Swarming drones and civilians

Future risks and prospects of drones and swarm technology in civil defence

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Cover: A drone light show is staged in Qionghai City, southernmost China's Hainan Province, 2 December, 2024. Picture by: SplashNews.com

Sammanfattning

Den här rapporten undersöker på vilket sätt drönare, och framförallt drönarsvärmar, kan komma att påverka framtidens krigföring och befolkningsskydd (på engelska *Civil Defence*). Rapporten visar att organisationer och myndigheter som arbetar med befolkningsskydd, bör planera för att svärmande beteende generellt kan komma att bli en del av den framtida luftkrigföringen. Framtida anfall kan innehålla en blandning av vapenbärare, inklusive drönare, för att åstadkomma maximal effekt mot t.ex. kritisk infrastruktur eller mot staten i sin helhet, även om de strider mot internationell humanitär rätt. Exempelvis i kriget i Ukraina ser vi redan nu sådana anfall mot civila miljöer. Viss teknik finns tillgänglig för att begränsa effekterna av vissa drönartyper, men dessa behöver anpassas och analyseras utifrån en krigföringskontext. Drönarsvärmar kan även vara användbart för befolkningsskydd i sig självt.

Användningen av drönare i krigföringen och drönarsvärmarnas konsekvenser för civila är ett område som bör bevakas framgent och att det finns behov av fortsatta studier, både tekniska, samhällsvetenskapliga och juridiska. Särskilt viktigt är det att övervaknings,- och varningssystem kontinuerligt anpassas i syfte att skydda civila och civil infrastruktur från ökad mängd och svärmande vapenbärare. Även metodutveckling av övervaknings,- och räddningsuppgifter av drönare och drönarsvärmar för användning i fredstida krissituationer samt för civila under krig kan behöva utvecklas. Parallellt behövs också samhällsvetenskapliga studier kring riskmedvetenhet, offentlig rädsla och asymmetrisk krigföring, kopplat till nya tekniksprång såsom drönare med svärmarkapacitet.

Nyckelord: drönare, svärmar, befolkningsskydd, civilt försvar; juridik, civila, UAS, UAV, C-UAS.

Summary

This report investigates how drones, and particularly drone swarms, may affect the future of warfare and civil defence (in Swedish, *befolkningsskydd*). The report shows that civil defence/civil protection organisations must expect that antagonists will use various forms of drone swarms or a mixture of drones and other weapon carriers against, for example, critical infrastructure and other civilian objects. Swarms could be used locally, as part of denial attacks, or in terrorising fashion towards the state as a whole. From the war in Ukraine, we already see examples of such uses. This trend might develop further, seeking to gain asymmetric advantages for coercive purposes by threatening to carry out attacks against civilian objects and infrastructure with large numbers of drones and other weapons. Countermeasures are already available and could be adopted by civil defence/civil protection organisations to mitigate risks, but they need to be considered from the context of war and with swarming capability in mind. Drone swarms themselves could also be useful for civil defence in various ways.

Developments in drone swarm technology and capabilities should be followed from a civil defence perspective, and there is a need for continued research in numerous areas. Important examples include the development of surveillance and warning systems for drones and drone swarms. Method development for surveillance and rescue tasks using drones and drone swarms would also be beneficial in peacetime crises and for civilians during armed conflict. In addition, social science studies on risk awareness, public fear, and asymmetric warfare related to technological leaps such as drones with swarm capability would also be beneficial.

Keywords: Drones; swarms; civil protection; civil defence; international humanitarian law; civilians; UAVs; unmanned aerial systems; counter unmanned aircraft systems.

List of abbreviations

CBRN: Chemical, biological, radiological, and nuclear
CCW: Convention on Certain Conventional Weapons
C-UAS: Counter-unmanned aerial system
FOI: *Totalförsvarets forskningsinstitut* (Swedish Defence Research Agency)
FPV: First-person view
GGE LAWS: Group of Governmental Experts on Lethal Autonomous Weapons Systems
GNSS: Global navigation satellite system
HPM: High-power microwave
IHL: International humanitarian law
ISR: Intelligence, surveillance, and reconnaissance
ISTAR: Intelligence, surveillance, target acquisition, and reconnaissance
LM: Loitering munitions
LAWS: Lethal autonomous weapons systems
MAV: Micro aerial vehicle
MALE-RPAS: Medium-altitude long-endurance remotely piloted air system
PGM: Precision-guided munitions
RMA: Revolution in military affairs
SAM: Surface-to-air missile
SAR: Search and rescue
UAV: Unmanned aerial vehicle
UAS: Unmanned aerial system
UCAV: Unmanned combat aerial vehicle
UGV: Unmanned ground vehicle
US: United States of America
USV: Unmanned surface vehicle
UUV: Unmanned underwater vehicle
WMD: Weapons of mass destruction

Contents

1. Introduction

In the armed conflict in Ukraine, hundreds of projectiles and weapon carriers have been used continuously by Russia to wear down the Ukrainian power system and other infrastructure.[1] Unmanned aerial vehicles (UAVs, or drones) have been central in providing the means to launch attacks in massive swarm-like formations to saturate aerial defences, allowing enough drones and missiles to get through to cause significant damage.[2] The aerial attacks in Ukraine since 2022 are not unique, however, and what we see is perhaps a general trend towards greater mass in the aerial domain during war.[3] This has significant implications not only for the military, but also for civilians and critical infrastructure. Drone technology today is developing the potential for *true swarm* capabilities that might make these massive attacks even more efficient, complex, and difficult to defend against.[4]

The purpose of this report is to consider the development of large-scale drone attacks and swarming capabilities from the perspective of civilians, critical infrastructure, and civil defence, and to identify and suggest future areas for research. Previous research on drone warfare has focused on military strategy and tactics, and little attention has been given to civilian objects and civilian infrastructure. Using existing literature in technology, history and international humanitarian law (IHL) as the foundation for the analysis, this report considers how opponents in future armed conflicts might use swarming drones, and how this might impact civilian objects and civilian infrastructure. Based on this analysis, the report discusses how both military and civil defence organisations might need to adapt, and whether there may be positive developments in drone technology that could benefit civil defence functions. It goes on to address how international law is developing in this area, and whether new international legal instruments can be anticipated that regulate the use of drone swarms.

These are big questions to address. As such, this report marks a starting point of research into these issues, rather than a comprehensive analysis. As Sweden is currently in the process of revising its civil defence planning, it is also timely to address these developments. Research to date on *drone warfare* and *civilians* has mainly focused on the problem of civilian harm and damage in attacks, risks associated with autonomous

1 Odell et al., *Russian Attacks on the Ukrainian Power System*.

2 For further discussion, see Section 1.3 and Chapter 2.

3 Fedorchak, "The Mass Approach in the Air War Over Ukraine: Towards Identifying a Critical Mass."

4 King, "Robot Wars"; Fedorovych et al., "Military Logistics Planning Models"; Kallenborn, "The Plague Beckons: On the Proliferation of Drone Swarms."

targeting, and psychological effects on civilians from the United States' "war on terror."[5] The Swedish Defence Research Agency (*Totalförsvarets forskningsinstitut*, FOI) has a long history of research into the risks and potential uses of drones, counter-unmanned aircraft systems (counter-UAS), and their potential use in emergency management. However, the civil defence context has been absent in this research.[6]

1.1 Outline

The report is primarily a literature study consisting of three parts from three different areas, namely technology, history and law, to discuss how drones and drone swarms might expose civilians and civilian objects to harm arising from the conduct of hostilities.

