European Agency
for Safety and Health
at Work

DISCUSSION
PAPER

Unmanned Aerial Vehicles and OSH

Review Article (OSHA/2022/VLVP/0019)

Abstract

This document reviews the current panorama on Unmanned Autonomous Vehicles (UAVs, also commonly named *drones*) and discusses the implications of their growing use on the safety and health of workers and the public in general. The distinctive motion capabilities of UAVs, namely being able (i) to move in the 3D space inhabited by humans, and (ii) to move at high velocities, represent opportunities for novel applications but also raise important concerns directly related to OSH, e.g., safety, privacy, and liability.

Foreseeable UAV applications can be potentially disruptive, requiring significant societal transformations, namely in terms of the necessary legislation, but also in new emerging risks. In the occupational context, it is seen as very important to adopt a worker-centric approach in the development of systems including drones. The paper highlights recommendations for stakeholders, centred on the workers, namely, (i) the importance of adequate interaction strategies between humans and UAVs, including the creation of specific interaction languages for non-expert workers to communicate with UAVs, and (ii) the need to have workers (and stakeholders in general) undergo an extensive training on how to interact with UAVs at work and raising awareness to prevent risks, e.g., on novel (potentially disruptive), UAV-enabled, social rules.

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Introduction

The current blossoming of Unmanned Aerial Vehicles (UAV) is generating a plethora of exciting applications in the civil domain. In the military domain many of these are already known and managed. However, either controlled by humans or operating in fully autonomous mode, using the same technology for every-day use can lead to new problems emerging next to profound societal transformations.

UAVs[1] are a class of devices including multirotor drones, as well as single rotor and fixed wing devices, hybrid versions, and, potentially, other alternative propulsion systems. The common characteristic of these devices is that they are all able to move, with or without a load of some type, in the same (work)space inhabited by humans. In a simplistic view, UAVs are robots that can fly. From all UAV types, drones are, unquestionably, the fastest growing class (both in sheer numbers and capabilities). Therefore, the term is often used for the full class of UAVs. As of May 2022, the FAA[2] acknowledged 865K registered drones in the USA, including commercial and recreational, with an estimated annual increase of approximately 6.4%. In Europe, the annual increase is estimated between 5.3% and 6.3%, with an acceleration trend (from data available in Molina & Oña, (2017)). In both markets, military applications represent the biggest value.

The engineering simplicity of multirotor drones, the main UAV category, has been a key factor in their massification. In simple terms, they are a collection of electric motors and propellers, connected through rigid bodies, able to carry a variety of loads, including cameras and other sensors (see Figure 1. Nowadays, these devices are widely commercially available at a range of prices affordable to the general public.

Figure 1: UAV typologies. A four-rotor drone on the left (the load is visible in the underside of the drone – www.publicdomainpictures.net). A fixed wing UAV is sown in the right image (Wikimedia Commons).

Single rotor and fixed wing UAVs, though relevant, have not experienced a growth close to that of multirotor UAVs. Building a basic drone is nowadays a task that can be carried out by anyone with basic skills. Moreover, it can be a highly educational activity, e.g., motivating young people to learn STEM[3] topics. This document focus on this class of UAVs, the multirotor drone, though most, if not all, the conclusions are also applicable to generic UAVs.

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[1] Unmanned Aerial Vehicles can be fully autonomous or have some form of external control, e.g., a human pilot. More generally, Unmanned Aerial Systems, or UAS, is also a common terminology for this global class of devices when including ground controller, possibly a human, and the communications link between them, i.e., the full infrastructure.

[2] US Federal Aviation Administration.

[3] STEM is an acronym often used for Science, Technology, Engineering, and Mathematics.

UAVs are easily perceived as devices that can move stably in the common 3D space. This single characteristic qualifies them for a variety of tasks, ranging from inspection or monitoring to targeted positioning due to their ability to navigate along precise routes. Current propulsion systems, mostly based on propellers, bring the need to impose physical contact limitations (even when safeguarding devices are used), i.e., avoiding any contact between propellers and people or any other surface. The perception of danger in people standing in the proximity of an active UAV is often amplified by propellers rotating at high speeds and enabling the UAV to make complex manoeuvres. This naturally raises safety concerns.

The increase in the use of UAVs is strongly linked to economics. Whether as recreational or professional devices, their low cost is a strong incentive for people and employers to use drones. Their versatility is creating expectations of efficiency improvements, both economic and technological. However, human factors may disturb the value chains, e.g., poor acceptance of UAVs by workers due to increased stress levels may lead to productivity issues, and hence it is fundamental to understand how to manage these links.

Integrating UAVs in working environments can be done (i) as intelligent tools, with regulated operational conditions known to everyone involved, or (ii) as working colleagues/mates, where UAVs and workers are required to, somehow, interact with each other. In either case, people's perceptions of the technologies and their utility and usefulness may create biases. Though rotating propellers may induce a perception of danger and hamper the integration of UAVs in working environments, careful communication among stakeholders can help reducing fears and clarify liability sources. With good communication UAVs can be presented as devices to augment workers' skills and create pathways for acceptance while minimizing safety and privacy risks.

An overview of the UAV field

Typologies and applications

Roughly, a UAV encompasses the physical design (airframe and other hardware) and the software systems to control the hardware, supervise task executions, and communicate with remote entities. Commonly classified as military, commercial, and hobby devices, UAVs have reached an evolution stage where most of such architectural aspects are well understood (see for instance Petrioli *et al*, 2018, fig 3). Physical designs of UAVs can be roughly classified as **(i) fixed wing, e.g., aircraft-like, (ii) single rotor, e.g., helicopter structure, (iii) multi-rotor, and (iv) hybrid fixed-wing-rotor-based** (Wich & Koh, 2018). Size based classification is also used, as **mini, nano, and large UAVs**. **Hovering capability** is a distinctive characteristic of multi-rotors, enabling pick-and-place and sensoring tasks (as in consumer deliveries or aerial photography). Regarding autonomy, (Sholes, 2007) presented a taxonomy with 10 **autonomy levels** for UAVs. Though targeting the military context, this taxonomy is applicable to UAVs operating in other generic scenarios.

The diversity of physical configurations (either lab-based or commercial off-the-shelf) is vast. Combining simulated and real elements, e.g., simulating the physical structure of the UAVs and combining it with the real software systems has been discussed as a mean to accelerate development stages, (Day *et al*, 2015). From the simple designs to the more sophisticated ones, nowadays the range of development tools available contributes to the massification of UAVs.

