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POLICY BRIEF

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THE REGULATION OF EMERGING RISKS IN SWARM DRONE TECHNOLOGIES

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What are Swarm Drones?

According to the US Government Accountability Office (GAO)[1], drone swarms are coordinated assemblies of three or more drones, which can scale to thousands, and execute missions with minimal human oversight. Using swarm intelligence modeled after biological systems, these drones leverage AI and machine learning to counter obstacles such as GPS jamming, signal interference, and hostile environments, while maintaining synchrony through centralized or distributed control.

A swarm consists of more than simply a group of unmanned aerial vehicles (UAVs) operating at the same time. True drone swarms demonstrate swarm intelligence, which is a collective behavior arising from decentralized units following simple operational rules. Inspired by social insects, like bees or ants, each drone relies on local sensing and minimal communication to navigate, avoid obstacles, and adjust to neighboring drones.

Swarm algorithms such as Boids and Consensus[2] facilitate this by enabling drones to maintain formation and accomplish complex tasks cooperatively. For example, China's 2017 fixed wing swarm test[3] demonstrated autonomous drones performing coordinated maneuvers without direct human control. Similarly, the U.S. Perdix demonstration[4] showcased small autonomous drones working in real time to complete complex missions, highlighting the benefits of decentralized decision making.

Unlike standard multi drone operations that are typically centralized with prescripted behaviors, swarms operate with decentralized control, where each unit can respond dynamically to its environment and other units.

Taxonomy

UAV swarms use fixed wing drones for long range missions, rotary wing multirotors for precise maneuvering, single rotor drones for heavy payloads, hybrid VTOLs for versatile flight, and nano/micro drones for stealth and indoor tasks.[5] Their missions include intelligence, surveillance, reconnaissance (ISR), strike operations, electronic warfare, communication relay, and logistics. Swarm behaviors feature flocking to avoid collisions, sweep patterns for surveillance, encirclement for attacks, and saturation attacks to overwhelm defenses. Control architectures can be centralized, which risks a single point of failure, or decentralized, allowing autonomous interaction, resilience, and self healing. Human control modes vary from in-the-loop, on-the-loop, to out-of-the-loop, affecting ethical oversight and accountability. Sensors such as barometric, temperature, proximity, inertial measurement units, and GPS provide environmental awareness and navigation. Communication networks form mesh links for fast data sharing but face risks like jamming and cyber threats, requiring secure technologies like 5G and blockchain. The figure bellows explains the taxonomy.

Challenges in Regulating Swarm Drones

The technological characteristics and operational complexities, rooted in autonomous AI driven behaviors, directly inform the subsequent legal and regulatory challenges.

Definitional Ambiguity and Lack of Unified Legal Terminology

One of the foremost challenges in regulating swarm drones lies in the absence of a universally accepted legal definition. Existing legal frameworks governing UAVs rely heavily on the purpose and manner of their use in determining legality. While this approach has worked for individual drones, the exponential increase in capabilities, risks, and autonomy associated with swarm technology creates unique regulatory complexities.[6] The lack of clarity raises fundamental questions regarding liability, as the collective and partially autonomous nature of swarms blurs traditional lines of accountability. Determining whether responsibility should rest with the operator, programmer, or manufacturer becomes increasingly uncertain in the absence of a shared definitional baseline.[7]

Although no international consensus currently exists, attempts have been made to conceptualize swarm drone operations across different domains. Technical experts, such as Irving Lachow[8], describe swarms as "distributed collaborative systems... flocks of small unmanned aerial vehicles that can move and act as a group with only limited human intervention." Military definitions, exemplified by the U.S. Department of Defense, frame swarms as "large numbers of dispersed individuals or small groups coordinating together and fighting as a coherent whole."[9] International legal perspectives, such as those advanced by the International Committee of the Red Cross (ICRC)[10], regard swarms primarily as weapons platforms, assessing their legality through the prism of existing rules of IHL.

This ambiguity risks not only inconsistent regulation but also uneven accountability, as different actors may interpret swarm use through technical, operational, or humanitarian lenses.