Firstly, the report provides an overview of the technical basics of what drones and swarms are, together with a description of the enabling technologies, the limiting technical factors, and the potential technological developments in warfare. Secondly, the report considers drones and large-scale attacks against civilians and critical infrastructure historically, and assesses to what extent current developments can be argued to constitute a new situation in the general technological development of war-making. Robert Pape's categorisation of the rationale behind bombing campaigns is used to structure this analysis.[7] This chapter also outlines how civil defence organisations develop in tandem with military technological progress, as well as includes a discussion on how emergency management and civil defence practices might benefit from drones and drone swarm technologies. Thirdly, an analysis of the legal framework and international debates on drones and swarms in armed conflict is provided, in order to identify to what extent the legal framework might limit or enable drone use.

The report uses a transdisciplinary method in an attempt to provide a comprehensive understanding of the different variables that determine technological progress on the battlefield, and how such progress could affect civilians and civilian objects. A foundational stepping stone for this work is that technological developments are determined by various societal factors and cannot be derived from any single aspect.[8] Whilst other fields might also have been included, as noted above, this report marks a starting point for analysing the issues raised.

5 Hijazi et al., "Psychological Dimensions of Drone Warfare"; Gupta, "Phenomenon and Experience"; Talbert and Wolfendale, "Drone Warfare, Civilian Deaths, and the Narrative of Honest Mistakes"; Ams, "Blurred Lines"; Ling, "Armed Drones: An Instrument of Terror"; González, "Death by Remote Control."

6 Wingfors, Forsberg, and Landström, *Drönare med CBRNE-sensorer för räddningstjänst: En kunskapsöversikt*; Petersson and Ahlberg, *Counter-UAS för säkerhet i offentlig miljö: Redovisning av metoder och verktyg för att hantera hotet från obemmanade flygande system*, 6; Drone swarms were already identified as a potential threat to civilians in 2021, but the topic has not yet been thoroughly researched. Hagström, Forssell, and Stensbäck, "Swarming Drones—A Realistic Future Threat?," 46.

7 Pape, *Bombing to Win*.

8 For further discussion, see scholarship on the history of technology, such as Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*.

1.2 Drones and civil defence research at FOI

FOI has followed developments and conducted its own research on drones since the late 1990s. Most of this research has been of a technical nature, such as methods of communication, autonomous systems and UAVs, system integration, radar and sensors, tactical use and intelligence, surveillance, target acquisition, and reconnaissance (ISTAR).[9] Since the 2000s, however, FOI has also produced reports related to defence studies and security policy.[10] In 2024, FOI produced a report on the low-density battlefield and the use of UAVs.[11] FOI has also carried out research into how international law regulates loitering munitions (LMs) and autonomous weapons systems, as well as studies on the development of new international law specifically for autonomous weapons systems.[12] FOI has further been monitoring Russia's full-scale invasion of Ukraine since 2022 and has published several works on this topic in which UAVs play a part.[13]

Related to the civilian context, FOI has published several reports on how rescue services might benefit from drone technology, including studies on how UAVs could be used in for intelligence, surveillance and reconnaissance (ISR), counter-unmanned aerial systems (C-UAS), and chemical, biological, radioactive, and nuclear (CBRN) monitoring.[14] Less focus has been placed on the extent to which UAV and drone research matter for civil defence purposes until recently, but civil defence as a research topic has been recurrent.[15] In addition, FOI established a research program into civil defence in 2024, of which this report is a part.

1.3 Definitions

1.3.1 Civil defence and civilian protection during war

As this report is mostly concerned with the use of drone swarms in armed conflict, we use the definition of civil defence in Article 61 of the 1977 Additional Protocol I to the Geneva Conventions of 1949 (AP I) to define civil defence.[16] Under Article

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9 Forssell, "Sammanställning av tidigare studier på RPAS."

10 Neuman Bergenwall, *Drönarkriget i Pakistan—Säkerhetspolitiska konsekvenser*.

11 Hörnedal, *Rare Birds: A Look at the Low-density Battlefield and Armed Drones*.

12 Hagström and Forssell, "The Use of Drones in the Russo-Ukrainian War"; Appelgren et al., "Autonoma vapensystem—Dagens debatt och en väg framåt: Tekniska, legala och etiska aspekter"; Winther, "Grundläggande humanitärrättsliga regler vid användande av patrullrobotar"; Andersson, *Utveckling av den folkrättsliga regleringen av autonoma vapensystem*; Winther, "Folkrättslig reglering av autonoma vapensystem: En översikt av rättskällor, rättsutveckling och forskning om användning och ansvar."

13 Lundén et al., *Another Rude Awakening—Making Sense of Russia's War Against Ukraine*; Nilsson and Ekman, "'Be Brave Like Ukraine': Strategic Communication and the Mediatization of War"; Odell et al., *Russian Attacks*.

14 Wingfors, Forsberg, and Landström, *Drönare med CBRNE-sensorer för räddningstjänst*; Näsström et al., *RPAS inom ramen för förstärkningsresursen för stöd till samverkan och ledning*; Petersson and Ahlberg, *Counter-UAS för säkerhet*.

15 Swarming drones were already suggested as a future threat in 2021, but have not been studied until now. Hagström, Forssell, and Stensbäck, "Swarming Drones."

16 Protocol Additional to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of International Armed Conflicts, adopted 8 June 1977 in Geneva, entered into force on 7 December 1978 (AP I), Article 61 (1125 UNTS 3). Ratified by Sweden on 21 June 1979, SÖ 1979:22.

