are dynamic. Privacy, security and acceptance were the main concerns, although their dominance is declining. Also, understanding the social impact of drones, particularly in terms of human interactions and regulatory issues, is a key problem. Research gaps reported in the UAV literature are mainly related to organizational/management aspects and are closely related to risk minimization (Sequeira, pp. 11-13).

Figure 2 summarizes the main research as arising from the currently envisaged applications for UAVs and the associated concerns.

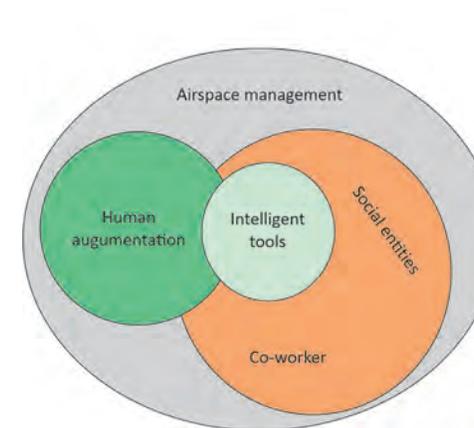


Figure 2: Research gaps in the field of UAVs

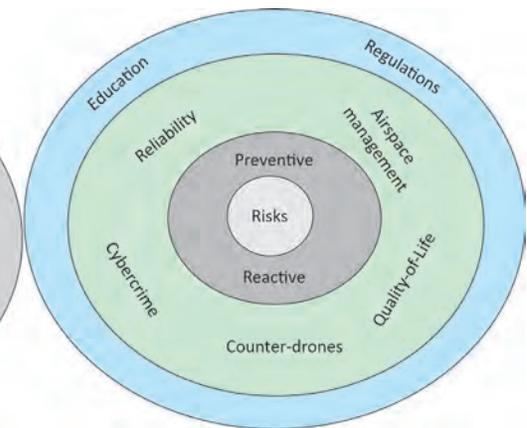


Figure 3: UAVs-associated risk management

(Sequeira, 2023)

Risks in the UAV field are commonly identified as: drone pilot/audience injury (physical to psychological); breach of confidentiality; generating liability, creating general property damage, including the UAV itself. These risks are not independent and their management must take into account several factors (Sequeira, pp. 11-13).

Since the metaverse is generally described as a space constituted by XR (VR, AR) technologies, the worker safety and health risks identified within XR also apply to those associated with the metaverse. Thus, the need to learn new skills and interact with new equipment, to reduce physical interactions, as well as the isolation and risks of interacting with and between avatars, have the potential to cause stress and are identified as psychosocial risks (Grassini, 2024, p. 1). Potential pathogen contamination of the equipment worn by the VR user (HMDs) is identified

with biological hazards. Ethical-legal risks refer to the new and unregulated nature of technology, the ethical implications of digital interactions, and the technical characteristics of technology that make them prone to privacy violations (EU OSHA, 2024, pp. 1-3,7-8).

### FUTURE RESEARCH DIRECTIONS

The new paradigm of training unmanned aerial vehicle (UAV) pilots is not merely an extension of existing aviation practices but defines a distinct discipline that requires a detailed understanding of technological complexities, regulatory frameworks, and the impact of the training process on occupational health. Advanced simulators (Amarasooriya, p. 127), combined with synthetic environments and augmented reality, offer training solutions with unprecedented levels of immersion and interactivity, preparing operators for the challenges of future airspace and ensuring operational excellence (Wiegand, 2023, p. 1).

Although UAV pilots frequently adopt safety practices, the hazards associated with using unmanned aerial vehicles during training and operations remain insufficiently documented in the literature, necessitating further research (Rahmani, 2023, pp. 63-64). In this context, a dynamic review of safety standards and procedures is needed to keep pace with new technological and operational challenges.

The current study does not aim to provide an exhaustive action plan but highlights the need for an approach based on concrete data and the reform of occupational safety and health policies. The use of the PRISMA methodology to filter the available literature clearly demonstrates the need for proactive risk management associated with these evolving technologies.

Future research directions should focus on evaluating the current tools used to analyse the effects of virtual environments on UAV pilots, investigating best practices in recruitment and training, and examining the ethical challenges associated with the use of human-UAV interfaces and intelligent technologies.

The technological challenges posed by new interfaces and autonomous systems must also be explored to ensure the safe and efficient integration of UAVs into various fields of activity. Future research will need to address in particular the risks to occupational health and safety in this context of rapid development of disruptive technologies.

### CONCLUSIONS

This paper identifies significant gaps in the existing literature, particularly regarding the occupational safety and health of unmanned aerial vehicle (UAV) pilots. The original contribution consists of a critical synthesis of the existing literature, identifying weaknesses and the need to develop risk assessment tools integrated into UAV platforms, as well as educational models based on augmented (AR) and virtual reality (VR) simulations. These models can be used to train pilots in a safe and efficient manner.

The analysis highlights the lack of empirical studies on emerging risks associated with UAV operation and underlines the importance of integrating emerging technologies into the training process to mitigate these risks. This approach provides a solid foundation for formulating policies and recommendations aimed at improving occupational safety and contributing to the creation of a robust regulatory framework.

