Journal of Intelligent & Robotic Systems (2024) 110:46
https://doi.org/10.1007/s10846-024-02056-9

REGULAR PAPER

Check for updates

Regulating Autonomy in Civilian Drones: Towards a Spectral Approach

Samar Abbas Nawaz[1,2]

Received: 3 October 2023 / Accepted: 11 January 2024

Abstract

Civilian drones are becoming more functionally independent from human involvement which sets them on a path towards "autonomous" status. When defining "autonomy," the European Union (EU) regulations, among other jurisdictions, employ an all-or-nothing approach, according to which a drone is either able to operate fully autonomously or not at all. This dichotomous approach disregards the various levels of drone autonomy and fails to capture the complexity of civilian drone operation. Within the EU, this has regulatory implications, such as regulatory lag, hindrance in better safety regulation, and incoherence with the Union's regulatory approach towards Artificial Intelligence (AI). This article argues that understanding autonomy as a spectrum, rather than in a dichotomous way, would be more coherent with the technical functioning of drone and would avoid potential regulatory problems caused by the current dichotomous approach. In delineating this spectral approach, this article (1) analyses manifestations of autonomy in drone operations, (2) delineates efforts in the technical literatures and drone standardization to conceptualize "autonomy", and (3) explores definitional attempts for autonomy made in three other technologies: self-driving cars, autonomous weapon systems, and autonomous maritime ships.

Keywords Drone · UAS · Autonomy · Regulation · Safety · EU law · AI

1 Introduction

Civilian drones are having a disruptive impact across the private and public sectors.[1] Drones are being used for a wide variety of purposes, among them to spray or inspect crops, to inspect vast areas for the energy sector, to deliver life-saving instruments such as defibrillators, and to provide security through effective surveillance. Their integration into farming has led some to declare the beginning of a fourth agricultural revolution [1] while delivery drone market is forecasted to jump from USD 228 million in 2020 to USD 5,556 million by 2031 [2]. Some drones are as large as a helicopter, others, as small as a bee [3]. Paralleling the quick expansion in the variety of drone sizes and uses is the rapid development of technological enhancements. What was once a device heavily controlled by a human is gaining more independence—in technical terms, more "autonomy"—in its ability to navigate, avoid obstacles, and process data without immediate human involvement. Yet, the regulatory approach to ensure safe drone operations in many countries begs adjustment to the gradual expansion of autonomous behavior. While the EU has been putting efforts to address various implications of drone technology, its regulatory approach towards autonomy is concerning. Conceptually, regulations are often based on a dichotomous approach to "autonomy"—understanding a drone as either fully autonomous or not at all—and not recognizing gradations of autonomy. There is thus a disconnect between how autonomy in drones works and how the regulations address it. From a regulatory standpoint, autonomy remains an important concern in the short and medium-term for the safety regulation of drones. Moreover, through the Drone Strategy 2.0, the EU places drones as explicit part of broader policy goals such as, civil-military

[1] While different terms are imputed to the aerial technology under discussion, such as, Unmanned Aircraft System (UAS), Unmanned Aerial Vehicle (UAV), or Unmanned Aircraft (UA), this paper employs the term "drone". It would include the aircraft as well as the remote system which enables its operation. In the context of this paper, "drones" do not include military or law enforcement drones but the ones which would be used in the civilian airspace for private and commercial purposes.

This article is part of the Topical Collection on N, New and Emerging

✉ Samar Abbas Nawaz
samnaw@prio.org

1 Peace Research Institute Oslo (PRIO), Hausmanns Gate 3, 0186 Oslo, Norway

2 University of Oslo, IKRS, PO Box 6706, St. Olavs Pass, Oslo 0130, Norway

Published online: 18 March 2024

relations, sustainability and urban mobility [4–6]. Hence, discussion around drone autonomy and its challenges is useful for broader reasons.

While the paper is specifically targeted at the implications for the EU drone regulations [7–9], it also synthesizes regulatory conceptions found in Australia and the United Kingdom (UK). The synthesis is conducted to highlight a trend in other comparable jurisdictions. The rationale for selecting these specific jurisdictions is twofold: they have been working on drone safety laws longer than most other jurisdictions [10, p. 8] and they have also sought to integrate drones into civilian airspace.[2] It is thus worthwhile to also look at their approaches towards autonomy.

Drawing on the literature addressing other technologies, this article then proposes a "spectral" conceptualization of autonomy more suitable to drone regulation. Here, the technical literature includes mostly human factors/ergonomics (HFE) scholarship and, to some extent, purely engineering literature. The HFE discipline is specifically chosen because it contains multidisciplinary perspectives, such as engineering and psychology—pursuing two design outcomes in systems, namely "performance" (such as, effectiveness, and reliability) and "well-being" (such as, health and safety, and satisfaction) [13]. Ultimately, the paper shows that abandoning the dichotomous approach to defining autonomy in preference to one that recognizes that autonomy falls along a spectrum would not only harmonize regulation with the technical understanding of autonomy but could also tackle potential regulatory issues.

2 Literature Review

Emanating from the Basic Aviation Regulation [7], two regulations were passed by the EU in 2019 specifically covering civilian drones—yet to be fully operationalized [8, 9]. This lack of operationalization generally hinders assessing the effectiveness of these regulations [14]. Mapping out the prevailing EU aviation framework applicable on civilian drones, Uva and Rebane show that the regulatory work is far from completion [15]. Generally, several scholars also summarized the EU framework on civil drones [16, 17]. Exploring the EU governance structure, Pagallo and Bassi explore three modes of regulation applicable on drones: a top-down model in the shape of aviation regulations (the ones discussed in this paper); a co-regulatory model in the shape of data protection regulation; and coordination mechanisms visible in the experimentation of drone technology, for example allocation of areas for drone activities [18]. Difficulties in the enforcement of these regulations by Member States are also highlighted [19].

The trouble of using terminologies that do not sit well with how drone technology works has been discussed in the past. For instance, the analysis of the terms used for drones—some of them being "unmanned aircraft" or "remotely piloted aircraft"—in international frameworks shows either less or more inclusivity in their application [20]. Recognizing such implications, Scott and Veloso synthesize various terms in vogue breaking down characteristics of each term—to better understand their purport [21]. This paper contributes to such conceptual debates by examining the concept of "autonomy" as employed in the EU drone regulations.

Scholarly work on regulatory solutions for civilian drones' safety alludes to the evaluation criteria for a regulatory regime based on product, process, and outcome [22] or development of robust infrastructure to deal with the emergence of drones [23]. In contrast to these important contributions, this article recommends a way of regulating autonomous feature of drones, at a conceptual level. Somehow closer to this article, Matalonga and others highlight standardization challenges when it comes to the autonomous detect and avoid (DAA)[3] capability of drones [24]. However, they abstain from deeply examining conceptual issues of autonomy.

It is acknowledged in the paper that drones have brought about a "sociotechnical change" in the civil aviation sector [25]. The sociotechnical change occurs because relative to manned aviation, many drone operations—if not all—can be accessed in a cheaper way; drones are operated either remotely or autonomously; and drones can be flown from virtually any location—not requiring typical aerodromes for manned aircraft. Such a change gives rise to various legal issues, namely vacuum in terms of legal rules, over- or under-inclusiveness, irrelevance or ineffectiveness of older provisions, and injustice with regard to provision of fair treatment. For instance, the EU drone regulations deviate from traditional manned aviation rules when it comes to gaining access to the Single European Sky regardless of the nationality of the aircraft [26]. Rooted in such sociotechnical change approach, this paper questions the implications of the current European approach towards regulating the concept of autonomy.