Thrust redundancy is a relevant feature when minimizing the probability of hardware failures, i.e., even if one engine fails the remaining ones can still ensure a stable flight. Dyer *et al*, (2019), presented a UAV with eight propellers which was able to explore this redundancy. Such redundant arrangements of rotors improve manoeuvrability and safety. Reconfigurable airframes, i.e., where the physical aspect can be adjusted during flight, have also been proposed to mitigate structure problems occurring in-flight, (Derrouaoui *et al*, 2021). Hybrid propulsion, combining internal combustion engines and electric motors has been addressed to account for **energy concerns**, (Yezeguelian & Isikveren, 2020).

Hardware control, mission supervision, safety, fault-tolerance, and communications are key elements of a UAV that are managed by the onboard software. These are systems some authors argue that need to evolve to suit advanced autonomy (see Mejias *et al*, (2021).

In terms of **application scenarios**, the following have been often referred to in the literature. The list is non-exhaustive and, as the UAVs expand their capabilities, the trend is for the scenarios to increase.

1. Military, in defensive and offensive tasks as covered by defence industries.
2. Reach dangerous and hard-to-reach places, e.g., areas of dangerous pollutants or nuclear contamination.
3. Disaster response, e.g., acquiring real-time information in regions affected by earthquakes.
4. Monitor construction progress and maintenance of large structures, e.g., mapping the structures, and visual inspection.
5. Survey power lines and wind turbines, searching for damaged wires in conductors or defects in turbine blades.
6. Surveillance wildlife, e.g., tracking endangered species.
7. Observe road traffic patterns and aerial photography mapping.
8. Wildfires scouting and assistance, namely early detection and progression monitoring in difficult areas.
9. Media and entertainment, e.g., aerial photography and video, and drone formations in exhibitions.
10. Parts handling and delivery, namely inside warehouses.
11. Restaurant waitressing, i.e., delivering customers' orders at restaurant tables.
12. Pipeline inspection, e.g., detecting corrosion areas and leaks.
13. Law enforcement, e.g., providing long range distributed vision of operational scenarios to police officers.
14. Farming and precision agriculture, pollination, precision application of pesticides, surveying livestock and cultivated fields, and monitoring illegal logging.
15. Social activities, e.g., assistance to people, and monitoring for healthcare emergencies (see Figure 2).

Figure 2: A MEDcopter X4 drone in Beyond Line of Sight (BVLOS) operations in India (Wikimedia Commons)

As can be seen from the above list, UAVs are, essentially, logistics (transportation), surveillance, and monitoring/inspection devices. A variety of **loads** can be installed onboard, **including sensors and tools** to physically interact with the environment, e.g., grabbing some part or pushing a button.

Most of these applications are driven by some type of economic value (an estimated €10 billion per year impact and 100K direct jobs, according to the survey of the European panorama reported in

SESAR, 2016). Currently, **benefits for humans, for example worker safety, are mostly a by-product of the economic value chain, and not an objective *per se***.

The good news is that social roles are on the rise in Robotics (see for instance Giansanti, 2021, for a range of social areas), and are also more and more related to UAVs. For example, in the field of healthcare, drones are often used for logistics (see for instance Bhattacharya *et al*, 2020). Social care is becoming challenging and highly resource intensive, (Savage, 2022) and, moreover, and the increasing aging population is creating difficulties finding skilled workers. Directly assisting people through robots, namely UAVs, requires a high degree of autonomy and is likely to remain a long-term goal. The Wizard-of-Oz concept[4], common in social robotics experiments, (Steinfeld *et al*, 2009), where a remote operator can, whenever necessary, control the robot and compensate for limitations in its social skills, can be used to mitigate the lack of intelligence/autonomy and humanize the behaviour of UAVs operating in social environments.

Applications in other areas, such as in agriculture, include precision farming, classification and crops scouting, biomass estimation, wildlife and forestry monitoring, and water stress assessment, among others, (Rejeb *et al*, 2022). In the construction industry, monitoring sites in real time, contributing to increasing safety, mapping sites gathering elevation and volumetric data or simply taking aerial photos and marketing real estate are becoming regular activities (Mahajan, 2021). The increase in performance of drones is also making possible the execution of technical activities, e.g., tightening bolts or moving large metal pieces, (Mishra, 2019).

European projects

Multiple European projects addressed some of the applications listed above. The selection below, though not being exhaustive, shows a trend of favouring the economics value chain.

- The RAPID project (rapid2020.eu) addressed inspection and maintenance in ports and inspection of ship hulls, with projected economic and worker's safety gains.
- Project AW-Drones (aw-drones.eu, 2019-2021) aimed at harmonising standards for drones to improve the safety of drone usage.
- Project DroneWise (dronewise-project.eu) aimed at increasing the cooperation and coordination of first responder organizations to handle the aftermath of UAV based terrorist attacks.
- Project ALLADIN (alladin2020.eu) studied the neutralization of suspicious/rogue light UAVs flying over restricted areas.
- Project Drones4Safety (drones4safety.eu) aimed at developing a team of collaborative drone for inspection of large transportation infrastructures in continuous operation.
- Project Harmony (harmony-h2020.eu) addressed the sustainable mobility in urban transport solutions, including drones to collect data from citizens and freight operators in traditional transportation systems.
- Project labyrinth2020 (labirynth2020.eu) addressed the coordination of a set of drones sharing a common airspace aiming at integrating drones in the European airspace.
- Project PRESTIGIOUS (prestigiousdrones.eu) aimed at strengthening the competitiveness of European SMEs active in the field of drones by working with European clusters and SMEs to provide internationalization support.
- Project 5G!Drones (5gdrones.eu) focus on the use of drones to test the capabilities of 5G technology in a set of use cases (UAV air traffic management, public safety, situation awareness, and ensuring connectivity during crowded events).

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[4] The technique originated from the work of Kelley, (1984).

- Project SkyFall (www.projectskyfall.org) focused on identifying the best existing systems that can bring down an UAV in a controlled (safe) way.

These research projects have clearly identified the potential safety threat represented by UAVs. Unsurprisingly, **the technological issues are no longer the focus of research topics. Instead, organization and management issues and their effects in performance and safety are dominant**.

Projects outside the European sphere include, among others, flood monitoring, illegal logging (Malaysia), shark attack prevention (Australia), and rice farming (Indonesia), and city planning and reservoir inspection (Singapore, see Whalley & Yun-yuan, 2022). In the USA, commercial applications have been recognized to have a strong growth and to influence worldwide markets, (Cohn *et al*, 2017), whereas military applications also continue to have a solid growth under multiple programs (see Congressional Research Service, 2022).

Legislation

UAVs have long been recognized to require specific regulatory frameworks to ensure sustainable growth and risk minimization. In the academic perspective, this can be seen clearly from the research panorama in the previous section. In a wide societal perspective, the media have been keen to report scenarios that inspire fear. The dynamic nature of regulations regarding UAVs has been recognized, (Goldman Sachs, 2022), and, as the number of applications and UAVs in operation grows, regulations may become increasingly important and can even lead to a decrease in the risks to human life, (RHC,2021).