Cybersecurity Vulnerabilities

Swarm drones are inherently vulnerable to cyber threats. Communication, a critical aspect of these swarms, exposes them to such threats. Each drone typically acts as both transmitter and receiver, creating a mesh network that allows quick sharing of information and distributed decision making. This network must handle large volumes of data and resist interference. However, these decentralized networks, while providing autonomy and flexibility, introduce vulnerabilities like crowded radio frequencies and cyber threats, including jamming, spoofing, and the injection of false data to disrupt operations.[11]

New technologies like 5G, edge computing, and blockchain can help secure and accelerate communications, but they also introduce complexity and potential weak points that require robust system design to maintain swarm reliability and security.

Beyond communication, swarm drones face significant exposure to cyber physical attacks targeting sensors, actuators, or navigation systems. Exploiting these vulnerabilities allows adversaries to remotely manipulate drone behavior, potentially causing a total loss of control that can lead to catastrophic consequence.

To manage these risks, robust human oversight systems are essential, enabling operators to intervene even when communications are degraded. For instance, one control

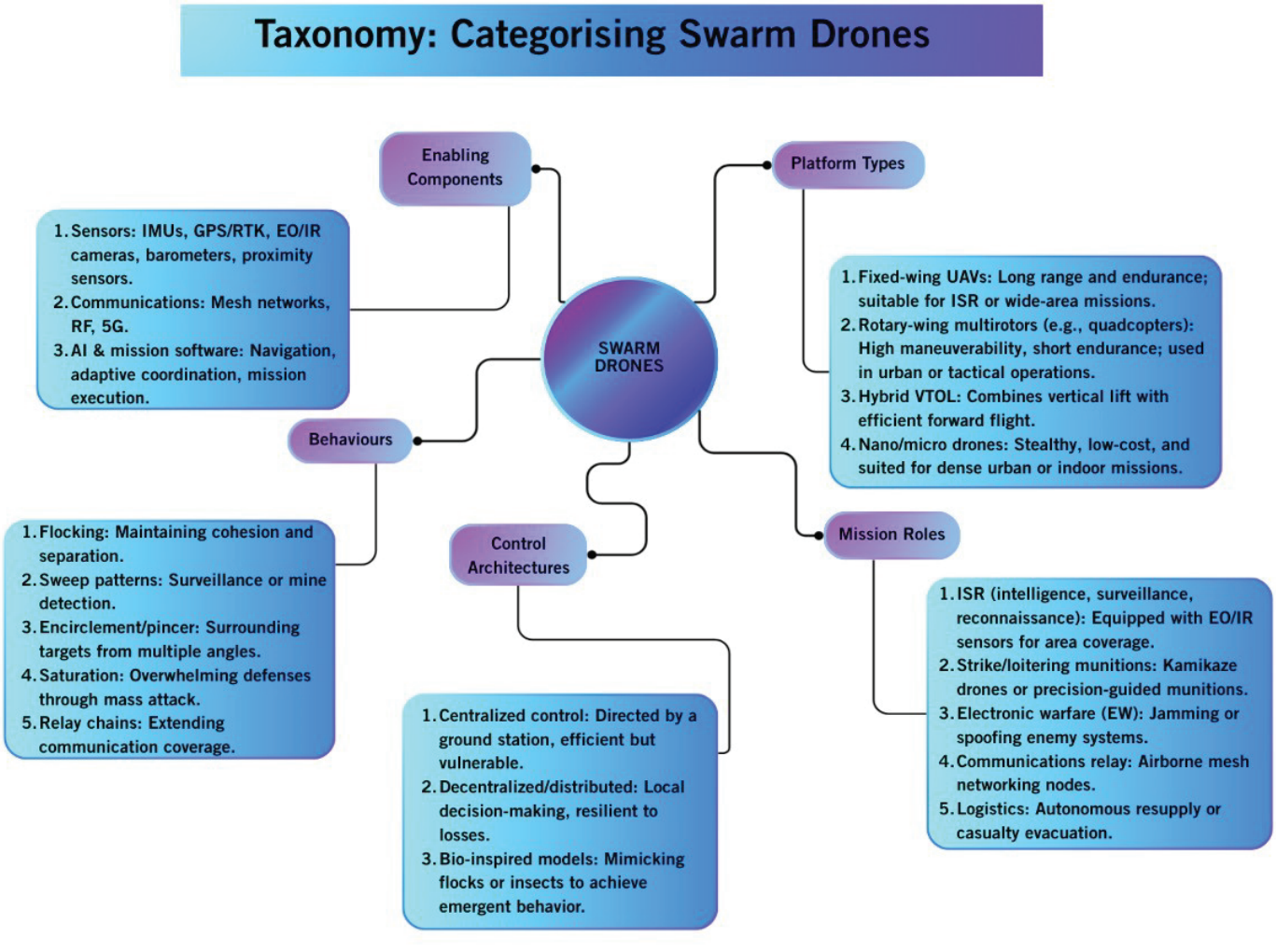

Figure 1: Taxonomy: Categorising Swarm Drones
Source: Author's Own Construct

model allows operators to halt swarm actions within three seconds under strong signal conditions. Another more realistic approach provides up to thirty seconds for intervention when signals are weak. Recent military exercises demonstrate that longer intervention windows may be necessary in complex environments. These models establish clear rules for human oversight, which is especially critical given the high risk of unintended escalation when lethal decisions are delegated to autonomous algorithms.[12]

Classification Challenges in Arms Control Regimes

Swarm drones present significant challenges to legal classification under existing arms control regimes. Traditional arms control frameworks primarily regulate distinct categories such as UAV, missiles, or conventional munitions, each with established definitions and thresholds of destruction. This raises legal uncertainty and controversy, as existing frameworks struggle to determine whether swarms should be regulated as UAVs, loitering munitions, or entirely new categories of weapons.13