As aviation training technology evolves, the training of UAV pilots faces a unique set of challenges, particularly regarding regulatory aspects, technological advancements, and operational risk management. The rapid pace of innovation often outpaces the development of standardized training protocols. In addition, public perception of unmanned aerial vehicles use and the social responsibility of operators play a crucial role in establishing an ethical framework for these technologies.

Digital transformation should not be analysed solely in terms of increased productivity but also in terms of new professional roles and the need for continuous learning. Emerging technologies such as IoT, Big Data, cloud computing, unmanned aerial vehicles, and the metaverse redefine the interactivity between the human factor and technology in environments characterized by volatility, uncertainty, complexity, and ambiguity (VUCA). The incorporation of digitalization opens new opportunities for innovation and optimization, providing solutions for preventing occupational risks and improving safety and health in complex environments.

### BIBLIOGRAPHY:

1. Achimowicz, J.Z. (2024). *Autonomic Drones with Quantum Computing Artificial Intelligence?* DOI: 10.13140/RG.2.2.12642.71364, retrieved on 22 August 2024.
2. Amarasooriya, S. (2024). *Mathematical and Machine Learning Based Methods for UAV Simulation: A Systematic Literature Review*, <https://doi.org/10.5281/zenodo.1108448>, retrieved on 5 August 2024.
3. Badea, L. (2023). *Tehnici avansate de Inteligență Artificială în știință și domenii aplicative*, <https://ici.ro/ro/proiecte-in-derulare/program-nucleu-future-tech-2023-2026/>, retrieved on 20 August 2024.