However, upcoming risks show the need for regulatory frameworks although the current initiatives are often seen as barriers that are slowing down the development of the field, (Pauner *et al*, 2015).

Commercial viability has been linked to the simplification of regulations and operator certification and to extending flights **beyond visual line-of-sight (BVLOS)**. Shared airspace management between manned aircraft and UAVs is being considered a fundamental step in the evolution of UAVs and associated systems. Without adequate airspace and air-traffic management, BVLOS operations may become compromised, namely as the density of UAVs sharing space with workers/people increases. Current restrictions to UAV operations in the neighbourhood of airports, prisons, nuclear sites, and others, are being claimed as excessive. Instead, there is a call for detection and avoidance technologies to be mandatory onboard UAVs. Geographic and demographic factors, operational height, the onboard existence of electronic transponders, and temporal windows for operations, have been identified as factors to be accounted for when regulating airspace and air-traffic.

Despite the identification of the relevant factors and the reliability of forecasts on UAV expansion, current regulation efforts are concentrated on specific aspects, e.g., imposing height limits for commercial UAVs, and have **not accounted for the variety of services/applications** under development.

In specific applications, such as wildlife monitoring and biodiversity conservation, Sandbrook, (2015), has been advocating self-regulation of UAV usage, at least while the effects of UAVs are not fully understood from the legal perspective. The argument is that **self-regulation is suitable in case of rapidly emerging technologies**. This can easily be expanded to most, if not all, areas where UAVs can intervene. A simplification of restrictions is also foreseen by Goldman Sachs, (2022).

The **legislation in the USA** is **non-uniform** among the states but also follows a safety and risk-based approach. Some states, e.g., South-Dakota, **prohibit drones from observing** or taking pictures of people in private places, or, in the case of Vermont, using facial recognition[5].

European regulations 2019/945 and 2019/947 (with the amendment 2022/425) have **underlying safety, security, privacy, data protection, liability, insurance, and environmental protection concerns** (see EASA, 2022, p.19). In this document we group these concerns into three classes, namely, safety, privacy, and liability. Furthermore, these are concerns transversal to most, if not all, societies/cultures and hence combining different legal frameworks may be a form to overcome any current limitations.

Safety is arguably, the most important of the three areas identified above, namely direct physical safety, involving physical contact between people and UAVs (also often termed bodily injury, Sehrawat, 2018, pp.10-11). A **broader definition of safety** may also include personal injury, e.g., accounting for damaging effects on physical safety due to invasion of a personal space.

However, **the complexity of the laws and regulations has been considered as a limiting factor** in the development of the field and, may even not address safety properly, (Calandrillo *et al*, 2020). The legislator perspective makes the risk-benefit balance lean to the risk side leading to overly restrictive regulations.

Transportation and recreational activities suggest safety restrictions on maximum flight height, flying over people, respecting no-fly zones, e.g., airports, and ensuring proper flight behaviour in scenarios with multiple UAVs. These are characteristics that must be embedded in the design of the UAVs (Clarke & Moses, 2014).

Events affecting safety derive from unintentional actions but also from intentional ones. The simplicity of building UAVs with significant flight capabilities makes them suitable for **terrorist activities**. Restrictive laws can-not fully prevent terrorist activities and the natural solution is the development of counter-UAV devices. These are commonly classified in (i) military, (ii) kinetic, and (iii) electronic jamming solutions (see Stoica *et al*, 2020, for a review of strategies based on the analysis of RF communications), and their use must also be subject to strict regulations. In addition, counter-UAV specific regulatory frameworks are also evolving (see Liu & Ziemba, 2021), e.g., addressing the privacy issues when a counter-UAV is in operation.

Regarding **privacy and data protection**, current public reports acknowledge specific concerns (see RHC, 2021) and regulations forbidding UAVs from operating in the vicinity of (loosely defined) groups of people. Given the quality of current sensors, namely cameras, these regulations are virtually useless. Moreover, **the privacy concerns for comparably invasive devices, such as smartphones**, have been practically dismissed by regulatory bodies, leaving it up to app manufacturers the onus of keeping their data safe through encryption tools. The fact that smartphones are widely accepted, even without privacy warrants, has been used as an argument to lighten/avoid regulating the UAV field. Also, public engagement has been used when addressing this topic, thus amounting to recognizing the difficulty of regulating a topic sharing different stakeholders.

Data obtained by UAVs is commonly required to be always available to anyone directly interested, namely images, and permissions granted prior data acquisition, (Sandbrook, 2015). However, this is an elusive goal. Much like images acquired through smartphones, the existing regulations may not be enough due to the rapid evolution of the field, (Comtet & Johannessen, 2022) - taking pictures with smartphones is nowadays a practice growing at a fast rate and fully encouraged by manufacturers and operators. Other authors, (Pauner *et al*, 2015), are adamant in that current EU regulations are not

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[5] See https://www.ncsl.org/

enough to ensure citizens' privacy and argue that standardization in the field of UAVs may mitigate privacy risks.

The widespread use of **AI enabled apps**[6] installed onboard UAVs, e.g., allowing the recognition of people from facial expressions, from clothes they wear or even from particular characteristics in the way they move, amplifies the effects of privacy violations. However, these apps can also contribute to safety by monitoring streets for people in distress, as when moving with an abnormal walking gait that may indicate that some accident has occurred. This is a simple example where trade-offs between privacy and safety need to be carefully constructed.

Liability is commonly associated with (i) bodily injury, (ii) property damage, (iii) personal injury, and (iv) third party liability, (Sehrawat, 2018). Applicable laws include (i) those originating from specific regulatory bodies, e.g., aviation authorities, (ii) state/national laws, (iii) trespass laws, (iv) nuisance law, and (v) negligence law.

Currently, owners/guardians/operators are the main stakeholders possibly liable in case of accidents with UAVs, (Konert & Kotliński, 2020). In fact, liability fears have been referred to as the cause for heavily restraining the use of drones, (RHC, 2021), and the existence of insurance products/services tailored to UAV systems does not contribute to the development of the field. However, the fact that there are no special regulations regarding civil liability, (Konert & Kotliński, 2020), and the lack of precise definition for key concepts, such as that of U-Space[7], adds difficulties to the development.

Training UAV operators is strongly dependent on the class of UAV. For large size UAVs, with, possibly, significant costs involved, operators may need a strong technical background in addition to adequate flight skills. For small size, recreational, UAVs, mandatory operator training may simply not be practical/feasible. In practical terms, it is akin to the use of bicycles in the city where mandatory training could hamper urban mobility.