Conceptual work on the term "autonomy" often treats human autonomy from a philosophical perspective. In such regard, legal scholars have alluded to the elements of personal or human anatomy from the lens of "agency" (a

[2] See UK's recent commitment to build world's biggest drone super-highway [11]; and Australian Digital Economy Strategy of 2021 with drone being a critical technology for Australian national interest [12].

[3] Drone's capability of detecting and avoiding any obstacle in its path.

capacity to act) while "autonomous" is any action arising from such agency [27]. Accordingly, free action and purpose are seen as the essential components of an agency. Applying it on drones, autonomy can be seen as the characteristic of an operation, not necessarily the system. A more nuanced approach presents the notion of "remote control" to understand human autonomy [28]. It recognizes the human capability of looking at themselves from another perspective through so-called reflexive loop. While most of the legal work dealing with autonomy has highlighted human aspects of "agency", engineering literature generally perceives autonomy by studying the technical components of the machines. Those attempts somehow converge on the independence of machine to operate without human control [29]. Arguably, machine autonomy and human autonomy are two sides of the same coin; it ultimately boils down to free action either by machine or a human. This adjacency of autonomies allows analysis of the impact of machine autonomy on human autonomy in, inter-alia, online commerce [30]. Similar confluence is also reflected in the proposal to regulate technology products in a way that respects human autonomy [31]. While such overlaps in scholarly discourse are acknowledged, this paper abstains from delving into human autonomy; rather it focuses on machine autonomy.

The implications and regulation of autonomous systems also forms part of the literature. For self-driving cars, autonomy challenges the notion of "driver" within the internationally recognized treaties on road traffic safety [32]. As states promote autonomous vehicles' (AV) development, many AV regulations are found to be lacking strict rules [33]. In drones, the issue of control—amongst other challenges—generates the need for regulating them [34]. Firlej and Taeihagh show how a typology of autonomy could sharpen standardization efforts for autonomous systems—of various kinds—and help in targeting the points at which the human factor is subject to change [35]. For Autonomous Weapon Systems (AWS), a comparative analysis of definitions by different states and international institutions reveals four factors to define AWS: "autonomy, adapting capabilities of AWS, human control, and the purpose of use" [36]. Anderson and Waxman regard an all-or-nothing approach to defining AWS as a deviation from reality—where automation manifests in a "continuum" with various gradations [37, p. 1101–1102). Autonomy, in their view, is not just about the machines' capability but broader human–machine interaction. To assess the "functional autonomy" of any system, one would need to examine the functions handled by machine and humans, and their interaction. Partly inspired by such understanding and drawing on technical literature on autonomy, this paper presents a spectral approach to define autonomy.

The following discussion is divided into four sections, followed by a conclusion. The first section discusses the growing autonomy in drones. In the second section, the definition of "autonomy" in the EU, the UK, and Australia, are analysed which shows that each region follows the same dichotomous, either/or approach. The third section discusses the regulatory implications emanating from the dichotomous approach. Drawing on the technical literature and conceptual work in analogous technologies, the fourth section suggests usage of a "spectral" approach—instead of dichotomous one—to deal with the regulatory implications. Finally, the conclusion section summarizes key arguments of this paper and points for the future research.

3 Autonomization of Drones

To explain the autonomization of drones, this section starts off by first distinguishing "automation" and "autonomy". Secondly, it explains how drones are gaining autonomy. And thirdly, it remarks the importance of understanding context to better comprehend autonomy. Overall, this section serves to provide a general technical understanding of autonomy.

3.1 "Autonomy" versus "Automation"

Any technology that functions without human control is generally perceived as either "automated" or "autonomous". There is a difference between these two concepts, however. In Engineering etymology, "autonomy" refers to a system's ability to make its own decisions while performing different tasks with no need for an exogenous operator or system. The term derives from Greek, in which "autos" means "self" and "nomos" means "law" [38]. Peter A. Hancock, an HFE expert, differentiates automation and autonomy according to the deterministic quality of a system [39]. Accordingly, an automated system relies on a set of largely deterministic steps and operates in a repetitive manner to pursue pre-defined results. Autonomous systems are generative in nature and are able to learn, evolve, and permanently change their functions upon interaction with their environment. Hence, a distinction between these two concepts is that "autonomous" indicates adaptive and learning behavior whereas "automated" does not.

Despite this difference, drone manufacturers tend to use the word "autonomy" for operations that are "automated" in nature. Take, for example, Wing delivery drones, which are run by Google's parent company, Alphabet. These drones—which the company calls "autonomous"[4]—are being used in the US and Australia on an expanding scale [40]. The Australian Civil Aviation Safety Authority (CASA), which

[4] On the homepage of their website, Wing states that "our aircraft operate autonomously." See https://wing.com/.

authorized Wing's operations, regards these operations as backed by "programmed flight", with any deviation prompting the need for pilot intervention [41]. Hence, a Wing delivery drone better fits the criterion of automated, rather than autonomous, operation. This can create the impression that the drone operates deterministically, even though this is often not the case. Concerns around such use of the term autonomy have been raised in the past [42].

It must, however, be acknowledged that the distinction can be more nuanced. For instance, the Joint Authorities for Rulemaking of Unmanned Systems (JARUS)—a body of experts from various aviation authorities working on standardization for drone safety—perceives autonomy as "an emergent effect of a collection of increasingly automated functions. As the level of automation increases across a set of interacting functions autonomy may emerge" [43, p. 11]. It indicates that automated and autonomous features can be intertwined; leading also to their interchangeable usage, as discussed later in the paper.

3.2 Infusion of Autonomy in Drones

AI is an enabler of autonomy in drones as well as some other technologies. Although there is no universally accepted definition of AI. This article follows the understanding of AI as machines that are "capable of performing tasks that, if performed by a human, would be said to require intelligence" [44, 45]. Machine learning (ML) aims to improve the performance of a system by training it with vast datasets. Deep learning (DL) is a subset of ML; it mimics human neural networks to make sense out of unstructured data. In drones, DL allows interpretation of data gathered by sensors and could aid autonomous navigation. For instance, in situations where Global Positioning System (GPS) signals are weak, neural networks are being tested to allow the drone to autonomously navigate using vision-based method [46]. Finally, reinforcement learning employs a reward function within the system to ensure that optimized solutions are sought. It is shown to be useful in allowing the drone to land on a moving platform [47]. Aiding in its safety function, AI is helping drones with DAA capabilities. A practical example is the software architecture Independent Configurable Architecture for Reliable Operations of Unmanned Systems (ICAROUS), which is being tested at the National Aeronautics and Space Administration (NASA) Langley Research Center. ICAROUS provides algorithms for path-planning, traffic avoidance, geofence-handling, and decision-making that interface with an autopilot system to enable safe, autonomous drone operations [48]. Through the infusion of techniques and measures such as these, drones are able to perform more independent or autonomous functions—with decreasing dependence on constant human control.