61 AP I, civil defence encompasses functions and activities aimed at preventing and mitigating damage to civilians and civilian property caused by acts of war. This includes efforts such as providing information to civilians, issuing air raid alarms, establishing air raid shelters, offering CBRN protection, including gas masks and area decontamination, fire-fighting, search and rescue (SAR), and providing evacuation and emergency accommodation for internally displaced persons (IDPs). As such, civil defence under AP I is closely aligned with peacetime emergency management and rescue services, although it is applied in the context of armed conflict.[17]

It is important to note that the term *civil defence* varies in meaning depending on the context and country. For example, the European Union (EU) uses the term *civil protection* to refer to similar functions as those mentioned above. Sweden also employs civil protection in this manner today, but used civil defence prior to its entry into the EU in 1995. In the North Atlantic Treaty Organization (NATO) context, civil protection generally relates to the overall resilience of society, of which civil defence is only a part. Slight variations in terminology can also significantly alter meanings of the terms. For example, "protection of civilians" can refer to certain obligations under IHL, and civilian defence has sometimes been used to describe non-violent resistance movements against occupation.[18]

This report similarly uses the definitions of civilians, civilian population, and civilian objects in accordance with their respective definitions in AP I. Civilians and civilian objects are defined as those who do not fall within the definition of combatants, and the civilian population comprises all persons who are civilians.[19] Civilian objects, including infrastructure, are all objects that are not military objectives.[20] However, civilian objects, including infrastructure, may lose their protection if they fall within the definition of military objectives under Article 52(2) AP I. Under which, objects which by their nature, location, purpose, or use make an effective contribution to military action, and whose total or partial destruction, capture or neutralisation, at the time, would offer a definite military advantage. In such circumstances, they may be subject to attack by the opposing party to the conflict. Whether objects are so used or located, and whether their destruction would offer such a military advantage, may be difficult to ascertain for anyone other than the parties to the conflict and is based on the facts at the time. As such, the report does not provide detailed analysis of the legality of specific attacks.

17 In a Swedish context, emergency management includes functions similar to those of civil defence (*befolkningsskydd*), such as, rescue services, CBRN protection, evacuation routines, IDPs, and fire-fighting.

18 See, for example, Roberts, *The Strategy of Civilian Defence*.

19 AP I, Article 50. Combatants are defined in AP I, Article 43. See, further, GCIII Article 4A(1), (2), (3) and (6).

20 AP I, Article 52.

1.3.2 Drones

The term *drone* has its origin in the 1930s and has been used as a generic term in military contexts since then to describe various forms of remotely piloted aircrafts. Originally drones were remotely piloted biplanes used for anti-aircraft target practice, and sometimes for experimental bombing raids.[21] Today, the term is used generically to describe various types of UAVs, both military and civilian. This report uses drone in a similar way. There are, however, many different types of drones used across various domains. The domain in which they operate, be that air, ground, on the surface, or underwater, is indicated in the acronym used (e.g. unmanned ground vehicles, UGVs). The defining feature of drones is that they are unmanned and controlled either remotely by a human operator or by an autonomous system with little to no human involvement. This report mainly focuses on UAVs, although unmanned vehicles in other domains are discussed occasionally. The term drone is used to designate an unmanned vehicle in some non-specific domain. Drone is, therefore, less precise than UAV.

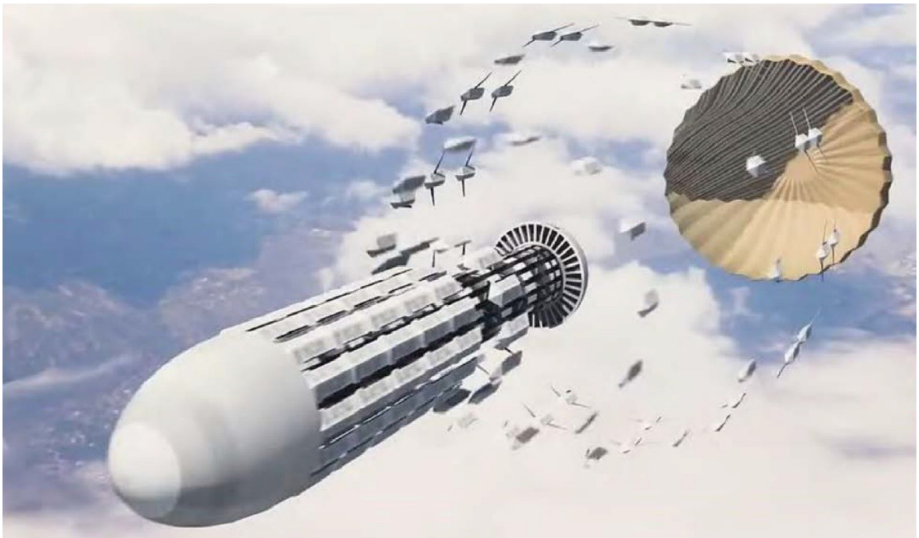

Figure 1: In 2019, the US Air Force published a report analysing how autonomous systems might be used in the future. In the report, they speculated that the goal was to "[overwhelm adversaries with complexity, unpredictability, and numbers through a collaborative and autonomous network of systems and effects." The quote was accompanied with this image produced by the Air Force Research Laboratory.
Source: USAF, "U.S. Air Force Science and Technology Strategy: Strenghtening USAF Science and Technology for 2030 and Beyond," 8.

21 See further discussion in Chapter 2.

1.3.3 Swarms

In academic literature, the term *swarm* is used to describe both the everyday sense of a swarm of insects and certain technological systems of systems, such as those encountered in swarm robotics.[22] In some cases, the same model used to describe fireflies flashing can also be used to describe networked power systems and vehicles moving in formation.[23] One of the main advantages of the swarm is that it can perform tasks that any single, larger, or more capable individual would not be able to do alone, or at least, perform them better than a single individual could. For swarms consisting of some type of vehicles, it is important whether the vehicles are remote controlled by a human or autonomous. The term swarm is used in this report to refer to a number of unmanned, cooperating, autonomous vehicles.

Like civil defence and civil protection, the term swarm has different meanings depending on the context. Taken together, the term *drone swarm* is also diffuse. It is therefore often advisable to use more precise terms such as *cooperative systems of UAVs*. However, as this report aims to contribute to an ongoing discussion in academic literature on drone swarms, where such terms are predominantly used, it is more appropriate to adopt the terms of that discussion.[24]

Moreover, it is difficult to draw a line between different UAV/unmanned aircraft systems (UAS) and other forms of various LMs in the way drones and other types of aerial weapon carriers are used in armed conflicts today. Sometimes drones, LMs, cruise missiles, and manned aircraft are used together for maximum effect during attacks (more on this below). It is thus difficult to entirely separate the use of drones from the simultaneous use of other aerial-bound weapons.[25] War is seldom waged with only one type of weapon at a time.

A difficulty when discussing swarming capability and drones is separating the technical definitions of *true swarms*—that is a technical system—from socio-technical means of controlling large numbers of drones to achieve swarm-like behaviour, or what we in this report call *socio-technical swarms*. A true swarm is defined by certain computerised modes of control with more or less autonomy at play, and is, for the most part, either centralised or decentralised in nature (more on this in Chapter 2). Socio-technical means of controlling multiple drones are not as easy to define and may involve a group of drones each controlled individually by an operator, resulting in swarm-like characteristics. For example, this can be a group of First-Person View (FPV) drone operators on the battlefield trying to overwhelm a position, or a series of LMs, cruise missiles, or ballistic missiles launched in calculated intervals to saturate aerial defences and strike critical infrastructure (so-called *en masse* attacks). The

22 Sumpter, "The Principles of Collective Animal Behaviour"; Brambilla et al., "Swarm Robotics."

23 Dörfler and Bullo, "Synchronization in Complex Networks of Phase Oscillators."

24 King, "Robot Wars"; Kallenborn, "The Plague Beckons"; Kallenborn and Bleek, "Swarming Destruction"; Johnson, "Artificial Intelligence, Drone Swarming and Escalation Risks in Future Warfare"; Fedorovych et al., "Military Logistics Planning Models."