If the UAV has no direct human operator, but instead flies autonomously, at least during some periods of time, **human mission planners** become potential liability sources. They may not have flight skills, but they must understand flight principles and plan for safe missions.

The use of safeguarding technologies to minimize liability, e.g., automatically deployed parachutes in case of failure, is still being developed. Also, defining maintenance schedules that ensure airworthiness requires knowledge from past experience and adequate monitoring equipment, which tend to be available only for service UAVs. Moreover, mission planners or operators must be aware that failing to comply with adequate maintenance may lead to liability issues (see the discussion on Australia's regulations in Vines *et al*, 2022).

In the UAV field, liability is still an open issue and it is being recognized that reliable regulatory frameworks must be developed in conjunction with technical solutions. Similarities between the current situation concerning the initial development of airplanes and cars are also being identified (Sehrawat, 2018).

Trends on Occupational Safety and Health at Work

Interaction with UAVs

Generic OSH principles have been described in a vast range of literature (see, for instance, Alli, 2008). With the increase in the use of UAVs the safety and health concerns are the *moto* defining development

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[6] Short designation meaning software application programs.

[7] Roughly, the U-Space includes the airspace and services associated.

trends. Interaction between humans and robots (and technology in general) is the main area addressing the effects of UAVs on people.

Multiple built-in failsafes is a natural strategy to increase safety of UAVs, though they may tend to increase costs and hence are applied mainly in service and military (medium/large) UAVs. Such failsafes may take multiple forms, e.g., when a UAV is perceived as flying unsafely, changing flight mode to increased autonomy has been reported to induce an increase in the perceived safety (Kong *et al*, 2018).

Poor interaction, as caused by poorly designed interfaces, e.g., a poorly defined flight control device or even poor mission planning graphical interface can easily lead to safety and/or health issues (media reports on accidents related to interface design are largely available - see for instance Pogue, 2016, Besnard & Cacitti, 2005, Fairbanks & Caplan, 2004). In the human-machine domain, **interfacing has been recognized as an emerging risk for OSH and, simultaneously, to improve health and safety**, (EU-OSHA, 2009). This apparent contradiction only highlights the importance of adequate interface and interaction design, namely as the autonomy levels of machines increase and they become ubiquitous in the social domain of humans.

Social proxemics has been recognized as playing an important role in the interaction among humans (Hall, 1966). The extension of the **human proxemics** concept to interactions between humans and drones is natural, e.g., the proximity between a UAV and people is a form of communicating, intentions and/or showing confidence/discomfort (Han & Bae, 2018).

Interfacing and how it shapes the interactions are thus at the core of OSH concerns related to UAVs. The recent developments in the fields of robotics and machine learning, enable (i) **sophisticated interfacing** between humans and machines/devices, and (ii) a **variety of autonomy modes in decision making**. Interfacing between humans and machines, or humans and computers, has already identified factors that may limit performance. Gertman & Bruemmer, (2008), identified factors such as sensation, attention, cognition, effort, utility, physiological and psychological. Dix *et al*, (2004), also included emotions in this list. For example, attention and emotional disturbances can easily lead to errors in interaction, e.g., staying too close to a flying drone and possibly leading to collisions and/or forcing the drone to contingency manoeuvres.

Smartphones are a typical example of a computer-based device with growing intelligence levels and autonomy and for which novel forms of interaction are constantly being developed by manufacturers. **OSH concerns related to smartphones** go from (i) distracting people, e.g., during car driving, and workers during critical tasks, to (ii) the alleged effects of the electromagnetic radiation emitted, and (iii) the privacy concerns and the possibility of hacking (and hence of potential severe disturbances for the owner).

UAVs simply add motion capabilities to computational devices similar to smartphones and hence the motion factor adds to OSH concerns. The “ease of use” has been reported as a relevant factor when using UAVs (see the study in Kim *et al*, 2016, on construction sites). Also, related to the use of UAVs in construction sites, Namian *et al*, (2021), point to ``distraction'' (a common human factor) as one of the main safety risks.

Although piloting through some form of interface is still the common form of having a UAV executing a task, interfacing strategies such as **gestures, speech, brain signals, and combinations of these** (multimodal interfacing), are under development, (Tezza & Andujar, 2019). Having UAVs evolving towards these bio-inspired lines has also been claimed as necessary for safety (Nonami, 2020).

Furthermore, UAVs are expected to have the possibility to **decrease workers workload**. Natural examples are the use of drones to transport goods between locations in a manufacturing environment, or monitoring large areas, thus eliminating the need for workers to physically move between places.

However, the **perceived workload may differ from the actual real one**. Moving in the 3D spaces tends **to induce cognitive loads** higher than, for example, driving a car. To induce a feeling of control in people, and hence contribute to reduce the perceived workload, UAVs must be controlled for precision, feedback, and latency, and be equipped with emergency procedures (Christ *et al*, 2016), (Tezza & Andujar, 2019), and in some situations reducing the flight capabilities may be a solution to keep the perceived workload under acceptable bounds.

Foreseeable impacts

The current trend in UAV applications considers industries and their related services of economics value in **a cost/risk-reducing logic**, i.e., the UAVs are used to reorganize the current tasks and hence generate some kind of competitive advantage. Even in applications where the apparent primary benefit is safety/security of workers, the underlying motivation still is strongly linked to optimizing the value chain. Meanwhile, workers will be required to adapt working with UAVs, as new tools allegedly bring efficiency gains.

This adaptation may come at a cost, namely, as mentioned before, that of **smoothing privacy** concerns and this should lead workers associations/unions to constructively interact with other stakeholders.

Physical and psychological security have a direct impact on the safety concerns, i.e., people are concerned with UAVs hitting them and causing physical damage or having to be in a surveillance mindset looking for UAVs in the vicinity. However, safety concerns are also known to cause delayed **impacts on health**. If a UAV causes personal property loss this can impact negatively on the health of people. Similarly, people inhabiting the workspace of UAVs may develop the perception that their physical safety is under threat and easily lead to long stress periods with potential impacts on health.

The requirement on establishing **synergies among stakeholders**, previously identified, extend to the OSH domain. Workers and employers must understand each others values and concerns.

As UAVs take over challenging tasks from humans, some jobs may become more oriented towards the supervisory side and **less challenging/motivating**. This can reduce job satisfaction and increase stress levels (HSE, 2018).

With the worldwide consistent aging of the population, the needs for **augmented social care** are becoming visible even in developed societies. A (i) chronic shortage of healthcare technicians, (ii) a wrong perception of the real costs of healthcare services, (iii) the increase in the elderly demography, and (iv) the asymmetries in the distributions of the populations, often caused by geographical and economics constraints, are factors affecting healthcare quality.