3.3 Understanding Drone Autonomy

Drones perform multiple actions during the course of operation, commencing with take-off, continuing with navigation of the airspace and performance of their intended function, such as parcel delivery at a given location, and concluding with landing at a designated location. Within the layers of these various actions, drones can exhibit some form of autonomy. A DAA feature, as discussed above, is one such example. Autonomy can also be infused for operational benefits. Take, for example, the "Connected Agriculture" system designed by SAP—a multinational company which develops enterprise software—for agricultural drones. This system, which allows drones to provide actionable intelligence by using AI-powered data analytics, facilitates assessment of the impact of seasons or actions, such as the effect of fertilizer use on the quantity and quality of a given field's harvest [49, p. 45–56]. In such a case, drones, acting independently of direct human instruction, acquire and process the needed data to provide insights about the agricultural field. Even if such a drone were to be flown by a human pilot; its autonomy, in terms of sensing and processing the field data, could not be denied. In contrast, "swarm drones"[5] would appear to be significantly more autonomous as they would function with minimal human support [50]. In the latter case, drones' independent decision-making ability, or autonomy, is indispensable, particularly during the flight and performance of the intended goal.

Thus, although SAP's system and swarm drones each exhibit autonomy, they are not equally autonomous. The former is autonomous in the collection and processing of agricultural data, whereas the latter are autonomous in their navigation, coordination, and fulfillment of a goal. These examples show that autonomy can be delegated to drones from different sources, and that, although it may not be incorrect to call these drones autonomous, it is essential to take into account the context within which this autonomy is manifested. The same may also be said about Wing drones, if they are autonomous in functions other than the flight. Thus, JARUS takes a position that automation can be present within a so-called Operational Design Domain (ODD) [43]. The ODD is marked by the limits of operational conditions such as environmental, geographical and other operation specific characteristics. Full autonomy is only achieved if a drone performs every one of its actions independently. While

[5] This term is used for a network of drones operating in a swarm-like structure to fulfil a single goal.

Table 1 Regulatory conceptions of "autonomy" and "automation"

	Automated/ Automatic/ Automation	Autonomous operation/aircraft
EU	"…an automatic operation…refers to an operation following pre-programmed instructions that the UAS [Unmanned Aircraft System] executes while the remote pilot is able to intervene at any time."[a]	"An operation during which an unmanned aircraft operates without the remote pilot being able to intervene."[b]
Australia	"Systems such as a pre-programmed flight or an automated 'return to home' are features of automation."[c]	"… that does not allow pilot intervention during all stages of the flight of the aircraft"[d]
UK	"Automation is the capability of a system to act using a set of pre-designed functions without human interaction (e.g. robotic manufacturing)."[e] "Highly automated – those systems that still require inputs from a human operator (e.g. confirmation of a proposed action) but which can implement the action without further human interaction once the initial input has been provided." "High authority automated systems – those systems that can evaluate data, select a course of action and implement that action without the need for human input. Good examples of these systems are flight control systems and engine control systems that are designed to control certain aspects of aircraft behaviour without input from the flight crew."[f]	"The concept of an 'autonomous' UAS is a system that will do everything for itself using high authority automated systems."[g]

[a]GM1 Article 2(17) [51]

[b]Article 2(17) [8]

[c]Section 2.1.4.4 [52]

[d]101.097(1)(a), Subpart 101.C [53]. Notably, Australian regulations use the term autonomous "system" instead of "operation" (as used by the EU). While that may be significant, this paper avoids delving into that difference as it is broadly concerned with the purport of autonomy

[e]Section 3.9.2 [54]

[f]Section 3.9.1, ibid

[g]Ibid

this section highlighted general technical understanding of autonomy, deeper discussion can be found later.

4 Regulatory Conception of Autonomy

The preceding section highlighted elements that constitute autonomy and some underlying complexities. This section shows the regulatory conceptualization of "autonomy" by reproducing the definitions from either the statute or regulatory guidance in the EU, UK, and Australia. As shown in Table 1 below, only Australian and EU statutes provide the definitions linked to autonomy. Other definitions are copied from the regulatory guidance provided by the competent authorities in the three regions.

The independence of a system determines whether it is automated or autonomous, as was shown in the previous section. However, as can be seen in the extracts in Table 1, a remote pilot's "intervention" is the sole distinguishing feature between autonomous and other operations, according to EU and Australian regulations. Indeed, some scholars find no incompatibility between pre-programmed instructions and categorization of a system as autonomous, in a regulatory sense, provided that the remote pilot is not able to intervene [55, 56

This approach not only disregards the general understanding of autonomy but also partially deviates from the definition used by the UK Civil Aviation Authority (CAA). In explaining the concepts of automation and autonomy, the UK CAA pays explicit attention to "human input." In their view, what distinguishes a "highly automated system" from a "high authority automated system" is the need for human input. So long as human input is required, a system is not autonomous. A system is classified as "high authority automated"—which enables autonomous operation—if it requires no human input, with the drone able to evaluate and perform an action entirely on its own. The UK authority also downplays the element of human intervention, determining that a "highly automated" system can also operate without interaction with a human although it does depend on human input. Such a system would be perceived, according to EU and Australia regulations, as performing an "autonomous" operation; whereas in the UK, it would be seen as "highly automated."

Apart from this difference, UK regulations generally set as high a bar for categorization as an "autonomous operation" as do Australia and EU regulations, stating that an autonomous system "will do everything for itself." This rules out any system that can perform many but not all functions on its own. For instance, where a pilot can only intervene at the supervisorial or assistance level. As such, neither SAP's Connected Agriculture system nor swarm drones would be categorized as autonomous according to these regulations.

In the EU drone regulation, the dichotomous approach also takes its roots from the Basic Aviation Regulation which defines the "unmanned aircraft" as "any aircraft operating or designed to operate autonomously or to be piloted remotely without a pilot on board".[6] A bare reading of this definition shows that autonomous operation is not piloted by any remote pilot. Hence, an unmanned aircraft or drone is already divided into two categories: remotely piloted; and autonomous. Since this dichotomous approach emerges directly from the Basic Aviation Regulation, the EU agency responsible for aviation i.e., the European Union Aviation Safety Agency (EASA) cannot deviate from it whilst creating drone related rules. The high threshold is further supported by EASA's explanation that an emergency procedure activated by a drone would not be regarded as "autonomous" behavior.[7] This implies that such a procedure might be considered automated. Strengthening the high threshold, the UK CAA also states that an autonomous drone would maintain its flight on a planned route, communicate with other airspace users, and detect and recover from any faults, all the while maintaining operational safety at least on par with drones with which humans are continuously involved [54, p. 125].

Although the regulatory concepts presented in Table 1 are not verbally identical, they all commonly regard "autonomous" functionality as a distinct and exclusive category that does not recognize varied levels of autonomy. In effect, drone regulations—of not only EU—create a dichotomy: operations are either autonomous or non-autonomous. Thus, making it inadaptable to varied forms of autonomous drone operations such as, SAP's Connected Agriculture and swarm drones.

5 Regulatory Implications of the Dichotomous Approach

Statutory definitions ought not be seen as trivial, especially in technology regulation, as they tend to "steer sociotechnical changes into certain directions" [25, p. 37]. The high threshold for autonomy—attracting only fully autonomous operations—emerges as a case of under-inclusive trait of regulating a sociotechnical change [25]. The regulatory definition of autonomy is so strict, in fact, that it raises the question of whether any drone currently in existence conforms to it [54, p. 122]. Importantly, the prevailing approach bears implications for the success of regulatory measures within the EU. Among them the potential to promote regulatory lag, to invite safety implications, and to conflict with an AI-related framework.