Experts have highlighted the difficulty of classification with reference to smaller systems that can serve multiple functions depending on mission requirements. For instance, Hambling[14] notes that some UAVs are designed as payload carriers but can also be fitted with explosives for direct strikes, making distinctions between UAVs and loitering munitions increasingly arbitrary. Similarly, Matthew Bolton and Wim Zwijnenburg point to platforms such as the "Switchblade,"[15] described by its manufacturer as a "miniature flying lethal missile" that can be operated manually or autonomously. This example illustrates the broader challenge. Should such systems be categorized as combat aircraft, missiles, or munitions for the purposes of arms control treaties like the Arms Trade Treaty (2013) or the UN Register of Conventional Arms?

Recent Developments and Case Studies

Modern warfare has evolved as swarm technologies have transitioned from experimental to regular military use. This shift raises a key question: How does swarming impact military deterrence? The next case studies examine how swarms impact the balance of cost, speed, and responsibility in conflict, and how they shape military thinking regarding deterrence, escalation, and the balance between offense and defense.

U.S. Perdix Demonstration (2016)

The 2016 Perdix test is often seen as the starting point for modern swarm warfare. When the U.S. released 103 micro-UAVs from F/A-18 aircraft, it demonstrated that decentralized rules could lead to organized group behavior without central control. From a doctrinal point of view, Perdix demonstrated that swarms are not merely groups meant to be lost, but rather act more like adaptive organisms. They can recover and keep working after losses, which David Kilcullen might call "resilience through redundancy."[16] Strategically, the test suggested that teams of manned and unmanned systems will depend more on new, spontaneous behaviors rather than fixed commands. This marks a move from top down control to more distributed systems.

Saudi Aramco Attack (2019)[17]

The September 2019 attack on Abqaiq and Khurais, which used both drones and cruise missiles, put swarm logic into practice. By sending numerous low cost systems from different directions, the attackers caused significantly greater damage than the cost of their weapons, temporarily halving Saudi oil production. The lesson is not about technology, but rather about economics and scale. When dozens of inexpensive systems can impose multi billion dollar losses, the offense–defense balance tilts dramatically. As Paul Scharre has argued in his book Army of None, the advantage goes to the actor able to "flood the zone" with cheap precision, thereby overwhelming air defenses optimized for scarce and expensive threats.