UAVs are already being considered in research literature as viable candidates for healthcare applications (Greve *et al*, 2020, Smith *et al*, 2022, Tucker, 2013) in the three areas of Figure 3.

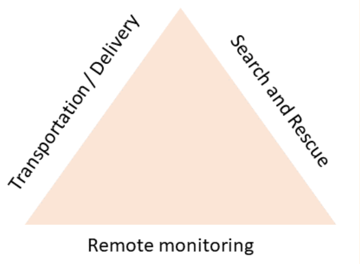

Figure 3 – Healthcare application domains for drones – As suggested by the triangle, there are neighbouring relations among these domains

Endowing UAVs with social skills, becoming truly social robots, socially assistant, with human-like interaction is likely to become a trendy application. In domestic environments, which often have a spatial organization that creates difficulties in the movement of ground-based robots, UAVs have a competitive advantage and hence this is a potentially very large market. In healthcare scenarios, whether inside hospitals or in outdoor areas, UAVs can be i**ntermediating agents** in a wide variety of tasks, as suggested by Figure 3.

The impact of the existence of such agents in workers' (and general people's) health can be huge. Common examples can be the delivery of a defibrillator to attend a cardiac arrest, possibly relaying video to remote medical staff, reaching a car accident well before medical assistance can physically reach the place or delivering vaccines to a remote area. UAVs have been recognized to improve quality-of-life by improving emergency medicine and, furthermore, they are accepted by the public (Johnson *et al*, 2021).

The positive impacts related to **innovative methods** of delivering medicine are thus clear: UAVs are expected to streamline the delivery of healthcare. However, there are strong underlying assumptions, namely on the existence of a **complex infrastructure to regulate** (i) airspace, and (ii) the interactions with people. This has already been recognized in the SWOT analysis in (Laksham, 2019).

In workplace environments, the presence of robots with social skills may be used to lighten workers concerns. For example, if UAVs ``know'' the **social proxemics rules**, workers do not need to always be concerned with robots approaching them too closely. Interaction between UAVs and people has been recognized as having little attention by the UAV community. This may lead to poor quality working places which in turn may induce health problems. For example, Stephan *et al*, (2022), reported that that only a few studies exist on the user experience.

In psychologically demanding applications, e.g., handling military UAVs, where pilots may be subject to stress levels and ethical concerns, (Wallace & Costello, 2017) long term health monitoring and the inclusion in decompression programs to relief psychological pressure are proposed. Naturally, such measures can be adapted to civilian applications, and combined with specific physical/mental exercises and carefully scheduled working periods.

UAVs can be used to **monitor or survey dangerous areas** thus reducing the need for workers to enter such areas. This includes the construction industry, with building sites, but also mining industry, monitoring areas after explosions.

Disaster response and search and rescue operations seem natural environments for UAVs. Providing detailed visual information, **carrying monitoring sensors**, or delivering emergency tools/medicines, seem to be in the range of current UAVs' capabilities. Nevertheless, current surveys point to the need to conduct additional performance assessment studies (Daud *et al*, 2022).

Safety is often associated to security. UAVs are natural candidates for **surveillance/monitoring agents to acquire information, e.g., visual data, that can be used for security purposes**. Law enforcement agencies are already using UAVs to monitor large areas and confined spaces, completely covered by current legislations.

Personal security is becoming a relevant application for UAVs. Farmers wanting to verify large areas of personal property are using inexpensive drones to detect intruders and unauthorized actions, well as to check the crops, livestock, and wildlife. Small size UAVs tend to be cost effective when compared to fixed camera systems and their motion introduces an element of uncertainty when searching for intruders.

While large research efforts are being focused on reaching maximal autonomy levels (see Scholes, 2007, for a comprehensive scale), current UAV capabilities can also be directed to the augmentation of human skills. Research on **human augmentation skills** via artificial devices, e.g., robots, has a direct impact on the quality of life of people. Exo-skeletons and robotized canes are two examples of robotic devices used, for example, in physical rehabilitation of people with locomotion problems. With the increase in load capacities, UAVs may replace at least some of these devices (for instance the devices in Neves & Sequeira, 2021, and O'Connor et al, 2021, can be replaced by UAVs equipped with adequate supports to hold humans moving in tight spaces).

The diversity of loads that can be installed onboard a UAV, **namely sensors such as cameras or even odour sensors, can extend human sensing abilities**, provided that adequate interfacing human-UAV is used. For example, a camera-equipped UAV can transmit the images it acquires to smart glasses[8] to **augment the vision field of the people** wearing them. This type of product is already available off the shelf. The concept can be extended to include multiple UAVs. Furthermore, the augmentation paradigm can be amplified to that of a proxy, i.e., **constant monitoring of people with a health condition, e.g., dementia, or people under legal restraining**.

In the workplace this type of augmented vision can be used by a **human supervisor** to monitor the evolution of the work being executed. This type of monitoring does not significantly differ from normal direct inspection by a human. Moreover, the UAV activities can be **recorded** (which may be a safeguard against excessive pressure by the management on workers). Also, the monitoring is not constant (as opposed to using fixed cameras) which can contribute to acceptance by the workers.

UAVs capable of transporting humans are already available, thus augmenting humans with flight capabilities and expanding mobility. These new capabilities are likely to amplify the concerns as human factors, now intrinsic to the UAV, can have an impact in behaviour of the UAV itself and in the surrounding systems.

Risks

Risks in the UAV field are commonly identified as,

1. Injuring the drone operator (from physical to psychological),
2. Injuring the public (from physical to psychological),
3. Creating general damage to property, including the UAV itself,
4. Privacy violation,
5. Generating liability.

These risks are not independent (for example, a safety issue can result from a violation of privacy) and their management must account for multiple factors (represented in the form of layers in Figure 4).

In general, risk mitigation implies regular and preventive maintenance and regular inspection, which may represent an important overhead (affecting economics and work organization and management). Failing to comply with an adequate maintenance schedule may create, for example, a significant collision risk.

Health risks related to UAVs can be of a double nature, (i) due to direct physical contact, and (ii) induced by UAV behaviours, i.e., their operation and flight manoeuvres. Collisions, the noise of engines, exposure to possibly dangerous loads, or the perception induced in workers about their lack of control of UAVs movements, are primary examples.

In **domestic and working environments** the former can be addressed by having the UAVs equipped with obstacle avoidance behaviours. The latter may require behaviours accounting for the dynamics of the workers, e.g., recognizing discomfort/stress or even monitoring bio-signals (for example, the need

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[8] Smart glasses are lightweight computers with display integrated in the lenses of the glasses. People wearing these glasses can have information displayed superimposed directly in their visual field.

to pay attention to flying UAVs may create additional stress and/or distraction in workers and increase the risk of accidents).