25 See further discussion in Chapter 3.

attacks against the Ukrainian power system since 2022 are a good example of the latter type of attack. Note, however, that true swarms also entail a social component, namely, someone is in control. As such, there is no strict dichotomy between true swarms and socio-technical means of controlling mass. Both true swarms and socio-technical means of using multiple drones to achieve swarm-like behaviour are discussed in the report. The term *swarming technology* is used to signify the development of technologies needed to achieve true swarms.

1.3.4 The problem with drone swarms

Regardless of what type of drone swarm is discussed, the underlying problem that drone swarms aim to solve is efficient control of mass so as to perform tasks that single drones would not be able to do, such as overwhelming the enemy and creating chaos. This is a military-tactical problem with ancient origins. Many militaries and states have attempted to harness mass as a means to overcome technical superiority. The advantage of mass as a counter to technological superiority was predicted by the Lanchester Laws during the nineteenth century.[26] The Lanchester Laws are differential equations that determine the outcome of a battle between two armies that engage using either hand-to-hand combat or ranged weapons. However, since the Lanchester Laws are based on abstract mathematical modelling, they overlook many of the complexities of battle. In an in-depth analysis of a scenario involving disproportionate mass distributions, such as a potential Chinese invasion of Taiwan, a more complex picture emerges.[27]

What is new today, however, is that drones are being utilised on a different scale as a result of the mass production of drone technology, and that swarm technology has been developing over the last decade and can be used for the efficient control of drones. There are also examples from the ongoing war in Ukraine of developments in socio-technical means of using multiple drones for swarm-like *en masse* attacks.[28] It is this mixture of available mass on the one hand and the means of controlling mass on the other that poses risks for civilians in future wars, and further motivates a discussion on how civil defence might have to adapt to these developments.

26 Scharre, "Robotics on the Battlefield Part II: The Coming Swarm."

27 Shlapak et al., "A Question of Balance."

28 Odell et al., *Russian Attacks*.

1.4 Previous research on drones and civilians—From the "drone wars" to Russia's full-scale invasion

Drones are not a new topic in military and security studies. Since newer models of ISTAR-drones were introduced during the late 1980s and 1990s, the topic of "drone warfare" has stirred debate.[29] The primary issue has been to what extent drones can be considered a revolution in military affairs (RMA) that could potentially change the fundamentals of strategic thinking, or whether drone technology is merely a continuation of technological development within an already existing strategic paradigm.[30] Since 2024, there has also been an increase in academic publications discussing the potential of swarm-technology in combination with drone warfare.[31]

Research on the way civilians might be affected by increased use of drones in warfare has changed considerably during this period. Up until the 2020s, the focus was mainly on the ethics of drone warfare, the risk of incidental civilian harm and damage, and the psychological effects of drone warfare. These became important topics as the Obama administration increased its use of drone strikes abroad in late 2000s. From 2005 until 2013, the US's acquisition of drone systems increased from 50 to 7500, thus constituting a significant part of its aerial power. The numbers illustrate the tidal change towards drone warfare during these years.

The US's argument for using drones (most often medium-altitude long-endurance remotely piloted air systems, or MALE-RPAS, such as the MQ9 Reaper) in these circumstances was to suppress terrorist activity abroad while committing as few land forces as possible, and in the process minimising the risk of American casualties.[32] Significantly, expensive high-end systems were used asymmetrically against technologically unsophisticated enemy forces. This asymmetrical relationship between fighting forces led to debate on whether drone warfare was morally justified. For example, it was argued that the US was developing a "Jupiter complex," and that the way the technology allowed drone operators to sit in an office building in the US while conducting lethal raids in countries as far away as Libya, Afghanistan, or Pakistan was immoral.[33]

The impact on civilian objects and civilian infrastructure played a quite small role in the military discussions, partly because the whole purpose of the drone wars was to use drones to pin-point terrorist cells (i.e. individuals), rather than,

29 Biddle, "The Past as Prologue."

30 See, for example, Calcara et al., "Why Drones Have Not Revolutionized War"; Rossiter, "Military Technology and Revolutions in Warfare: Priming the Drone Debate"; Biddle, "The Past as Prologue"; For a critical discussion of the RMA, see Black, *War and Technology*, 231–233.; also O'Hanlon, *Technological Change and the Future of Warfare*.

31 King, "Robot Wars"; Fedorovych et al., "Military Logistics Planning Models"; Javed et al., "State-of-the-Art and Future Research Challenges in UAV Swarms."

32 Black, *Air Power*, 286.

33 Dowd, "Drone Wars: Risks and Warnings," 13; Ling, "Armed Drones"; Henriksen and Ringsmose, "Drone Warfare and Morality in Riskless War"; see, also, Benjamin, *Drone Warfare*.

Figure 2: Ukraine's "Sea Baby", a USV used for attacking the Russian black sea fleet, as well as striking the Kertch Bridge in July 2023.
Source: Security Service of Ukraine, (CC).

for example, striking infrastructure for area denial during military operations.[34] Some scholars have also studied the psychological effects of drone warfare on both civilians and drone operators.[35] Current discussions on the potential implications of artificial intelligence might for the capabilities of drones are, in part, a continuation of these debates on the relationship between operator and combat in drone warfare.[36]

However, the Russian full-scale invasion of Ukraine in 2022 has changed the general outlook in publications about drone warfare. The ongoing war in Ukraine is very different from the drone wars of the Obama administration, and the discussions on the role of drones also differs. In current debates, the focus is on the diversification of drone use and the radical increase in the number of drones used, rather than the extended use of MALE-RPAS and the remoteness of warfare.

Drones are now being used in all domains against both military targets and civilian infrastructure.[37] This new era of drone warfare has sparked great concern. The war in Ukraine is a war between two states, and thus does not involve the same asymmetry as the drone wars of the Obama administration. Both sides have found incentives to use large drone systems of various kinds to strike targets such as harbours and oil refineries. Particularly emblematic is Russia's use of massive quantities of mixed weapons, including drones, against civilian infrastructure in urban environments, with the purpose of terrorising the population and undermining the Ukrainian economy. Russia has used large-scale drone strikes to saturate Ukrainian aerial defences and then strike power systems with those few drones

34 However, there were several instances in which civilians and civilian objects suffered harm and damage when terrorist targets were struck in close proximity to populated areas or within urban environments. Gupta, "Phenomenon and Experience"; González, "Death by Remote Control"; Ling, "Armed Drones"; Wargaski, "U.S. Drone Warfare and Civilian Casualties"; Henriksen and Ringsmose, "Drone Warfare and Morality in Riskless War"; Rogers, "Investigating the Relationship Between Drone Warfare and Civilian Casualties in Gaza"; Rogers, "Rethinking Remote Warfare."