5.1 Furtherance of Regulatory Lag

Regulations often lag behind technological developments. Governmental rules regarding drones are no exception [16]. In his notable book, *Social Control of Technology,* David Collingridge defines as a dilemma a circumstance in which control and predictability function inversely. According to the dilemma, when technology is nascent, controlling it is very difficult because the impact of the technology is not yet predictable. But once the technology has been adopted widely and its adverse impacts are clearer, controlling it is also very difficult [57]. With the operation-centric risk based approach—whereby drone operations are split into three categories (open, specific, and certified)—EU regulations tend to take a gradual approach by firstly focusing on low risk operations and then regulating high risk ones in the future.[8] Since the prevailing forms of civil drones do share some form of autonomy, the current obscurity regarding regulation of drone autonomy is concerning. The lag is reinforced as the regulation defines autonomous operation in a dichotomous manner—lacking coherence with the technical reality. Regulation of drones has been historically seen as "inadequate and very slowly-adaptive" [22, p. 280], and the confusion over the definition of autonomy makes this observation worrisomely relevant despite various regulatory changes since that publication in 2014. While EASA aims to provide guidance around the levels of autonomy when the concept gains global acceptance,[9] the existing dichotomous definition will stand as a challenge.

The current regulatory definition is also quite rigid, requiring the complete absence of human intervention from the operation. Given the evolving nature of technology, less rigidity with respect to regulation is preferable as greater flexibility ensures more sustainability in the future. In the case of drone autonomy, flexibility may be helpful in regulating drones that involve less human control. The two regulatory categories of drone allow for a drone that is either fully autonomous or not, ignoring the many drones that do not fit neatly into either category. As a result, it can be expected that there will be a significant regulatory lag and possibly an irresolvable dilemma when it comes to a regulatory framework for such drones.

[6] Article 3(30) [7].
[7] GM1 Article 2(17) [51].
[8] Article 3 [8].
[9] GM1 to UAS.SPEC.050(1)(b), Part B [58].

Within the EU, such a lag would be prominent, as the term “autonomous operation” permeates a variety of instruments being developed by EASA. These include Certification Specification (CS), which provides objective airworthiness standards for the issuance of and changes to Type Certificate (TC) for those drones that will perform autonomous operation.[10] EASA, in another context, also explicitly excludes autonomous operations from the ambit of low-risk operations; requiring a competent national authorization of such operations.[11] However, because of the rigid categorization, drones that involve significantly less human control would elude such regulatory attempts. This mismatch between a regulatory concept and the technical understanding of drones and autonomous systems has the potential to extend the delay between technological development and its regulation as well as perpetuate the disconnect between technology and law.

5.2 Safety Implications of Autonomy

The definition of autonomy should be understood in terms of the overall goal of the regulation, which is to ensure an acceptable level of safety. Generally, autonomous systems, to varying degrees, carry various safety implications that make effective regulation necessary. For instance, constraints of time and transition from automated to manual control can lead to accidents involving drones. HFE scholars have been studying this at length. Although a human, operating at a supervisory level, could intervene to stop the system, as in the case of swarm drones, such human supervision may not permit the exercise of control at the moment it is needed. A case in point is the 2018 fatal accident in the United States of America involving a self-driving car. The human in control of the brakes hit a jaywalker, killing her. In that case, although the human had the ability to exert control, the driver’s lack of attention hindered the driver’s effort to stop the car at the right time [60]. Automation bias is of relevance here which conveys the human tendency to rely too much on machines rather than human judgment. Some have speculated that increasing reliance on machines will inevitably render humans dull and inactive. Increased stress is also likely in the case of those humans responsible for but with no authority over the system [61].

Yet another safety-related issue concerns the system’s design. Burton and others show that complexity and unpredictability surrounding autonomous systems could hinder safety assurance at the design level.[12] In their first AI Roadmap, EASA also introduces a number of potential problems when a system is infused with ML techniques, among them explainability and the redundancy of the traditional safety assurance framework [62, p. 14]. As discussed earlier with respect to drone autonomization, ML techniques do enable autonomous functionality in drones.

The JARUS also split automated functions based on their impact on safety as, “safety independent functions”, “partially safety dependent functions”, and “safety dependent functions”. They consider that automation from levels 3 till 5 will have a medium to high impact on safety [43, p. 26–27]. These levels are further discussed later in the paper but what ought to be mentioned here is that level 3 automation bears supervisory control by humans whereas level 5 exhibits full automation without any possibility of human intervention. It indicates that safety risk enhances as human involvement depreciates. Given the potential for safety problems arising from a lack of active human control, inadequate regulation of drones that are less than fully autonomous is highly undesirable.

5.3 Incoherence with EU's AI regulatory approach

The EU is currently working on the AI Act which sets out broad requirements for AI systems [63]. Article 14 of that proposed Act requires “human oversight” for high-risk AI systems and intervention remains one of the elements of that requirement. The “high risk AI systems” include the AI systems that require conformity assessment[13] for their safe use and are part of the EU harmonized regulations mentioned in the annex to AI regulation.[14] Some drone operations would, therefore, fall into this category.[15] But, by virtue of the drone-specific regulation, the operations lacking any human intervention—which the regulation deems as “autonomous” operations—would still be permissible. EU's broader regulatory approach for high-risk AI systems is thus incoherent with EU drone regulations, as the former necessitates human oversight of systems posing high risk, but the latter allows operation where human intervention is completely absent.

[10] Light-UAS.2000(a)(4), Subpart A [59].

[11] GM1 UAS.OPEN.060(2)(d) [58] deals with the scope of “Open” category (low-risk operations which can be performed without formal authorization) while excluding “autonomous operation”. GM1 UAS.SPEC.050(1)(b) of the same instrument states that “autonomous operations” would be subject to authorization.

[12] Particularly as they highlight the ‘semantic gap’ which reflects difference between intended and specified functionalities [29].

[13] Conformity assessment is the process to ensure that a given product follows relevant safety requirements as prescribed in EU regulations.

[14] Article 6 [63].

[15] This is because the Basic Aviation Regulation [7] which also regulates drones is a part of the annex of the proposed AI Act; and conformity assessment is mandated under Parts 7 and 8 of Regulation (EU) 2019/945 [9].

Table 2 Taxonomy on drone autonomy adapted from Clough's work [67]

Levels	Description
Remotely Piloted	Humans make every decision
Remotely Operated[a]	Drone pilots itself but the actions to be performed such as, destination and consequent actions upon reaching the destination are decided by a human
Remotely Supervised	Drone executes its own tasks and human takes control upon failure of drone to execute them properly
Fully Autonomous	Humans set goals and drone designs its own tasks without human involvement; drone has full authority to make all the decisions

[a]Noteworthy is the distinctive use of the terms "piloted" and "operated"; the latter excludes manipulation of flight controls

In a nutshell, the prevailing regulatory definition of autonomy—because of its dichotomous nature—bears significant implications for the future. It could lengthen regulatory lag, lead to safety implications, and stands at odds with EU's regulatory approach towards AI. Given the regulatory implications just discussed, a strong case can be made for adopting a new way of regulating autonomy; one that abandons dichotomous categories and opts instead for understanding autonomy as falling along a spectrum.