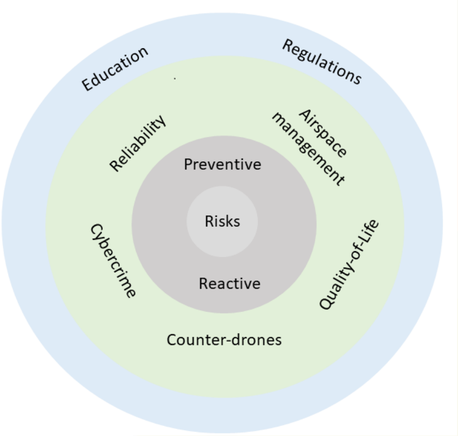

Figure 4 – Layers of management for risks associated to UAVs – Outer layers constrain the inner ones

Contingency plans may involve soft/hard and partial/total shutdown of the UAV infrastructure, e.g., commanding the UAVs to autonomously return to a landing area or simply force them to land immediately.

In recent years, public statistics show **incidents** in the range of hundreds per year (see Gorucu & Ampatzidis, 2021 for USA data). **Commercial and military drones** have very different reliabilities and required maintenance schedules, with combined MTBF[9] of approximately 19400 and 33000 hours for the military and commercial, respectively, (Petritoli *et al*, 2018). Alternatively, personal UAVs, not subject to mandatory maintenance and operating in conditions they may not have been designed for, may be assumed to have MTBF significantly smaller than the reported in (Petritoli *et al*, 2018).

The distribution of risk per system in (Petritoli *et al*, 2018) shows that the power plant, navigation system, and ground control stations are the systems generating the highest failure risks. **Redundant systems** are a natural form to reduce risk (already mandatory in commercial aviation), though increasing costs.

Risks and benefits associated with UAVs are being acknowledged by regulatory bodies with safety being a major concern. The components of a system involving single or multiple UAVs, namely the physical structure (airframe and hardware), the flight control system, combining hardware, e.g., sensors, and software, e.g., drivers to interface sensors and actuators, and the mission supervision software, have different reliability degrees and hence place different risks. Following Petritoli *et al*, (2018), generic drones have a failure rate of 1/1000 flight hours including catastrophic, severe, moderate, and soft failures.

Counter-drones and cybercrime

As cyberphysical systems, UAVs are being considered as the next big thing in cybercrime, (Bressler & Bressler, 2017). Devious and questionable applications are limited only by imagination and hence as

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[9] Acronym for Mean Time Between Failures.

UAVs are being developed it becomes imperative to develop tools to eliminate them, i.e., counter-UAVs, that is, UAVs to deactivate other UAVs.

The presence of drones in several airport areas has been the cause of air traffic disruption and near-accidents. As such, incidents become public knowledge, besides the increased economic costs with additional security measures, stress levels in everyone involved may rise, potentially leading to operational errors and health issues. Physical collision and psychosocial risks are thus entangled.

Counter-UAVs are therefore destined to enter research and development paths parallel to those of UAVs. Inevitably, counter-UAVs are expected also to be part of malicious/illegal activities (Europol, 2017).

Sophisticated cybercrime, requiring vast resources, has been in the eye of authorities since UAVs appeared. Small UAVs for recreational or commercial uses may tend to embed unsophisticated systems hence becoming more vulnerable to be hacked and easier to convert into cyberattack weapons. A UAV can be simply a vehicle to carry out a cyberattack, for example carrying a camera to illegally capture images of some target or even an explosive device. Alternatively, the hacking can occur only on specific systems onboard, e.g., communications.

The impact of these cyberattacks tends to be geographically limited. UAVs able to fly BVLOS tend to be more sophisticated than those flying short distances.

An equally intrusive attack may simply have a drone flying around a target, e.g., buzzing around a person, without any explicit malign intentions but using the intrinsic fear of people of close moving devices to create a psychological disturbance. In a common workspace this type of attack may even be misleadingly considered as normal behaviour by the UAV. The line between normal and malicious behaviours may be a thin one. Moreover, the accumulated exposure to disturbing behaviours by UAVs may have a long-term health impact.

Research gaps

The large amount of applications already reported in the literature and the corresponding economical value is expected to contribute to the sustainability of research in the UAV field. Research gaps reported in the literature are mainly related to **organizational/management aspects** and have tight connections with **risk minimization** and addressing the main concerns identified.

In 2017 commercial UAVs were already in the “slope of disappointment / trough of disillusionment” in the Emerging Technologies forecast of the Gartner cycle[10]. Beyond 2018, emerging technologies does not include estimates for UAVs which may be interpreted as the innovation potential being exhausted.

This however sees UAVs as a separate technology and not as another class of robots. Emerging technologies in the 2021 cycle, such as **“digital humans'”, or “AI-augmented software engineering'”**, can be brought to the UAV field, e.g., as a special class of social robots.

Research priorities are dynamic. Following (Merkert & Bushell, 2020), **privacy, security, and acceptance** have been main concerns, though their dominance is decreasing. Also, understanding the **societal impacts of drones**, namely regarding interactions with humans and regulatory issues, is a key issue.

Figure 5 summarizes the main areas of research that result from the applications currently envisaged for UAVs and the associated concerns.

[1010] The forecast published yearly by Gartner Inc, USA, see www.gartner.com

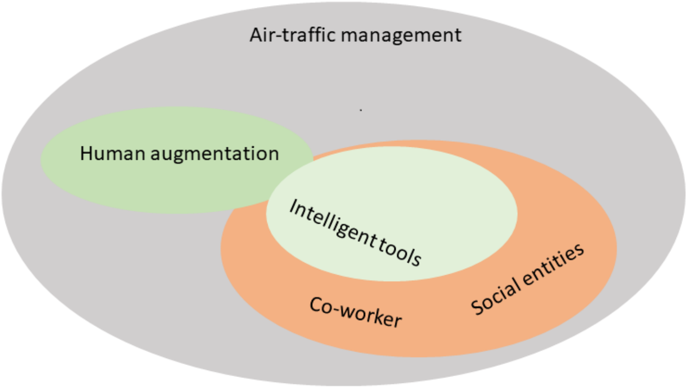

Figure 5 – Research gaps in the field of UAVs.

Applications such as air taxis (see Figure 6) are foreseen to increase urban mobility but also to require more sophisticated air traffic control as piloted and autonomous UAVs share air space. The variety of applications, requiring different types of UAVs (operating in isolation or as teams) and operational workspaces with very different spatial structures is likely to push for standardization measures in workspace organization and air traffic management. Current regulations are mainly defined around the max operational height of the UAVs (120m for recreational/commercial drones, Cohn *et al*, 2017).

Figure 6: VoloCity air taxi (BBC Science Focus Magazine).