35 Richardson, "Drone Trauma"; Hijazi et al., "Psychological Dimensions"; Holz, "Victimhood and Trauma within Drone Warfare."

36 Ams, "Blurred Lines."

37 Kunertova, "Drones Have Boots: Learning from Russia's War in Ukraine"; Mantellassi and Rickli, "The War in Ukraine"; Kunertova, "The War in Ukraine Shows the Game-changing Effect of Drones Depends on the Game"; González, "Death by Remote Control"; Luzin, *Russian Military Drones: Past, Present, and Future of the UAV Industry*.

that manage to get through.[38] As an example, on 13 December 2024, Russia allegedly used almost 200 drones and more than 90 missiles in one such attack against Kyiv.[39] Ukraine, in turn, has developed its own unmanned surface vehicles (USVs) and UAVs to strike Russian infrastructure, such as the Kerch Bridge, oil refineries, and military bases.[40]

The Russo-Ukraine war has also highlighted the industrial aspects of drone warfare.[41] Both sides of the conflict are now producing millions of smaller models for battlefield use each year.[42] As a result, the potential use of drones in warfare is much more varied, and civilians might find themselves impacted by drone warfare in different ways than has been the case previously.

The growing interest in swarming technology can also be interpreted as a sign that states and militaries are seeking new ways to control the steadily increasing numbers of drones being used on the battlefield.[43] This is an issue that warrants attention for the future. There are also publications discussing how drones might be used for crisis management in civilian contexts, although these ideas remain at an experimental stage (more on this in Section 3.3.1).[44]

38 Odell et al., *Russian Attacks*.

39 AP, "Russia Targets Ukrainian Infrastructure with a Massive Attack by Cruise Missiles and Drones."

40 "Key Russian Bridge to Crimea Is Struck Again as Putin Vows Response to Attack That Killed Two."

41 Mantellassi and Rickli, "The War in Ukraine."

42 Ibid., 15–17; see news articles on this topic from 2024, i.e. Harmash, "Ukraine Ramps up Arms Production, Can Produce 4 Million Drones a Year, Zelenskiy Says."

43 King, "Robot Wars"; Kallenborn, "The Plague Beckons"; Kallenborn and Bleek, "Swarming Destruction"; Johnson, "Artificial Intelligence"; Fedorovych et al., "Military Logistics Planning Models."

44 Javed et al., "State-of-the-Art"; Alawad, Halima, and Aziz, "An Unmanned Aerial Vehicle (UAV) System for Disaster and Crisis Management in Smart Cities"; Gkotsis et al., "Swarm of UAVs as an Emergency Response Technology." See further discussion in Chapter 3.

2. Technical analysis of swarming capabilities

A comprehensive understanding of how drones and swarming capability might affect warfare in the future, and, by extension, civilians in areas affected by armed conflict, requires a technical assessment of drones and swarms. This chapter outlines these technical details. The chapter begins by discussing the technical prerequisites for autonomous "true swarms." It goes on to assess the limitations of swarms, as well as potential applications, providing examples of usage in different settings.

2.1 Historical background

True swarms have recently been realised in experimental settings and as prototypes by companies, but the idea of using swarms in a military context has existed for quite some time. An early example is the Russian 'Shipwreck' system, P-700, from 1983. Shipwreck was marketed as an anti-ship missile that flew in swarms of four to eight missiles.[45] The idea was that one leader would fly at a higher altitude to detect the target ship, while the followers stayed low to avoid detection and received targeting data from the leader. If the leader was destroyed, a follower could take its place. There is little evidence that the system actually had this capability, but it shows that the idea of using swarms is not new. The widespread military use of swarms is still not feasible today, but their development is not far off. Commercial swarm systems with capabilities such as control of a few vehicles by a single operator and cooperation between vehicles have recently been introduced by military industries, including Red Cat Holdings,[46] BlueBear,[47] Elbit Systems,[48] and the WB Group (see Fig. 3).[49]

45 Bronk, "Swarming Munitions, UAVs and the Myth of Cheap Mass"; Bronk, "IV. Swarming Munitions, UAVs and the Myth of Cheap Mass," 50–51.

46 Blain, "You Can Now Buy a Co-ordinated Multi-Drone Swarm in a Box."

47 "Products: Avionics Hardware & Software (BlueBear—A Saab Company)."

48 "Legion-X Autonomous Networked Combat Solution (Elbit Systems)."

49 "Swarm System (WB GROUP)."

2.2 Centralised or distributed systems

A key distinction between different types of swarms is how the vehicles in the swarm are controlled. Control can be either centralised or distributed.[50]

In a centralised swarm, there is a central computer, either on board a vehicle or located on the ground, that receives sensor data from all other vehicles and sends control signals to them. Centralised control is used in drone fireworks but is of questionable use for military purposes, as it creates a single point of failure. If the central unit is destroyed, the whole swarm ceases to function.

In a distributed swarm, each vehicle calculates its own control signal based on information it receives from a subset of other vehicles, sometimes referred to as its "neighbours." A distributed network is more resilient to the failure of individual communication links and the destruction of individual vehicles than a centralised network. In fact, many researchers argue that a centralised swarm is not even a swarm in the true sense.[51]

In this report, a true swarm is not defined by whether it is decentralised, but rather by whether it makes use of autonomy and vehicle-to-vehicle communication. This can also be achieved within a centralised control architecture, although it is more commonly associated with distributed control.

The relative position between one vehicle and its neighbour is a key aspect of swarm algorithms, enabling simple capabilities, such as collision avoidance, as well as more advanced behaviours such as collaborative search.[52] A key piece of information for swarm algorithms is the relative position between neighbours. Relative positions can be determined using the absolute positions of each agent. There is a dichotomy between agents that rely on an external system—such as global navigation satellite systems (GNSS) or a motion-capture system in a laboratory—for absolute positioning, and agents that rely solely on their on-board sensors for relative positioning in a local frame of reference.[53] The latter are more robust to disturbances such as electronic warfare.[54] In general, the centralised case with external positioning is well understood, whereas the distributed case with on-board sensing remains the subject of ongoing research (see Fig. 3).[55]

Drone lightshows, also called drone fireworks, provide a useful example to consider. These are night-time shows in which a swarm of drones equipped with colourful lights is used to create displays in the sky. Drone lightshows do not technically count as swarms as defined in this report, as the rotorcraft in such shows do not interact.

50 Coppola et al., "A Survey on Swarming With Micro Air Vehicles."

51 Brambilla et al., "Swarm Robotics"; Schranz et al., "Swarm Robotic Behaviors and Current Applications"; Murphy, "Swarm Robots in Science Fiction."