Nagorno-Karabagh Conflict (2020-2023)

This conflict is often considered an inflection point by analysts when it comes to military strategy and warfare related to drones.[18] This evolution demonstrated how drones could also be used as central systems of warfare within a multidomain campaign. The targeted use of drone technology by Azerbaijan generated a novel relationship between precision, visibility, and survivability on the battlefield. The Nagorno-Karabagh conflict unveiled a novel and strategic use of drone technology, whereby challeneging the existing air defence architectures that are optimized for high signature and speedy aircrafts compared to the use of low cost and efficient drone tech[19]. Azerbaijan through Turkish drone technology over powered Armenia, showing how states without high value air crafts can be capable of success through a combination of unmaaned platforms, real-time targeting and sustained, information led attacks. While Azerbaijan had no such command in aerial warfare, but its strategy to deploy drones to exploit significant gaps in the Armenian air defence systems gave them the space to use air to its advantage[20]. However, many analysts claim that the Azeris had an upperhand mainly because of oversight by the Armenians back then, and not necessarily because of the drone warfare. This conflict is still a relevant case study and probably the first open experimentation of drone warfare by states.

Israel–Gaza (2021–Present)21

In May 2021, Israel publicly acknowledged the combat use of a drone swarm. Reports indicate that small ISR swarms, integrated with mortars and ground based missiles, coordinated fires on dozens of targets. These operations evolved into a broader campaign, where multiple classes of UAVs including loitering munitions, quadcopters modified for lethal payloads, and larger

Hermes platforms operated as a layered swarm ecosystem. Independent investigations, such as Al Jazeera's Sanad unit, suggest that Gaza has been used systematically as a live testing ground for Israeli drone technologies.

Russia–Ukraine (2022–Present)22

Ukraine's "Spider's Web" operation epitomizes innovation under resource constraints. By smuggling 117 one way drones into Russia concealed within trucks, Ukraine bypassed range limitations and launched strikes against four strategic airfields, damaging or destroying dozens of aircraft by some accounts.

This operation demonstrates asymmetric deep strike capability as the proximity logistics were substituted for long-range precision. On the other hand, simple AI image classifiers guide drones to high value targets.

Meanwhile, Russia has institutionalized saturation swarming by combining hundreds of Shahed/Geran drones with cruise missiles and decoys. Russia systematically pushed to exhaust Ukrainian air defenses, which were forced to interact with their attacks, incurring massive costs.

India–Pakistan War (May 2025)[23]

The May 2025 crisis could potentially be the first bilateral conflict in which drones were employed as primary kinetic platforms.

India's unprovoked swarm drone attack on Pakistan bridged Israeli software and hardware: Harop and Harpy loitering munitions conducting SEAD missions, followed by Warmate and ASL drones integrated with missile strikes on Pakistani air bases. The sequencing reflected a deliberate doctrinal experiment: using expendable drones to probe, degrade, and saturate Pakistan's air defense systems.

Pakistan responded in defense with loitering drones and quadcopter platforms against Indian airfields and depots. Pakistan smartly showcased its layered defenses, including electronic warfare, decoy radars, and Oerlikon Skyguard guns. The most cost effective strategy employed was to initiate engagements with electronic warfare tactics, such as jamming and spoofing enemy drone communications, weakening their navigation capabilities. Oerlikon Skyguard guns were deployed for kinetic interceptions once the drones were disabled.

International Law Perspective

Currently, there are no legally binding international treaties to navigate the use of AI assisted drones. Reliance is placed on IHL and International Human Rights Laws (IHRL), but without specific binding guidelines, the regulation is limited.

At the international level, efforts to address the regulatory gap have taken different forms. The International Civil Aviation Organization (ICAO)[24] has adopted an interpretative approach, recommending amendments to 18 out of 19 Annexes to the Convention on International Civil Aviation to accommodate emerging technologies, including unmanned and AI-assisted systems. In contrast, the European Union (EU) has pursued a drone specific regulatory framework,[25] introducing targeted measures to ensure an acceptable level of safety, accountability, and oversight in drone operations. These parallel approaches underscore that the regulation of Lethal Autonomous Weapon Systems (LAWS) is not merely a regional issue but a global responsibility requiring cohesive and universally accepted standards.