In specific scenarios, e.g., large manufacturing areas with multiple UAV operators, as that reported in (Barrado *et al*, 2021), fully automated air traffic management systems may be applicable, though, as the authors acknowledge, scaling up the problem requires accounting for a greater diversity of parameters. However for more generic areas, e.g., urban spaces, there are still significant questions to be answered such as how the different UAV operators should coexist and how should the responsibilities of traffic coordination be distributed (see for instance the discussion in McCarthy *et al*, 2020). Increasing the capacity of currently installed ATC is expected to be difficult/impossible and disruptive technologies, e.g., in the domain of communications, need to be found and associated rules created/adapted (Finger *et al*, 2016). Moreover, as the systems scale up and human controllers need to supervise low level automated systems, human factors, e.g., memory, fatigue, and stress, are likely to come into play (see for instance Weiland, 2021).

Working with UAVs - From tools to social entities

As discussed before, full integration of UAVs in working environments requires **sound acceptance** of this particular technology by workers. Acceptance of a technology is often supported by a good perception of its utility and of how easy its use is, (Davis, 1989). Developing a good perception depends on a fair/good understanding of the technology. In a typical manufacturing environment, with UAVs being used in pick-and-place operations, workers may develop a good perception just by looking and understanding the UAVs motion patterns and/or knowing about explicit safety measures installed (Figure 8).

Figure 7: A parachute used to assist the landing of a Eleron-3SV UAV (Wikimedia Commons).

However, for more complex applications, e.g., monitoring temperature gradients in a large warehouse, the motion patterns may not yield an immediate perception of the mission the UAV is executing, thus creating potential discomfort in the workers. Endowing UAVs with social skills may simplify interaction and improve workers perceptions.

Such social skills may require thorough studies on, for example, (i) **the proxemic conditions and other social norms that need to be enforced in the working environments for the workers to be comfortable**, and (ii) **the technologies to be used**, e.g., having the workers wearing small electronic identification devices[11] or using facial recognition from a camera onboard the UAV.

Currently, healthcare, personal assistance, and specialized services are the predominant areas for social, land based, robots. Anthropomorphic robots have been struggling to achieve full integration in social domains. UAVs, with their advanced motion skills, face a challenge when trying to operate in environments inhabited by humans.

Autonomous UAV societies

The increase in applications and the need to coordinate/manage UAVs executing different tasks is likely to require the development of **languages for inter-UAV communication**. This opens a door to the creation of principles to organize drones as an autonomous society, that can **self-organize its members independently from humans** (at least up to some point).

As an example that illustrates how having inter-UAV communications can lead to self-organization principles, multiple UAV systems increase flexibility in the execution of a mission and in some scenarios it may happen that (i) one UAV in the team can no longer complete its mission and another UAV is called in, or (ii) the mission of the team of UAVs is executed more efficiently if the one UAV swaps missions with some teammate. This type of mission swapping can be highly relevant in, for example, disaster assistance when one UAV is low on power level and needs to be replaced by another one (see Bisio *et al*, 2022). If this type of mission transfer/swap is done automatically, i.e., without explicit

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[11] RFID technology has been used in multiple social robotics experiments for this purpose.

intervention from human controllers, it corresponds to a basic layer of a UAV society. Furthermore, market negotiation principles and game theory can be used by UAVs to “survive” in such a market.

Though, seemingly a long-term possibility, one must consider that such principles are already being used in the stock exchange domain through the dealer “bots”. Moreover, the expected complexity of managing the population of UAVs may push humans to develop automated management systems that, in the end, may rely on the above ideas. The creation of societies of artificial devices is a complex topic and sustainability a natural goal. The research interest is linked to the number of UAVs operating in a common airspace and hence, indirectly, also to their massification.

Stakeholders: perspectives and recommendations

The UAV field encompasses a diversity of stakeholders each with specific concerns, (see Upadrasta *et al*, 2021). Each of the classes below can be further divided in subclasses, each related to specific applications and concerns.

1. The owners/guardians, including developers and systems' engineers. Owners’ concerns are related to the scenarios UAVs are operating in and the performance of the whole system. Developers and system's engineers’ concerns are related to the operation and performance of the individual systems of the UAV, e.g., those related to positioning, and trajectory following.

2. The users/clients, i.e., people and organizations with direct interest in the work developed by UAVs. Users/clients may also be the owners and share the same concerns. Google, Amazon, and Uber are examples of major organizations with direct interest in UAV industry, e.g., for internal logistics and delivering goods to customers.

3. UAV operators. This is still a restricted class of people, organizations, or enterprises, licenced or not, to operate UAVs. UAV operators are expected to be well informed on the operation of the devices and regulations that should be complied with (Large size UAVs will, in general, require some form of operator certification). Adopting blackboxes (similar to those existing onboard of most commercial aircrafts) to register all the relevant parameters of the UAV may help when determining liabilities, e.g., as when legal and rogue devices operate in the same workspace.

4. People and organizations sharing the UAV workspace, with or without direct interest in the task UAVs are executing. This class of shareholders encompasses the workers, unions, government, and bystanders in the UAV workspace. As UAVs are becoming ubiquitous, this is the widest class of stakeholders as it includes, virtually, everyone.

5. Regulatory bodies, namely in the European Union[12]. European Union Aviation and Safety Authority, in the European Union, the Federal Aviation Administration in the US, the Civil Aviation and Safety Authority in Australia, the Civil Aviation Authority in UK, are prime examples regulatory bodies.

This list is representative of a broad range of applications. Specific industries, such as the oil industry, may use more detailed lists. Concerns have been classified as social, technological, and systemic (see

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[1212] https://dronerules.eu/sk/professional/eu_regulations_stakeholders

Kraus et al, 2020) for a taxonomy defined over these three classes. Market analysts emphasize potential difficulties creating synergies between stakeholders in commercial drones (see Cohn *et al*, 2017) and suggest using sandbox techniques to address safety concerns (WEF, 2022). Standardization has also been reported as a concern related to safe and secure operations (SESAR, 2020). However, interestingly, safety has not been reported as the main concern for industry stakeholders (Upadastra *et al*, 2022).

The interests of stakeholders enumerated above are related to the real and perceived utility of the drones, which determines their acceptance. Unsurprisingly, the interests of each of the stakeholders are not fully coincident. Companies such as Boeing, Google, Comcast, Lockheed-Martin, and Amazon, are reported to have spent large amounts of money lobbying. Projects aiming at delivering internet through high-altitude balloons, solar-powered UAVs, or ensuring network connectivity in constrained areas, are easily of interest to, for example, Google and Facebook, delivering cost-effective social media to remote communities.