52 Coppola et al., "A Survey on Swarming With Micro Air Vehicles."

53 Coppola et al.

54 Kallenborn, "InfoSwarms."

55 Coppola et al., "A Survey on Swarming With Micro Air Vehicles."

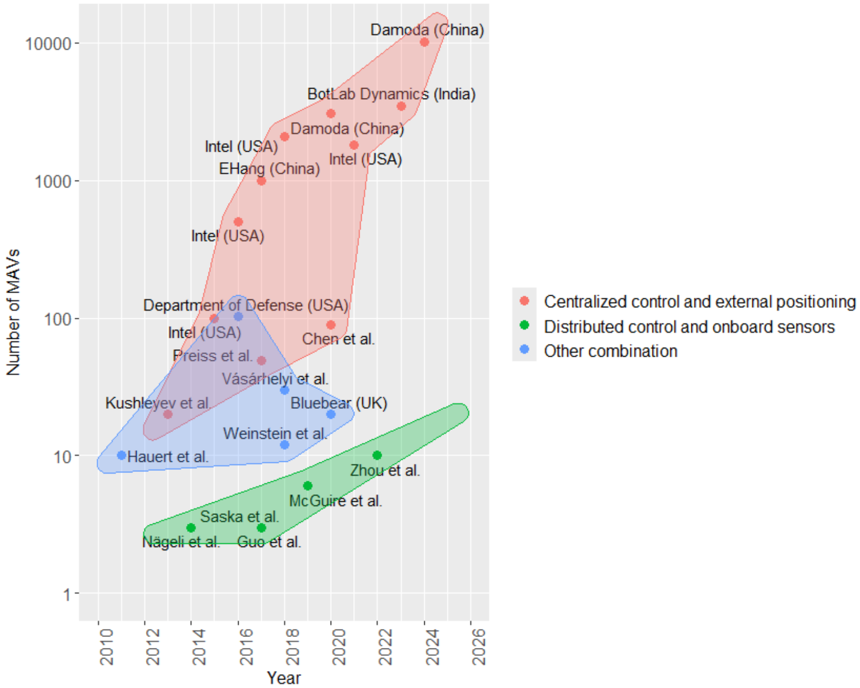

Figure 3: an experiment with the year on the horizontal axis and the number of MAVs on the vertical axis, which is in logarithmic scale. There are three clusters (green, blue, red) of comparable experiments based on the type of control and sensing that is used. The red cluster shows a trend of exponential increase in the number of MAVs for the case of centralized control and external positioning. In contrast, a similar increase has not taken place for the blue and green clusters, which may therefore be considered as more difficult.
Image by: Johan Markdahl (CC-BY-SA).

Their pattern display and collision avoidance are achieved through off-line path planning on a separate computer, implying that control is centralised.[56] Moreover, drone lightshows make use of GNSS receivers for positioning. As such, experiments with drone lightshows would be placed in the green cluster in Figure 3.

2.3 Technological prerequisites for drone swarms

A drone depends on a set of technologies to function. Consequently, the affordability and availability of these technologies have an enabling, or detrimental, effect on future developments. Until recently, developments in these areas were mainly driven by the civilian market, but this may change, as war often accelerates military technological development. For drones, size is a critical factor that determines performance, which in turn determines usage. In this section, we focus on relatively small drones.

56 Zerlenga, Cirillo, and Iaderosa, "Once Upon a Time There Were Fireworks. The New Nocturnal Drones Light Shows."

A small aerial drone consists of multiple subsystems, the key ones being sensors, battery, flight computer, and communication. The development of hardware sub-systems has been driven by advances in the civilian market, which has grown exponentially during the last decade. Partly due to its investment in military, surveillance, and artificial intelligence capabilities, China is currently ahead of the rest of the world in some areas of drone technology, particularly in the consumer segment. The civilian market is dominated by Chinese actors, such the company DJI, which holds a 70% market share in consumer drones.[57] China also holds the world record for the number of small drones flown simultaneously (see Fig. 3). However, these systems are centralised and use GNSS for positioning, and are therefore of limited use for military purposes.

2.3.1 Miniaturisation

Mobile phone technology has led to the miniaturisation of batteries and sensors. For small drones, the weight and energy density of batteries are key factors that limit endurance.[58] Lighter batteries and sensors have enabled the design of lightweight drones in the MAV class, weighing less than 1 kg. Such drones have limited range and endurance but are inexpensive and offer capabilities sufficient for certain military purposes, such as the FPV drones used by the Ukrainian armed forces. Miniaturisation is expected to continue, yielding smaller drones with better sensors and extended range.

For swarms of small drones (one or a few kilograms), miniaturisation is essential, as there is a trade-off between the quality of a drone's physical design and the quantity in the swarm.

2.3.2 Wireless communication

For a remotely controlled drone, it is necessary to maintain contact with an operator on the ground. This makes the system vulnerable to communication disruptions caused by electronic warfare.[59] A countermeasure to electronic warfare is autonomous capability, such as GNSS-free navigation, autonomous target selection, and final-phase attack.[60]

For swarms, a key technology is drone-to-drone communication.[61] Swarm phenomena are often based on the property of emergence, which, broadly speaking, refers to a meaningful pattern of behaviour in the swarm as a whole that arises through local drone-to-drone communication. Control algorithms for swarms are designed in such a way that the resulting pattern of behaviour enables the swarm to solve a specific task—this is the type of emergence that is most relevant for military purposes.

57 See Tomas Melin, in Weidacher Hsiung, *Strategic Outlook 10: China as a Global Power*.

58 Floreano and Wood, "Science, Technology and the Future of Small Autonomous Drones."

59 Kallenborn, "InfoSwarms."

60 Gyagenda et al., "A Review of GNSS-independent UAV Navigation Techniques."

61 Chen et al., "Toward Robust and Intelligent Drone Swarm."

2.3.3 Software and algorithms

The design and analysis of swarm algorithms were a mainstay of the control theory field during the 2000s.[62] While swarms have been studied in other fields, such as biology and physics, the advances made within control theory and robotics, focused on how to program a swarm to complete a task, are the most relevant to military applications. Today, this is a mature and well understood research area, with many algorithms available in the scientific literature. That said, novel algorithms may need to be developed to realize specific swarm warfare capabilities. In general, the development of such algorithms is a feasible task for scientists.

2.4 Potential and limitations of military swarm technology

Swarms of autonomous drones have the potential to become a disruptive technology. As such, they may change the way wars are fought in terms of representing a revolution in military affairs. It has been speculated that many roles currently held by manned forces could be automated, bringing benefits such as range, persistence, and expendability to the battlefield.[63] Swarms of autonomous vehicles would also add the additional benefits of mass, coordination, intelligence, and speed.[64] In terms of warfare economy, swarm technology has the potential to be relatively inexpensive. Mass production of many drones required for a swarm drives down unit costs. Moreover, if multiple expensive missiles are used to eliminate the swarm, an asymmetric cost advantage is achieved in the war economy. Cheap, expendable drones have proliferated on the battlefield in the Russo-Ukrainian war.[65] As such, cheap drone swarms are a viable future development.