6 Towards a Spectral Approach for Autonomy

Earlier in the paper, it was argued that to understand autonomy of any drone, one needs to look at the context within which autonomy manifests. This section delves deeper into such conceptual attempts made in technical literature and other autonomous technologies. Drawing from such an analysis, it is proposed to adopt a spectral approach instead of the dichotomous one.

6.1 Technical Conceptualization

Scholarly work offers taxonomies of varying complexity and starting points for comprehending autonomy. Parasuraman and others proposed four levels in such regard [64]. They consider information acquisition and information analysis as the initial two stages, followed by decision-making and action implementation function. A literature review on this topic [65] finds that Sheridan produced one of the most used taxonomies; it comprises ten levels based on six functions—"gets, selects, starts, requests, approves and tells" [66]. The reviewers conclude that there is no such thing as a "best" taxonomy and that the usefulness of a taxonomy is determined by the analytical character of its classifications. When it comes to the autonomy in drones specifically, Clough developed the following four-level classification scheme:

Using Clough's classification scheme, Wing delivery drones could fall into the third category of "remotely supervised". Noteworthy is the modifier "fully" before autonomous in the fourth category. Adding modifiers such as "partial", "semi", or "full" is another common approach to categorize autonomy. For instance, the US National Institute of Standards and Technology (NIST)—the US agency which works on measurement science, standards and technology—classifies autonomous operations as either "semi-" or "fully-" autonomous [68, p. 22]. Accordingly, the latter system accomplishes the assigned goal while adapting to its environment without human intervention. Semi-autonomous operations, however, require various degrees of human–robot interaction. In such systems, autonomy is exercised in between moments of human–robot interaction. Although providing a word or prefix to modify "autonomous" is less precise than the taxonomies in Table 2; doing so produces far less vagueness than simply employing the word autonomous or autonomy.

Laying emphasis on the operational context to assess the level of autonomy, Lee and others divide drones' navigational autonomy into five levels, and their navigational capacity into nine functions (among them, "obstacle detection", "collision avoidance", "environment distinction", and "take off/landing") [69].[16] This is closer to more functional approach as it invites attention to the relevant goals—not entire operation—that are achieved by the drone without external intervention [70]. Following a similar contextual approach, JARUS introduced following scale to comprehend drone automation [43]:

Level 0 "Manual operation": Humans perform all the functions without any machine support.
Level 1 "Assisted operation": Assistance to humans by, for example, providing information.
Level 3 "Supervised automation": Machine functions and human supervises with intervening capability.
Level 4 "Manage by exception": Machine functions and human intervenes only when alerted by the machine.

[16] Similar approach has been adopted to split autonomy in terms of DAA capability [24, p. 7].

Level 5 "Full automation": Machine functions and humans are unable to intervene.

Although autonomy taxonomies in the literature offer greater precision than regulatory ones, they also contain some ambiguities. For instance, Vagia and others find that although etymologically, "automation" and "autonomy" are distinct words, scholars have been using them interchangeably [65]. They note that many authors prefer "automation" over "autonomy", even when referring to systems that are technically autonomous, perhaps because they are more familiar with that term. Even JARUS makes classification in terms of automation and not autonomy; the premise being that autonomy manifests at a broader operational level and automation at both operational and functional level of a system. Here, one may question if the EU law could make use of such interchangeability of these terms—automation carrying the purport for autonomy. Here, the definition of "automation" as tabulated above can arguably be a hindrance. This is because "pre-programmed instructions" remain a sine qua non for automation—leaving no room for systems with self-deterministic capabilities. Hence, classifying automation, instead of autonomy, could create further incoherence.

6.2 Conceptualization in other Autonomous Systems

That autonomy is not an either/or condition but lies along a continuum has also been recognized in efforts to conceptualize other autonomous technologies, notably Autonomous Weapon Systems (AWS), self-driving cars, and the Maritime Autonomous Ship System (MASS). Interestingly, EASA also follows such an approach in context of broader aviation, including manned aviation, though taking somewhat contrasting stance in drone specific framework.

Autonomy in weapon systems is generally perceived through human operator's involvement in the operational loop where supervisory control is somehow seen as "human-on-the-loop" or "semi-autonomous"—distinct from fully autonomous weapon systems [37]. Self-driving cars, moreover, stand out as a technology for which one autonomy classification scheme has generally been embraced in industry, academic and policymaking circles. This scheme was introduced by the Society of Automotive Engineers (SAE) International—a global association of experts from automotive and aerospace industries—identifying six levels (0–5) of autonomy [71]. According to this taxonomy, human control diminishes from level 3 upwards, whereas a human is involved in an active or supervisory role in levels 0 through 2. In the drone sector too, scholars have tried to replicate this classification [24, 42, 69]. Lastly, in maritime sector, the International Maritime Organization (IMO)—the United Nations agency responsible for maritime safety—has been trying to bring MASS into sync with the existing framework, somewhat akin to EASA's catch-up with drone technology in the aviation sector. For this purpose, IMO conducted a scoping exercise in 2019, by which it defined MASS as "A ship which, to a varying degree, can operate independent of human interaction" [72, p.3]. The inclusion in this definition of the qualifying words "to a varying degree" offers space to distinguish levels of autonomy and thereby prevents the definition from being an either/or proposition. These conceptualization efforts all avoid setting a fixed, high threshold for autonomy, and instead create possibilities for recognizing levels or degrees of autonomy.

In the recently published AI roadmap for aviation sector, EASA also follows a spectral approach predicting the trajectory of AI related advancements and rule-making [73, 64], and split levels not under the heading of "automation" or "autonomy", rather "AI/ML". Accordingly, the first level AI/ML system would be assisting the humans, and the second level would exhibit human–machine collaboration and cooperation. Lastly, level 3 AI/ML would face reduction of the ability for human to override a system to complete absence of such ability at level 3B. Within that document, EASA's conception of "automation" and "autonomy" also stands at odds with the drone regulation. While seeking conceptual support from a technical standard, namely ISO/IEC 22989:2022 "Information technology—Artificial Intelligence—Artificial Intelligence concepts and terminology", human intervention is made part and parcel of "automation". Moreover, autonomy is defined as the capability of a system to modify its domain of use without "external intervention, control or oversight" [73, p.30]. This stands in direct contrast to conception of these two terms within drone specific framework where the lack of human intervention is the sole determining feature of autonomy.

6.3 Spectral Approach

Scholars' conceptualization attempts and the efforts to understand autonomy with respect to AWS, self-driving cars, and MASS suggest the benefits of adopting a spectral approach to autonomy. This also goes for the EASA's approach in their AI roadmap which contains leveled approach albeit, calling it AI/ML levels. Such an approach differs significantly from the prevailing regulatory conception of autonomy, which is dichotomous and inflexible, and therefore cannot capture the complexity of drone operation. Currently, there is no recognized taxonomy for drone autonomy along the lines of that developed by SAE for self-driving cars. For this reason, EASA deferred further guidance on the matter.[17]

[17] GM1 UAS.SPEC.050(1)(b) [58].

Perhaps, the recent methodology adopted by JARUS might attain that status, but it is too early to consider that to be the case.