Regarding OSH, it is necessary to account for dependencies among stakeholders, (Auvinen, 2017). These are mainly related to the social class of concerns in (Kraus *et al*, 2020, including, among others, privacy and related ethical considerations. The need for engaging stakeholders and create synergies among them is a common denominator among a wide range of literature (see, on different domains, Wang *et al*, 2021, Dubin *et al*, 2020, Smith *et al*, 2022, or Jeyabalan *et al*, 2020).

Recommendations to stakeholders

The following recommendations (including the relevant classes of stakeholders for each of them) are derived from the concerns and expectations identified in the previous sections (main stakeholders classes indicated). Directly related to OSH are recommendations 3 to 5. However, the general recommendation is that, prior to all concerns, the quality of life in the workplace must be a goal.

1. (All) Promote the establishment of synergies among stakeholders.

   The concerns and expectations discussed along the paper identify common factors. For example, safety was presented under different perspectives, modulated by different stakeholders. The regulations for UAV operations in the workplace often left human factors out of the equation, assuming that workers will adjust. Instead, we propose that workers be considered at the centre of the concern, as agents that must interact with UAVs.

2. (Manufacturers, Operators, Developers) Increase standardization efforts.

   Standardization has been claimed to be a key issue in the drone business (see the AW-drones EU project, Pauner *et al*, 2015). Improving the use of interchangeable hardware and software may facilitate the acceptance of UAVs by the workers and improve learning curves.
   The possibility of co-existence of multiple different frameworks regulating workspace and traffic needs to be accounted for. Necessarily, this will impose the development of tools/languages for these systems to interact with each other. Standardization may also help in the maintenance aspect, which is relevant for reliability and safety.

3. (Workers, Operators, Developers) Ensure workers training on generic and specific capabilities of UAVs.

   This may include one-way information (manuals, webpages, leaflets, workplace signs) and two-way information, e.g., requiring some form of certification, i.e., workers may have to be qualified to work in a UAV environment, adding responsibility to the worker, similar to having to attend training sessions to learn how to operate a delicate piece of equipment. On a negative side, the worker may perceive the need for certification as him/her being required to prove his/her skills and thus introducing competition inside the work team and disturb its cohesion.

4. (Workers, Manufacturers, Regulatory entities) Ensure an adequate communication interface between workers and UAVs.

   Even workers not directly related to UAVs operation must be able to communicate with UAVs in their proximities using unsophisticated languages and tools. To protect the worker's privacy or safety, this language must include orders to make the UAVs move away, e.g., to a distance from the worker further than some predefined value. The adequate level of sophistication of such language may vary. Move away orders may be mandatory or may have a tolerance grading, or even allow communication between worker and a human supervisor in charge of managing UAVs in the workspace.
   The natural evolution can be to have, in a first phase, a human supervisor for the UAVs, which may have assigned tasks such as

   - Ensuring adequate workers proxemics.
   - Managing communications with workers.
   - Assessing the levels of comfort by the workers (possibly using questionnaires for the workers to express their opinions).

   In a second stage the human supervisor may be replaced by a system able to make decisions on the UAV management autonomously.

5. (Workers, Organizations) Monitoring of generic health parameters and quality of life indicators in the workplace.

   The recent Covid experience shows that the monitoring of generic health parameters (possibly in real-time) may be a safety measure, e.g., having single or multiple UAVs equipped with thermal cameras to detect people with abnormal body temperatures, or equipped with UV light sources to perform local sterilization. Also, measurement of stress and distraction levels may provide relevant information on the social effect of the presence of UAVs in the workplace. However, measuring social variables of individuals implicitly leads to ranking those individuals. From the employer perspective this is useful information, though workers' perspective may differ.

Conclusions

The interest from all areas of society in UAVs is a clear indicator of their potential and it also feeds the interest of the scientific and technological community in the development of the concept. The paper overviews arguments from relevant stakeholders, from academy to industry, to show the diversity of perspectives but also the complex interdependencies among stakeholders, concerns, UAV typologies, and applications.

The concerns addressed are naturally ranked, e.g., as in Figure 9, with the highest importance at the base of the pyramid.

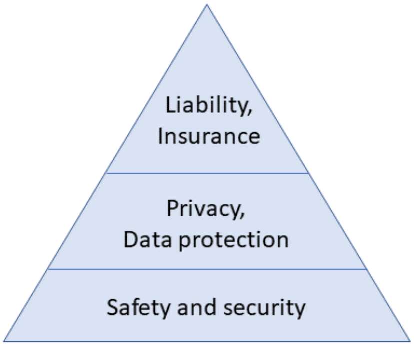

Figure 8 – Hierarchy of concerns in the UAV field – The pyramid is inspired in the hierarchy of needs from Maslow's theory of personality.

Though potentially limiting or slowing down the development of the field, addressing the concerns in a transparent form is fundamental. In generic situations the perceived safety is often the main concern of people (see the Psychology hierarchical model of needs which has safety at the base of the pyramid of needs). However, subjective factors can mislead this perception and hence transparency while explaining the UAVs characteristics and skills to workers (and to other general people) is paramount.

Safety is also at the root of the recommendations related to training people to work in workspaces shared with UAVs. Thorough training programmes are deemed essential to an adequate integration of UAVs in workspaces and to their acceptance by the workers. The research gaps identified, some of which are not likely to be solved in the short term, can be expected to produce intermediate products/services, in the field of UAVs, that will also modulate people's acceptance.

As referred to in the paper, workers must feel comfortable "living" together with UAVs in shared workplaces. This means that special attention must be given to designing forms of communication that do not overload the workers. Integrating UAVs in a worker-centric way means ensuring that workers have adequate knowledge on their UAV co-workers and can cope with increasingly sophisticated skills. The majority of research work addresses the expected boost in productivity UAVs can generate, assuming that workers can be trained. However, similarly to other areas involving interaction between humans and machines, human factors can become significant barriers to the successful integration of UAVs in workplaces (Figure 10).

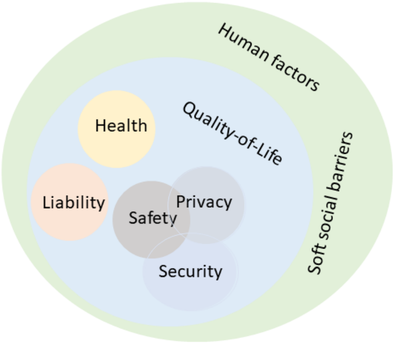

Figure 9 – From wide areas of human dynamics (outer shapes) to OSH concerns (inner shapes)

The increase in the number of UAVs brings challenges, identified in the research gaps, directly connected to other relevant concerns, e.g., privacy and liability. The legislation associated is evolving at slow speed, which restrains the evolution of the field, both by over-regulating and by discouraging people to be creative. These dynamics tends to create effective soft social barriers and, consequently, slow down the evolution of the field.

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