There are, however, limitations and uncertainties. For example, the technical capabilities of drone swarms remain unclear, such as whether they can be used accurately in targeting. It will also be necessary to determine whether it is economically feasible to use them. Will countermeasures render them ineffective? It is not currently possible to provide definitive answers based on the present state of research. Cheap drones in an aerial swarm are, by their nature, small, slow, and low-flying.[66] Equally inexpensive and technologically low-grade anti-air artillery can therefore be used to combat the swarm. The agents do have ways of avoiding artillery fire. For example, they may accelerate erratically in three-dimensional space to appear unpredictable, thereby increasing their chances of survival, or fly low, possibly through forests or

62 Chen and Ren, "On the Control of Multi-Agent Systems."

63 Scharre, "Robotics on the Battlefield Part I: Range, Persistence and Daring."

64 Scharre, "Robotics on the Battlefield Part II."

65 Daifullah Al-Garni, *Drones in the Ukrainian War: Will They Be an Effective Weapon in Future Wars?*

66 Schmuel, "The Coming Swarm Might Be Dead on Arrival."

urban canyons, to avoid detection. However, this limits the effectiveness of cheap drones. Even in the case of more advanced swarms, such as those consisting of unmanned fighter jets, the cost benefit of swarms may be lower than policymakers anticipate.[67]

A key anti-drone capability is electronic warfare, but here too it is not clear how effective such measures will be in the future, and swarms of drones might be able to counteract them.[68] By disrupting communication, electronic warfare counteracts the swarm's ability to coordinate and achieve emergence. Without emergence, a swarm still retains certain advantages, such as mass and redundancy.[69] To counteract electronic warfare, the swarm may concentrate within a small volume, thereby increasing the signal-to-noise ratio of its internal communication. However, this also makes the swarm more vulnerable to kinetic counter-swarm measures. For this reason, the most effective anti-swarm measures may involve a combination of electronic warfare and kinetic aerial defences. Finally, it should be noted that electronic warfare transmitters are typically ground-based and have limited influence at higher altitudes. The swarm may therefore take counter-measures, such as deploying some of its agents at higher altitudes.

2.4.1 Drone swarms and drones en masse

On record, true swarms have only been observed in actual battle when Israel used drone swarms during an attack on Hamas in May 2021.[70] However, socio-technical means of controlling large numbers of drones and other aerial weapons have been used by Russia and Ukraine, as well as by Iran against Israel, in the form of *en masse* attacks. These are simultaneous attacks in which the drones are either remotely piloted or autonomous, but do not communicate with one another.[71] Using the definitions presented above, this can be described as leaning towards socio-technical means of controlling multiple weapons while still achieving overwhelming mass. Drones *en masse* offer certain benefits, such as redundancy when multiple drones attack the same target, and the ability to saturate enemy air defences. Compared to true swarms, socio-technical systems are vulnerable to electronic warfare in a different way: they do not require inter-drone communication, but may rely on remote control by an operator or a GNSS signal for positioning.

In light of recent developments, it seems reasonable to assume that Russia and Iran may seek to improve their *en masse* attack capabilities to increase their effectiveness. One possibility could be advances in autonomy and communication,

67 Bronk, "Swarming Munitions, UAVs and the Myth of Cheap Mass."
68 Daifullah Al-Garni, *Drones in the Ukrainian War: Will They Be an Effective Weapon in Future Wars?*; Kallenborn, "InfoSwarms."
69 Scharre, "Robotics on the Battlefield Part II."
70 Kallenborn, "The Plague Beckons," 12.
71 Kallenborn and Bleek, "Swarming Destruction."

thus moving towards true swarms.[72] Currently, the technical capabilities of both Russia and Iran do not appear to support greater autonomy, but these developments demonstrate that there is demand, and that in the near future, these *en masse* attacks may well be carried out by true swarms.[73]

At the same time, the use of mixed aerial weapons in *en masse* attacks highlights the difficulties of separating drone swarm technology from other types of weapon carriers, and suggests that the future of swarms might not be limited to drones. While drone swarms should be understood as a technological phenomenon that merits study in its own right, the use of mixed aerial weapon carriers in this way underscores the significant overlaps between, on the one hand, socio-technical means of controlling various types of weapons in general, and on the other, the potential of "true" swarming capability. For the moment, swarming capability, when seen in the broader context of aerial weapon carriers, appears only to enhance and improve the efficiency of existing practices of warfare, rather than constituting something entirely new. The actual gains from developing swarm technology may, in the end, not lie in drone swarms themselves, but rather in the proliferation of swarming technology into other areas.

72 Kallenborn, "The Plague Beckons," 14.

73 See for example Kallenborns discussion on "demand" in Kallenborn, "The Plague Beckons."

3. Civilians, drones, and swarms in warfare

When the technological landscape on the battlefield changes, the way civilians are effected and how they can be protected changes too. Consequently, battlefield technologies also determines and inspires novel approaches to civil defence. This Chapter will focus on this relationship between technologies of war, and the effect on civilians and civil defence responses. The Chapter considers how civilians may be impacted by future swarming capability of drones, and in what way drones and drone swarms might be used for civil defence purposes. The Chapter also includes a discussion on how drone swarms of different sizes might be used to counter the use of drone swarms by the opponent.

3.1 War against civilians and new technologies: Denial and punishing attacks

The history of drone warfare highlights how societies and military strategy adapt to technological change. Developments in long-distance artillery, various types of aircraft, intercontinental ballistic missiles, and precision-guided munitions (PGMs) all resulted in changes to both strategy and tactics as they were introduced, and eventually also led to changes in civil defence. Drones are very much in the same category of weapons technology.[75] They are connected to the history of remote targeting, used to project power or coerce the opponent "from above," and the strategic rationale behind their use has its origins in the early twentieth century.[76] As such, while the use of drones in warfare today might appear revolutionary, that claim merits historical analysis. Drones are part of a much longer history of technological development and military strategy, and should be analysed accordingly.[77]

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75 For a brief introduction to drone technology, see Keane and Carr, "A Brief History of Early Unmanned Aircraft"; Kindervater, "The Emergence of Lethal Surveillance"; Cook, "The Silent Force Multiplier"; Rantakokko, *Tekniköversikt autonoma och obemannade system—Del 1*.

76 One of the reasons why drones were developed was to train anti-aircraft artillery crews to fend off incoming aircraft more efficiently by shooting at drone targets. For an introduction to the history of aerial warfare, see Black, *Air Power*; see, also, Pape, *Bombing to Win*.

77 This entanglement is also why many scholars have had difficulties in determining if drones constitute a revolution in military affairs or not. See, for example, Rossiter, "Military Technology."