4. Barbu, F.M. (2024), <https://gmr.mapn.ro/webroot/fileslib/upload/files/arhiva%20GMR/2024/2/BARBU.pdf>, retrieved on 6 August 2024.
5. Botezatu, U.E. (2024). *Cyber Orbits: The Digital Revolution of Space* (Security National Security in the Digital and Information Age, Sally Burt editor, on-line), <https://www.intechopen.com/online-first/1175598>, p. 6, DOI: 10.5772/intechopen.1005235, retrieved on 1 October 2024.
6. Casado Fauli, A.M (2024). *HADRON: Human-friendly Control and Artificial Intelligence for Military Drone Operations*, <https://arxiv.org/html/2408.07063v1>, retrieved on 21 August 2024.
7. Christenko, A. (2022). European Agency for Health and Safety at Work. Artificial intelligence for worker management: risks and opportunities, [https://osha.europa.eu/sites/default/files/documents/ai-worker-management\\_en.pdf](https://osha.europa.eu/sites/default/files/documents/ai-worker-management_en.pdf), retrieved on 5 August 2024.
8. DIGITALI (2023), <https://digitalio.ro/2023/10/30/oves-enterprise-lanseaza-o-platforma-de-secu-ritate-pentru-retele-de-drone-si-avioane-bazata-pe-blockchain-si-ai/>, retrieved on 5 August 2024.
9. Dumitrescu, C. (2021). *Using Brain-Computer Interface to Control a Virtual Drone Using Non-Invasive Motor Imagery and Machine Learning*, retrieved on 21 August 2024.
10. EASA (2023). *Artificial Intelligence Roadmap 2.0 Human-centric approach to AI in aviation*, European Union Aviation Safety Agency, <https://www.easa.europa.eu/en/document-library/general-publications/easa-artificial-intelligence-roadmap-0#:~:text=The%20EASA%20Artificial%20Intelligence%20Roadmap,deliverables%20and%20anticipated%20rulemaking%20activities>, retrieved on 22 August 2024.
11. EASA (2024). Artificial Intelligence and Aviation, europa.eu, retrieved on 7 August 2024.
12. EU OSHA (2021-2027). *EU Strategic Framework on Health and Safety at Work*, <https://osha.europa.eu/ro/safety-and-health-legislation/eu-strategic-framework-health-and-safety-work-2021-2027>, retrieved on 21 August 2024.
13. Eibin, M. (2021). *Survey of RPAS Autonomous Control Systems Using Artificial Intelligence*, IEEE Access.
14. Fan, B. (March 2020). *Review on the Technological Development and Application of UAV Systems*. In *Chinese Journal of Electronics*, vol. 29, no. 2.
15. Gaurav, S. (2018). *Unmanned aerial vehicle classification, applications and challenges: A review*. Preprints v1, <https://doi.org/10.20944/preprints201811.0601>, retrieved on 22 August 2024.
16. Goodwin, G.F. (2018). *The Science of Teams in the Military: Contributions from over 60 Years of Research* (In the public domain), vol. 73, no. 4, pp. 322-333. American Psychological Association, <http://dx.doi.org/10.1037/amp000025>, retrieved on 5 August 2024.
17. Grassini, S. (2024). *Worker exposure to virtual and augmented reality and metaverse technologies: how much do we know?*, EU OSHA, [https://osha.europa.eu/sites/default/files/documents/worker-exposure-virtual-reality\\_discussion\\_paper\\_EN.pdf](https://osha.europa.eu/sites/default/files/documents/worker-exposure-virtual-reality_discussion_paper_EN.pdf), retrieved on 4 August 2024.
18. Hanover, D. (2024). *Autonomous Drone Racing: A Survey*, IEEE, <https://ardupilot.org/>, <https://px4.io/>, retrieved on 22 July 2024.
19. Jungck, P. (2023), <https://www.baesystems.com/en-us/feature/the-future-of-military-training-synthetic-environments-and-the-military-metaverse>, retrieved on 11 August 2024.
20. Kim, J. (2022). *Bridging Human Intelligence and Artificial Intelligence. Augmented Intelligence: Enhancing Human Decision Making*, pp. 151-170. Springer.
21. Moraru, R.I. (2024). *Challenges and opportunities in occupational health and safety digitalization*, in *Digital Transformation*, Series: Intelligent Systems Reference Library, Booksubtitle: Technology, Tools, and Studies, pp. 189-213, editors Lucian-Ionel Cioca, Larisa Ivașcu, Florin Gheorghe Filip, Doina Banciu; SPRINGER Publishing House, eBook ISBN: 978-3-031-55952-5; ISSN: 1868-4394, Hardcover ISBN: 978-3-031-55951-8, <https://doi.org/10.1007/978-3-031-55952-5>, retrieved on 22 August 2024.
22. Mourtzis, D. (2023). *The Metaverse in Industry 5.0: A Human-Centric Approach towards Personalized Value Creation*, <https://doi.org/10.3390/encyclopedia3030080>, retrieved on 2 August 2024.
23. NIOSH (2024). *Robotics in the Workplace: An Overview*, <https://www.cdc.gov/niosh/robotics/about/>, retrieved on 22 August 2024.
24. Rahmani, H. (2023). *Working under the Shadow of Drones: Investigating Occupational Safety Hazards among Commercial Drone Pilots*, DOI:10.1080/24725838.2023.2251009, retrieved on 22 August 2024.
25. Rao, A.S. (2017). *Sizing the prize – What’s the real value of AI for your business and how can you capitalise?*, <https://www.pwc.com/gx/en/issues/analytics/assets/pwc-ai-analysis-sizing-the-prize-report.pdf>, retrieved on 5 August 2024.
26. Rosen, P.H. (2022). *Artificial intelligence, advanced robotics and the automation of tasks at work: taxonomy, policies and strategies in Europe*, [https://osha.europa.eu/sites/default/files/AI-based-systems\\_EN.pdf](https://osha.europa.eu/sites/default/files/AI-based-systems_EN.pdf), retrieved on 22 June 2024.
27. Saldiran, E. (2024). *Towards Global Explainability of Artificial Intelligence Agent Tactics in Close Air Combat*, <https://doi.org/10.3390/aerospace11060415>, retrieved on 22 August 2024.
28. Sequeira, J.S. (2023). *Unmanned aerial vehicles: implications for occupational safety and health*, [https://osha.europa.eu/sites/default/files/Unnamed-aerial-vehicles-and-OSH\\_en.pdf](https://osha.europa.eu/sites/default/files/Unnamed-aerial-vehicles-and-OSH_en.pdf), EU-OSHA, retrieved on 22 August 2024.
29. Tang, Y. (2024). *The application of metaverse in occupational health*, doi: 10.3389/fpubh.2024.1396878, retrieved on 5 August 2024.
30. Telli, K. (2023). *A Comprehensive Review of Recent Research Trends on Unmanned Aerial Vehicles (UAVs)*, <https://doi.org/10.3390/systems11080400>, retrieved on 22 August 2024.
31. Vevera, A.V. (2018). *Factorul uman vs. securitatea cibernetică/Human resource vs. cybersecurity*, doi: 10.13140/RG.2.2.28728.62722, retrieved on 22 August 2024.
32. Vevera, A.V. (2023). *Sisteme de comunicație reziliente și interoperabile bazate pe tehnologii distribuite și identitate digitală auto-suverană (RoDID)*, <https://ici.ro/ro/proiecte-in-derulare/program-nucleu-future-tech-2023-2026/>, retrieved on 5 August 2024.
33. Weinberger, M. (2022). *What is Metaverse? A Definition Based on Qualitative Meta-Synthesis*, <https://doi.org/10.3390/fi14110310>, retrieved on 22 August 2024.
34. Wiegand R. (2023), <https://www.baesystems.com/en/project-odyssey-to-form-backbone-of-new-military-training-collaboration>, retrieved on 27 August 2024. [
35. Williams, K.W. (2023). *Air Carrier Operations Survey: Training Requirements*, pp. 6. 24, 25; FFA, DOT/FAA/AM-23/09, Aviation Safety, Office of Aerospace Medicine, Washington, D.C. 20591, [https://www.faa.gov/data\\_research/research/med\\_humanfacs/oamtechreports/media/UAS%20Air%20Carrier%20Operations%20Survey-Training%20Requirements\\_0\\_0.pdf](https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/media/UAS%20Air%20Carrier%20Operations%20Survey-Training%20Requirements_0_0.pdf), retrieved on 4 August 2024.