Until greater clarity regarding the autonomous functionality of drones is reached, the regulation can benefit from a definition of autonomy that is "spectral": that any system that is free of human control—that is, fully autonomous—lies at one end of a spectrum, and any system that is controlled by humans throughout its operation—that is, non-autonomous—lies at the other end. Understanding autonomy as falling along a spectrum makes sense. By spectral approach, it does not mean that the regulation should define clear thresholds or levels of autonomy. Rather, the definition should provide room for future work on the leveled approach. It could, for instance, resemble the MASS definition proposed by IMO. This spectral approach recognizes that some operations have autonomous functions or capabilities without themselves being fully autonomous. Additionally, a spectral classification scheme, rather than a dichotomous one, can better accommodate types of drones not yet developed that will undoubtedly express varying degrees of autonomy.

EASA's abstinence regarding further guidance around autonomy levels in drones is owed to the lack of global acceptance around this subject. In this way, EASA does recognize the presence, albeit uncertainty, of non-binary nature of autonomy. Adopting such an approach would obviously invite questions around the context of autonomy and levels to target within such context. Once wider clarity is gained on that subject, the agency will be able to better accommodate the levels in a spectral—instead of dichotomous—definition. To frame such a spectral definition of autonomy, support could be sought from the scholarly and conceptual work discussed above. The definition need not deal with levels of autonomy; instead, it could also focus on the matter of "control". Scholars have made a similar suggestion for the UK regulation of AWS [36]. Those regulations also set too high a threshold for autonomous systems and leave out existing systems that fall into a gray area or lump them in with "automatic" weapons. They thus miss the opportunity to deal with the legal and ethical issues of those systems. Arraying the extent of human control along a spectrum would facilitate a focus on this feature, which needs regulatory intervention.

6.4 Addressal of Regulatory Implications

The prevailing definition of autonomy as found in EU drone regulation can cause regulatory issues as discussed earlier. Adoption of a spectral approach heads off potential problems by curtailing the regulatory lag, ensuring more safety, and allowing coherence with AI related framework.

The mismatch between the technical and regulatory understandings of autonomy will enhance the lag-time between developments in technology and the laws that govern them. When it comes to the regulation of technology, flexibility is essential, and a spectral approach would provide a better flexibility than the prevailing dichotomous approach. This is so because it will allow more focused safety regulation of drones with varied nature of autonomy. As more clarity around technological development is gained, regulators could work on more concrete classification. A spectral approach, in this regard, would provide a ground for that. In terms of safety oversight, a regulatory focus on differently autonomized operations could allow for improved regulation. For example, it could allow regulators to focus on operations that are autonomous but not fully autonomous, which current regulations fail to recognize. Regulators could then better deal with the human factor issues arising from reduced but not entirely absent human involvement in drone operation. Lastly, potential tension between drone regulation and EU's regulatory approach towards AI can be addressed by defining autonomy in a way that takes into consideration a variety of forms of autonomous operations. The current definition of autonomy encompasses only fully autonomous operations and thus hampers rather than facilitates human oversight. Indeed, JARUS also recognizes the need to have a common framework on different levels of automation and autonomy to support the regulatory development around this subject, therefore it developed the specific methodology quite recently [43, p.10]. This action by a drone standardization body further testifies to the regulatory need of having a common understanding of automation and autonomy.

7 Conclusion

The conceptual issue discussed here is another case of challenges arising from regulating a sociotechnical change brought about by autonomous technologies. Autonomy, as defined in the drone regulations of the EU, UK, and Australia, is out of sync with the technical meaning of the term and tends to be under-inclusive. This lack of sync means that there are attributes, implications and facets of technology that stay outside the coverage of law. This paper has shown the use of better consideration of a technical understanding of autonomy to deal with underlying implications. Perceiving autonomy as a self-deterministic quality, it can be embedded in drone technology from various fronts, such as navigation or DAA capabilities. However, the regulation contains a dichotomous, either/or definition, whereby only fully autonomous drone operation are deemed as "autonomous". While the EU is making efforts to address the implications of drone technology, the current under-inclusive approach carries significant implications for the EU, notably with respect to regulatory lag, ensuring safety, and potential incoherence with EU's regulatory approach towards AI. Here, a spectral approach. Here, a spectral approach could counter these issues, leaving room for further gradation of autonomy. This would bring more flexibility to the concept of autonomy as well as make it adaptable to future developments, such as the population of the civilian airspace by varied forms of autonomous drones. By bridging the disconnect between the regulatory and technical understandings around autonomy, this approach may curtail the regulatory lag. Moreover, human control can be regulated in a better manner for safety reasons by broadening the term autonomy to incorporate different forms of control. This speaks directly to ensuring effective safety and could be useful in harmonizing the human oversight requirement of the (proposed) EU AI Act and the drone regulation. As drone technology is planned to be integrated in society, it may be worthwhile to study the political facet of the current regulatory approach with a view to be cautious of its implications [74]. Future research is also needed to understand the safety–critical contexts within which drone autonomy manifests and legal ways to regulate them.

Acknowledgements Work on this article was conducted under the aegis of the research project 'RegulAIR: The integration of drones in the Norwegian and European Airspaces' funded by the Research Council of Norway. Thanks go to that institution for support and to my colleagues at Peace Research Institute Oslo—particularly Bruno Oliveira Martins and Kristin B. Sandvik—for their important feedback on my earlier drafts. Previous versions of this article were also presented at the 37th Nordic Conference on Law and Information Technology and at the Research Group on Law and Technology at the University of Oslo. I'm grateful for the feedback that I received from the participants.

Authors' Contribution Does not apply as it is a single authored article.

Funding Open access funding provided by University of Oslo (incl Oslo University Hospital). The research leading to these results received funding from Research Council of Norway under Grant Agreement No. 314615.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Ethics Approval This article does not require approval from national research ethics committee.

Consent to Participate No individual was asked to participate in this study. Hence, the requirement of consent does not apply.

Consent to Publish No individual was asked to participate in this study. Hence, the requirement of consent does not apply.

Conflict of Interest The author has no relevant financial or non-financial interests to disclose.

References

1. Frankelius, P., Norrman, C., Johansen, K.: Agricultural Innovation and the Role of Institutions: Lessons from the Game of Drones. J. Agric. Environ. Ethics **32**, 681–707 (2019). https://doi.org/10.1007/s10806-017-9703-6
2. ReportLinker, 'The Drone Package Delivery Market Is Projected to Grow from USD 228 Million in 2022 to USD 5,556 Million by 2030, at a CAGR of 49.0% from 2022 to 2030' (GlobeNewswire News Room, 17 May 2022) <https://www.globenewswire.com/news-release/2022/05/17/2444615/0/en/The-drone-package-delivery-market-is-projected-to-grow-from-USD-228-million-in-2022-to-USD-5-556-million-by-2030-at-a-CAGR-of-49-0-from-2022-to-2030.html> accessed 16 June 2023
3. 'RoboBees: Autonomous Flying Microrobots' (Wyss Institute, 5 August 2016) <https://wyss.harvard.edu/technology/robobees-autonomous-flying-microrobots/> accessed 23 Dec 2022
4. European Commission, 'A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe' COM(2022) 652.
5. Scott, B.I., Andritsos, K.I.: A Drone Strategy 2.0 for a smart and sustainable unmanned aircraft eco-system in Europe. Air Space Law **48**(3), 273–296 (2023). https://doi.org/10.54648/aila2023041
6. Nawaz, S.A.: Conflicting visions around technology integration: A look at recent EU drone policies. Contemp. Eur. Polit. **1**, e4 (2023). https://doi.org/10.1002/cep4.4
7. Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91
8. Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft.
9. Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems C/2019/1821.
10. McLachlan, S. and others. The Chaotic State of UK Drone Regulation. arXiv:2205.01041 https://arxiv.org/abs/2205.01041 (2022). Accessed 16 June 2023.
11. Ellerbeck, S.: 'The UK plans to launch the world's biggest drone superhighway. Could it really create 650,000 jobs?' World Economic Forum, 2 August 2022 https://www.weforum.org/agenda/2022/08/drones-superhighway-economy-technology/. Accessed 23 Dec 2022
12. Department of Industry, Science and Resources, Australian Government, 'Digital Economy Strategy 2030' Australian Government https://digitaleconomy.pmc.gov.au/sites/default/files/2021-07/digital-economy-strategy.pdf (2021). Accessed 16 June 2023

13. Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W.S., Wilson, J.R., van der Doelen, B.: A strategy for human factors/ergonomics: developing the discipline and profession. Ergonomics **55**(4), 377–395 (2012). https://doi.org/10.1080/00140139.2012.661087
14. Kasprzyk, P.: The Basic Premises of EU Regulations Regarding the Safety of Unmanned Aircraft in the Context of their Development Process. J. Intell. Robot. Syst. **106**(2), 38 (2022). https://doi.org/10.1007/s10846-022-01733-x
15. Uva, R.S., Rebane, G.: EASA Regulations and the Operation of Unmanned Aircraft: An Overview. In: Scott, B.I. (ed.) The Law of Unmanned Aircraft Systems, 2nd edn. Kluwer Law International (2022)
16. Schrijver, S.: Commercial Use of Drones: Commercial Drones Facing Legal Turbulence: Towards a New Legal Framework in the EU [2019] US-China Law Review **16**(8), 338–354
17. Alamouri, A., Lampert, A., Gerke, M.: An Exploratory Investigation of UAS Regulations in Europe and the Impact on Effective Use and Economic Potential. Drones **5**(3), 63 (2021)
18. Pagallo, U., Bassi, E.: The Governance of Unmanned Aircraft Systems (UAS): Aviation Law, Human Rights, and the Free Movement of Data in the EU. Mind. Mach. **30**, 439–455 (2020). https://doi.org/10.1007/s11023-020-09541-8
19. Konert, A., Dunin, T.: A Harmonized European Drone Market? – New EU Rules on Unmanned Aircraft Systems. Adv. Sci. Technol. Eng. Syst. J. **5**(3), 93–99 (2020)
20. Huttunen, M.T.: Unmanned, remotely piloted, or something else? Analysing the terminological dogfight. Air Space Law **42**(3), 349–368 (2017)
21. Scott, B.I., Veloso, G.: Terminology, Definitions and Classifications. In: Scott, B.I. (ed.) The Law of Unmanned Aircraft Systems, 2nd edn. Kluwer Law International (2022)
22. Clarke, R., Moses, L.: 'The regulation of civilian drones' Impacts on Public Safety. Comput. Law Secur. Rev. **30**, 263 (2014)
23. Custers, B.: Flying to New Destinations: The Future of Drones. In: Custers, B. (ed.) The Future of Drone Use: Opportunities and Threats from Ethical and Legal Perspectives. Information Technology and Law Series. T.M.C. Asser Press, The Hague (2016)
24. Matalonga, S., White, S., Hartmann, J., et al.: A Review of the Legal, Regulatory and Practical Aspects Needed to Unlock Autonomous Beyond Visual Line of Sight Unmanned Aircraft Systems Operations. J. Intell. Robot. Syst. **106**, 10 (2022). https://doi.org/10.1007/s10846-022-01682-5
25. Huttunen, M.: Sociotechnical Change and Law: The Case of Unmanned Aircraft Systems. In: Scott, B.I. (ed.) The Law of Unmanned Aircraft Systems, 2nd edn. Kluwer Law International (2022)
26. Scott, B.: Open Skies for Unmanned Aircraft in Europe: An Outlier or a New Approach? Air Space Law **46**(1), 57–80 (2021). https://doi.org/10.54648/AILA2021003
27. Brownsword, R.: Autonomy, delegation, and responsibility: agents in autonomic computing environments. In: Law, Human Agency and Autonomic Computing. The Philosophy of Law meets the Philosophy of Technology Hildebrandt, M. and Rouvroy, A. (eds.) A GlassHouse Book. Routledge, Abingdon (2011)
28. Mul, J., Berg, B.: Remote control: human autonomy in the age of computer-mediated agency. In: Law, Human Agency and Autonomic Computing. The Philosophy of Law meets the Philosophy of Technology Hildebrandt, M. and Rouvroy, A. (eds.) A GlassHouse Book. Routledge, Abingdon (2011)
29. Burton, S., et al.: Mind the gaps: assuring the safety of autonomous systems from an engineering, ethical, and legal perspective. Artif. Intell. **279**, 103201 (2020)
30. Mik, E.: The Erosion of Autonomy in Online Consumer Transactions. Law Innov. Technol. **8**(1), 1–38 (2016)
31. Pagallo, U.: Cracking down on autonomy: three challenges to design in IT Law. Ethics Inf. Technol. **14**, 319–328 (2012). https://doi.org/10.1007/s10676-012-9295-9
32. Vellinga, N.: Automated driving and its challenges to international traffic law: Which way to go? Law Innov. Technol. **11**, 257 (2019)
33. Taeihagh, A., Lim, H.: Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks. Transp. Rev. **39**, 103 (2019)
34. Clarke, R.: Understanding the Drone Epidemic. Comput. Law Secur. Rev. **30**, 230 (2014)
35. Firlej, M., Taeihagh, A.: Regulating human control over autonomous systems. Regul. Gov. **15**(4), 1071–1091 (2020)
36. Taddeo, M., Blanchard, A.: A comparative analysis of the definitions of autonomous weapons systems. Sci. Eng. Ethics **28**(5), 37 (2022). https://doi.org/10.1007/s11948-022-00392-3
37. Anderson, K., Waxman, M.: Debating Autonomous Weapon Systems, their Ethics, and their Regulation under International Law. In: Brownsword, R., Scotford, E., Yeung, K. (eds.) The Oxford Handbook of Law, Regulation, and Technology. Oxford University Press pp. 1097–1117 (2017). https://doi.org/10.1093/oxfordhb/9780199680832.013.33
38. Antsaklis, P., et al.: Autonomy in Engineering Systems: What is it and Why is it Important? Proceedings of the 1998 IEEE ISIC/CIRA/ISAS Joint Conference Gaithersburg, MD 0 September 14–17 (1998)
39. Hancock, P.: Imposing limits on autonomous systems. Ergonomics **60**(2), 284–291 (2017)
40. Heater, B.: Alphabet's Wing drones hit 200,000 deliveries as it announces supermarket partnership. TechCrunch, 23 Dec 2022 https://techcrunch.com/2022/03/01/alphabets-wing-drones-hit-200000-delivers-as-it-announces-supermarket-partnership/. Accessed 23 Dec 2022
41. Civil Aviation Safety Authority (CASA). Australia 'Drone delivery services' 10 January 2023 https://www.casa.gov.au/drones/industry-initiatives/drone-delivery-services. Accessed 16 June 2023
42. European Cockpit Association (ECA). 'Unmanned Aircraft Systems and the concepts of Automation and Autonomy' (European Cockpit Association (ECA) Briefing Paper 23 April 2020) https://www.eurocockpit.be/sites/default/files/2020-04/Automation_Autonomy_ECA_Briefing_Paper_20_0423_F.pdf. 3 Accessed 16 June 2023
43. WG-AW. JARUS Methodology for Evaluation of Automation for UAS Operations. Joint Authorities for Rulemaking of Unmanned Systems (JARUS) 25 April 2023 http://jarus-rpas.org/wp-content/uploads/2023/06/jar_21_doc_JARUS_Methodology_for_Evaluation_of_Automation_for_UAS_Operations.pdf. accessed 16 June 2023, 11
44. Scherer, M.: Regulating artificial intelligence systems: risks, challenges, competencies, and strategies. Harv. J. Law Technol. **29**;Number 2, pp. 353–400 (2016).
45. Häuselmann, A. Disciplines of AI: An Overview of Approaches and Techniques. In: Custers, B. and Fosch-Villaronga, E. (eds), Law and Artificial Intelligence, vol 35. TMC Asser Press (2022)
46. Mirtajadini, S.H., Fahimi, H., Shahbazi, M.: A Framework for Vision-Based Building Detection and Entering for Autonomous Delivery Drones. J. Intell. Robot. Syst. **107**, 46 (2023). https://doi.org/10.1007/s10846-023-01834-11
47. Rodriguez-Ramos, A., Sampedro, C., Bavle, H., et al.: A Deep Reinforcement Learning Strategy for UAV Autonomous Landing on a Moving Platform. J. Intell. Robot. Syst. **93**, 351–366 (2019). https://doi.org/10.1007/s10846-018-0891-8
48. Duffy, B., et al: Sense and Avoid Characterization of the ICAROUS Architecture. NASA/TM–2020–220591, May 2020 https://shemesh.larc.nasa.gov/fm/papers/NASA-TM-2020-220591.pdf. Accessed 16 June 2023