International Humanitarian Law

The deployment of drone swarms raises grave concerns regarding compliance with the core principles of IHL, namely distinction, proportionality, and military necessity.

Principle of Distinction

The principle of distinction[26] requires parties to a conflict to differentiate between combatants and civilians. Drone swarms, particularly when operating in a decentralized and autonomous manner, risk violating this principle. Their reliance on AI driven coordination and target identification systems may fail to adequately distinguish between legitimate military objectives and civilian objects. In complex and densely populated urban settings, this inability to make context sensitive judgments heightens the likelihood of indiscriminate attacks. Moreover, if certain drones in the swarm are tasked with surveillance while others carry offensive payloads, errors or miscommunication between units could result in strikes on non combatants, thereby undermining the distinction principle.

Principle of Proportionality

The principle of proportionality[27] prohibits attacks in which the incidental harm to civilians is excessive in relation to the anticipated concrete and direct military advantage. Drone swarms amplify this risk due to the sheer scale of simultaneous and coordinated strikes they can deliver. Even a minor error in targeting algorithms or in the swarm's shared data can escalate rapidly when multiplied across dozens or hundreds of drones. A disproportionate level of civilian harm may result if the swarm strikes areas with mixed civilian and military presence, as the collateral damage caused by such large scale operations would likely outweigh the military gain.

Principle of Military Necessity

Military necessity[28] permits only those measures indispensable for securing a definite military advantage. The autonomous operation of drone swarms, particularly when deployed for preemptive or wide area suppression, challenges this principle. Their use may exceed what is strictly necessary to achieve specific, legitimate military objectives, especially when swarms are capable of saturating targets or striking beyond the intended area. Furthermore, deploying swarms without robust human oversight risks transforming them into tools of convenience rather than necessity,

thereby conflicting with the restraint required under IHL.

Weapons Review under Article 36 GV I

Article 36 of Additional Protocol I (1977) to the Geneva Conventions provides that

> ***"In the study, development, acquisition or adoption of a new weapon, means or method of warfare, a High Contracting Party is under an obligation to determine whether its employment would, in some or all circumstances, be prohibited by this Protocol or by any other rule of international law applicable to the High Contracting Party."***

This provision imposes a binding legal duty on states to conduct a thorough review of new weapons to ensure their use is consistent with IHL and other applicable rules of international law. The weapons review is not merely procedural, it functions as a critical safeguard to prevent the deployment of technologies that may cause indiscriminate or disproportionate harm.[29]

In the case of swarm drones, Article 36 reviews acquire heightened importance due to the unique characteristics of these systems. Key risks include the potential for indiscriminate effects, malfunctions, loss of meaningful human control, and unlawful targeting in complex environments. Accordingly, the review process must extend beyond conventional assessments to include rigorous testing of algorithms, communications systems, and decision making processes embedded within the swarm's operational framework.

Convention on Certain Conventional Weapons

The Convention on Certain Conventional Weapons (CCW) serves as a key international framework designed to ban or restrict the use of specific types of weapons that are considered to cause unnecessary or unjustifiable suffering to combatants or to affect civilians indiscriminately. Since 2014, the CCW has increasingly turned its attention to LAWS, reflecting growing concern within the international community over their potential humanitarian, legal, and security implications.[30]

To facilitate these discussions, a Group of Governmental Experts (GGE)[31]was established in 2018 with the mandate of examining the legal, ethical, and operational challenges posed by LAWS, including technologies such as drone swarms. The GGE has emphasized critical issues such as ensuring meaningful human accountability in the use of force, assessing the risks of proliferation to non-state actors, and evaluating the broader implications of autonomy in warfare. While the group's conclusions are not legally binding, their deliberations play a significant role in shaping emerging norms and guiding state practice in this domain.