49. Sylvester, G. (ed): E-Agriculture in Action: Drones for Agriculture. Food and Agriculture Organization of the United Nations and International Telecommunication Union, Bangkok (2018)
50. U.S. Government Accountability Office. Science & Tech Spotlight: Drone Swarm Technologies. GAO-23–106930 https://www.gao.gov/assets/gao-23-106930.pdf. Accessed 16 June 2023
51. European Union Aviation Safety Agency (EASA). ED Decision 2019/021/R
52. Civil Aviation Safety Authority (CASA) Australia. Remotely piloted aircraft systems - licensing and operations. Advisory Circular AC 101–01v4.0 CASA
53. Australian Civil Aviation Act 1988 No. 63, 1988
54. Civil Aviation Authority (CAA) UK. Unmanned Aircraft System Operations in UK Airspace – Guidance. CAP 722 UK CAA. Available at: https://www.caa.co.uk/media/uwynsupf/cap722-edition8-p.pdf. Accessed 16 June 2023
55. Schnitker, R., Kaar, D.: Drone Law and Policy: Integration Into the Legal Order of Civil Aviation. Eleven International Publishing (Essential air and space law) (2021)
56. Scott, B., Veloso, G.: Terminology, Definitions and Classifications. In: Scott, B. (ed.) The Law of Unmanned Aircraft Systems, 2nd edn. Kluwer Law International (2022)
57. Collingridge, D.: The Social Control of Technology. Frances Pinter, London (1980)
58. EASA. Annex II to ED Decision 2019/021/R. Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Part-UAS UAS operations in the 'open' and 'specific' categories Issue 1, 9 October 2019.
59. EASA. Special Condition for Light Unmanned Aircraft Systems - Medium Risk. (SC Light-UAS Medium Risk 01), 17 December 2020.
60. T.S. Why Uber's self-driving car killed a pedestrian. The Economist (29 May 2018) https://www.economist.com/the-economist-explains/2018/05/29/why-ubers-self-driving-car-killed-a-pedestrian. Accessed 16 June 2023
61. Hancock, P.: Some pitfalls in the promises of automated and autonomous vehicles. Ergonomics **62**(4), 479–495 (2019)
62. EASA. Artificial Intelligence Roadmap A human-centric approach to AI in aviation. 07 February 2020
63. (Proposed) EU AI Act (Commission Proposal for a Regulation of the European Parliament and of the Council laying down harmonized rules on Artificial Intelligence (Artificial Intelligence Act) and amending certain Union Legislative Acts COM(2021) 206 final 2021/0106(COD)) sets out 'human oversight' as a necessary requirement for high-risk AI systems
64. Parasuraman, R., Sheridan, T.B., Wickens, C.D.: A model for types and levels of human interaction with automation. IEEE Trans Syst Man Cybern A Syst Hum. **30**(3), 286–297 (2000). https://doi.org/10.1109/3468.844354
65. Vagia, M., Transeth, A.A., Fjerdingen, S.A.: A literature review on the levels of automation during the years. What are the different taxonomies that have been proposed? Appl Ergon. **53**(Pt A), 190–202 (2016). https://doi.org/10.1016/j.apergo.2015.09.013
66. Sheridan, T.: Telerobotics, automation, and human supervisory control. MIT press (1992)
67. Clough, B.: Metrics, schmetrics! How the heck do you determine a UAV's autonomy anyway. Air Force Research Lab Wright-Patterson AFB OH. https://apps.dtic.mil/sti/pdfs/ADA515926.pdf (2002). Accessed 5 September 2023.
68. Huang, H. (ed).: Autonomy Levels for Unmanned Systems (ALFUS) Framework Volume I: Terminology Version 2.0. NIST Special Publication https://www.nist.gov/system/files/documents/el/isd/ks/NISTSP_1011-I-2-0.pdf (2008). Accessed on 5 Sept 2023
69. Lee, T., Mckeever, S., Courtney, J.: Flying Free: A Research Overview of Deep Learning in Drone Navigation Autonomy. Drones **5**, 52 (2021). https://doi.org/10.3390/drones5020052
70. Antsaklis, P.J., Rahnama, A.: Control and machine intelligence for system autonomy. J. Intell. Robot. Syst. **91**, 23–34 (2018). https://doi.org/10.1007/s10846-018-0832-6
71. SAE International. SAE Levels of Driving Automation^{TM} Refined for Clarity and International Audience. May 3, 2021 https://www.sae.org/site/blog/sae-j3016-update. Accessed on 23 Aug 2023
72. International Maritime Organization (IMO). Outcome of the Regulatory Scoping Exercise for the use of Maritime Autonomous Surface Ships (Mass). IMO MSC.1/Circ.1638. 03 June, 2021 https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/MSC.1-Circ.1638%20-%20Outcome%20Of%20The%20Regulatory%20Scoping%20ExerciseFor%20The%20Use%20Of%20Maritime%20Autonomous%20Surface%20Ships...%20(Secretariat).pdf. Accessed 16 June 2023
73. EASA. Artificial Intelligence Roadmap 2.0 A human-centric approach to AI in aviation. 10 May, 2023
74. Martins, B.O., Lavallée, C., Silkoset, A.: Drone Use for COVID-19 Related Problems: Techno-solutionism and its Societal Implications. Glob. Policy **12**, 603–612 (2021). https://doi.org/10.1111/1758-5899.13007

Samar Abbas Nawaz Doctoral Researcher at Peace Research Institute Oslo (PRIO).