Customary International Law

Customary international law establishes State responsibility as a core principle under which States remain accountable for ensuring that the use of any weapon, including swarm drones, complies with IHL. Additionally the principle of precautions[32] in attack, codified in Article 57(2)(a)(i) of Additional Protocol I, which obliges those who plan or decide upon an attack to "do everything feasible to verify that the objectives to be attacked are neither civilians nor civilian objects and are not subject to special protection but are military objectives."

In addition to these established norms, there is a growing recognition of meaningful human control as an emerging customary principle for autonomous weapon systems.[33] Increasing State practice and opinio juris indicate that human operators must retain decisive control over the choice and use of force. This nascent norm operates as a safeguard to preserve accountability, legitimacy, and compliance with IHL. However, the distributed autonomy of swarm drones challenges the practical application of this principle, raising doubts as to whether current mechanisms of oversight are sufficient to satisfy customary obligations under the principles of responsibility, precautions, and proportionality.

Recommendations

A Unified Definition

To close the regulatory gaps, any unified definition of swarm drone use must incorporate certain core aspects. First, it should emphasize the autonomous collective function, namely the ability of multiple unmanned systems to coordinate without direct, real time human control. Second, it should account for scalability, reflecting the ability to deploy large numbers of units in ways that multiply operational effects. Third, the definition must incorporate operational purpose, distinguishing lawful applications such as proportionate military use from unlawful deployments involving indiscriminate or disproportionate attacks. Fourth, it must explicitly require compliance with the core principles of IHL, including distinction, proportionality, and necessity. Finally, the definition should highlight control and accountability, specifying the degree of meaningful human oversight required and identifying mechanisms for assigning liability when harm occurs.

For example, when defining "chemical weapons," CWC did not merely list individual chemicals but emphasized their toxic effects, intended use, and necessity of control mechanisms to prevent misuse. Similarly, "ballistic missiles" are defined not just by their physical form but by their range, payload capacity, and function under missile control regimes.[34]

Thus, the recommended definition follows a proven pattern i.e. combining technical, functional, and normative elements to create a legally meaningful framework adaptable to evolving military technologies.

Promote Standardized Article 36 Weapons Review Protocols for Swarm Systems

States are urged to promote the harmonization and

strengthening of Article 36 weapons review protocols to explicitly encompass multi agent autonomous systems such as swarm drones. Given the unprecedented complexity and operational autonomy characterizing these technologies, standard legal review frameworks must be adapted and expanded to incorporate rigorous, standardized methodologies that assess the autonomous behavior of algorithms.[35]

Such reviews must thoroughly evaluate compliance with fundamental principles of IHL with particular attention to emergent risks of indiscriminate effects, technical malfunctions, and potential loss of meaningful human control.

Pakistan's proactive engagement in advancing these objectives within relevant multilateral forums will reinforce its commitment to upholding international legal standards and contribute meaningfully to the responsible integration and regulation of swarm drone technologies.

ICRC to Issue Commentaries

As the guardian of the Geneva Conventions, ICRC plays a crucial role in ensuring that IHL remains relevant in the face of evolving threats. Given the complex challenges posed by swarm drone technologies, it is incumbent upon the ICRC to issue detailed commentaries that clarify the application of existing IHL principles to these emerging systems.[36] Such commentaries would serve to interpret how foundational rules on distinction, proportionality, and precaution apply specifically to swarm operations.

By articulating explicit legal guidance on the permissible use, control requirements, and accountability mechanisms, these commentaries would reinforce humanitarian principles while offering States authoritative interpretative tools to adapt their national frameworks. This approach draws on the ICRC's precedent of shaping legal discourse on novel and complex issues, such as its Interpretive Guidance on the Notion of Direct Participation in Hostilities (2009), which clarified civilian and combatant distinctions for evolving battlefield realities.

Such normative clarity will be crucial to inform both the development of binding legal instruments and voluntary policy standards discussed in existing multilateral forums including CCW's GGE. Accordingly, it is recommended that Pakistan support and actively engage with ICRC efforts to provide these commentaries, thereby contributing constructively to the international legal architecture addressing the ethical and operational complexities of autonomous drone swarms.

Establish a Bilateral Hotline and No Strike Lists

The May 2025 India Pakistan conflict significantly heightened regional volatility and crisis escalation risks. To address these risks, it is recommended that India and Pakistan urgently establish a dedicated bilateral hotline specifically for drone related incidents. Such a communication channel would facilitate immediate dialogue between military authorities in times of ambiguity or crisis, enabling transparent incident clarification, de escalation, and crisis management. This direct line of communication is vital to prevent misinterpretation of swarm drone actions and to avoid inadvertent escalation.

Additionally, both countries should negotiate and implement no strike lists that explicitly identify critical civilian and strategic infrastructure, including air defense radars, command centers, and civilian population centers, as off limits to drone targeting.

Active and Strategic Participation of Pakistan in the CCW Group of Governmental Experts and the UNGA-ICRC Joint Call on Autonomous Weapons

Pakistan should enhance its engagement and leadership within the ongoing CCW's GGE on LAWS. The GGE sessions in 2025[37], held in Geneva, continue to provide a critical platform for States to collaboratively address the complex humanitarian, legal, and security challenges posed by autonomous and semi autonomous systems such as swarm drones. Pakistan's active participation should include proposing concrete normative language that emphasizes meaningful human control, accountability, and transparency mechanisms consistent with international humanitarian law. Pakistan's strategic involvement can be further reinforced by submitting evidence based working papers, engaging in technical and legal expert exchanges, and championing targeted capacity building cooperation for developing countries.

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Action Matrix

Options for Pakistan and the International Community

Option	Pathways to Solution	Implementation of Solution	Actors Responsible	Implementation Timelines
A Unified Definition	A universally accepted definition of swarm drones is essential for ensuring legal clarity, regulatory consistency, and international cooperation	Convene global discussions under UN bodies, UNGA, UNICRI, and UNODA to develop a comprehensive and legally recognized definition.	• UNGA • UNODA • UNICRI	3-6 Months for Initial Consultations; 3-6 Months for multilateral negotiations; 6-12 Months for adoption of the definition.
Promote Standardized Article 36 Weapons Review Protocols for Swarm Systems	Standard legal review frameworks must be adapted and expanded to incorporate rigorous, standardized methodologies that assess the autonomous behavior of algorithms	Develop national protocols incorporating algorithmic decision assessments and interoperability testing; submit policy proposals and working papers in multilateral forums (CCW GGE LAWS)	• Ministry of Foreign Affairs (MOFA) • Ministry of Defence (MOD) • ICRC • UNODA	6-12 months for development; 12-24 months for international advocacy and adoption
ICRC to Issue Commentaries	ICRC can issue commentaries that provide explicit legal guidance on permissible uses, control requirements, and accountability mechanisms,	The ICRC will conduct legal assessments, engage with international legal experts, and publish authoritative commentaries to guide states and military Institutions.	• ICRC Legal Division • CCW Secretariat • UNODA • MOFA	12-18 months for drafting and publication; ongoing engagement in multilateral forums
Establish a Bilateral Hotline and No Strike Lists	Establish a direct, encrypted hotline for drone-related military incidents between India and Pakistan. Develop no strike lists identifying critical civilian and strategic infrastructure	Negotiate and implement mutually agreed no strike lists. Conduct regular communication drills and crisis de-escalation training.	• MOFA • MOD • National Security Division (NSD)	3-6 months for hotline establishment; 6-12 months for negotiating a no strike lists
Active and Strategic Participation of Pakistan in the CCW Group of Governmental Experts and the UNGA-ICRC Joint Call on Autonomous Weapons	The GGE sessions in 2025 continue to provide a critical platform for States to collaboratively address the complex humanitarian, legal, and security challenges posed by autonomous systems	Pakistan's strategic involvement can be reinforced by submitting evidence based working papers, engaging in technical and legal expert exchanges.	• MOFA • Permanent Mission of Pakistan to the UN • MOD	Preparatory work 3-6 months prior to GGE sessions; Ongoing engagement through 2025-2026 CCW cycle