When harm to civilians has resulted from the use of remote weapon technologies such as drones, the rationale behind their use typically falls into one of two categories.[78]

The first, and most common, is when civilians are harmed during denial attacks.[79] Denial attacks are carried out to deny, hinder, or destroy the military capability of the opponent, and can in turn be divided into two categories. They may be used for coercive purposes against the entire state, in order to degrade the target's overall military capability, such as through remote attacks against industries, harbours, or other types of infrastructure. Denial attacks can also be used during ongoing military operations of a more local character. For example, a denial attack could be carried out against transportation hubs, such as bridges and train stations, or against military facilities or civilian buildings housing military personnel. A contemporary example in which civilians also suffered is the Russian sabotage of the Nova Kakhovka hydropower dam, which flooded the Kherson region in Ukraine in June 2023. This attack was not executed using drones but is a typical example of the rationale behind such attacks. The flooding stalled the Ukrainian military advance but also caused significant problems for civilians living in the area.[80] In denial attacks, there is no particular gain in civilian casualties per se, but there may be indirect advantages from the antagonist's point of view if the defender is forced to commit resources to protecting or assisting civilians.

Secondly, the civilian population might be affected by punishing attacks. These attacks do not directly relate to military capability or area denial.[81] In these situations, the opponent is targeted as a whole (even if the immediate target might be minor). Like denial attacks, punishing attacks can also be divided into two kinds. They may aim to coerce the political leadership into submitting to political demands of some kind, or they may be used as part of a war aimed at the total destruction the target state. This was the case in the "total" wars between states in the first half of the twentieth century, when the civilian population, military capacity, and war effort in general were seen as inseparable elements.[82] A contemporary example is the Russian attacks on the Ukrainian power system and civilian infrastructure, intended to destroy the economic and industrial capacity of the entire state.[83] The threat of attacks is keytothe

78 This segment is based on Robert E. Pape's discussion of strategies of military coercion. See Pape, *Bombing to Win*, 15–19; see, also, Pape, "The True Worth of Air Power"; Lake, "The Limits of Coercive Airpower"; Allen and Martinez Machain, "Understanding the Impact of Air Power."

79 Pape, *Bombing to Win*, 18.

80 Pape, *Bombing to Win*; Wulff, *Chockvågor i fjärde ringen. Människors reaktion på flyg- och robotangrepp*.

81 Pape, *Bombing to Win*, 19.

82 Bell, *The First Total War*; Black, *The Age of Total War, 1860–1945*; Chickering et al., *A World at Total War*. "Total" war is no longer lawful under international law. See further discussion in Chapter 4.

83 Odell et al., *Russian Attacks*. The legality of these attacks has been questioned by UN monitoring bodies, and the International Criminal Court has issued an arrest warrant against a Russian general in relation to the conduct of these attacks. See, UN Human Rights Council, "Report of the Independent International Commission of Inquiry on Ukraine," A/HRC/52/62, 25 September 2023, paras. 40–43; UN General Assembly, "Report of the Independent International Commission of Inquiry on Ukraine," A/78/540, 19 October 2023, para. 44–46; and UN General Assembly, "Report of the Independent International Commission of Inquiry on Ukraine," A/79/549, 25 October 2024, 8–23; see, also, International Criminal Court, "Statement by Prosecutor Karim A.A. Khan KC on the issuance of arrest warrants in the Situation in Ukraine," 25 June 2024, *https://www.icc-cpi.int/news/statement-prosecutor-karim-aa-khan-kc-issuance-arrest-warrants-situation-ukraine-0*.

underling coercive agenda against the opponent. Scaremongering is thus also an important part of punishing attacks. By way of example, the US and the Soviet Union used the threat of nuclear weapons to deter one another throughout the Cold War. Terrorist attacks by non-state actors also fall within the category of punishment attacks, as their purpose is to coerce the policies of the target state by inflicting fear and suffering on the civilian population.[84]

It is also noteworthy that tolerance for civilian suffering tends to increase as conflicts progress, making punishing attacks less effective over time.[85] This may lead the attacker to increase the severity of attacks and the impact on civilians as initial efforts are frustrated. Initially, an attacker might conduct denial operations, such as attacks against military installations, but when these fail to achieve a breakthrough, attacks may then be directed at civilian infrastructure instead, either as a last resort, for revenge, or to increase the likelihood of long-term success. The Nazi German bombing campaign against the United Kingdom (UK) in 1940, known as the "The Battle of Britain," as well as the subsequent V-1 flying-bomb and V2 rocket campaigns of 1944–1945, are classic examples of this mind-set.

This is an important dynamic to bear in mind when considering the future of drones and swarming capability. History demonstrates that the longer a war continues, the more likely it is that both sides of a conflict may resort to more extreme measures and begin using punishing attacks as a last-resort tactic or as an act of revenge.[86] This is notwithstanding the fact that these technologies may have been developed with the intention of being effective against military installations or used on the battlefield in accordance with IHL.[87]

Various forms of weapons designed for use in aerial attacks have been employed for denial or punishing purposes throughout the past hundred years, and the underlying rationale behind such attacks has not changed significantly in contemporary times.[88] New technologies play an important role in these situations by making weapons more effective, either by causing greater damage with less effort or by creating advantages over opponents in various ways, such as inducing panic or

84 Pape, "The Strategic Logic of Suicide Terrorism."

85 Pape, *Bombing to Win*, 22.

86 See further discussion in Chapter 4. One of the earliest examples of air raids being used as revenge can be traced to the First World War, specifically the British and French air raids on Freiburg and Karlsruhe; see Chickering, *The Great War and Urban Life in Germany*, 98 and following.

87 Directly targeting civilians or civilian infrastructure is always unlawful. In addition, both acts and threats of violence with the primary purpose of spreading terror among civilians are prohibited. However, both denial and punishing attacks that are directed against military objectives may be in accordance with IHL, including if they cause incidental and proportionate death or injury to civilians, or damage to civilian infrastructure and other protected objects. As noted in Section 1.3.1, civilian infrastructure can otherwise fall within the definition of a military objective if all the criteria set out in Article 52(2) AP I are fulfilled. By way of example, a bridge that is used by the opposing party's military and is essential for transporting military material to the front line, and whose destruction would offer a definite military advantage, may constitute a military objective. Accordingly, it may be lawfully targeted, subject to the further applicable requirements under IHL. The key determining factor is the status of the object, not the underlying purpose of the attack. See further in AP I, Articles 51(2) and 52(1).

88 For various perspectives on this, see Black, *Air Power*; Pape, *Bombing to Win*; Pape, "The True Worth of Air Power"; Horowitz and Reiter, "When Does Aerial Bombing Work?"

circumventing defensive systems.[89] For example, PGMs used in the Russo-Ukrainian war since 2022 serve a similar purpose to the bombing raids of the 1940s, to destroy industrial capacity and infrastructure, though they are more accurate and require fewer aircraft and less explosives. The US has been especially eager to gain tactical advantage by actively promoting new technologies, hoping to identify the next war-winning revolution in military affairs while limiting its own casualty rate.[90]

It is extremely rare for punishing attacks, or the threat of such attacks, against civilians or civilian infrastructure to have any decisive coercive effect in warfare. There are no examples of this in the wars of the twentieth century, and no war has been won by attacking civilians alone.[91] One reason for this is the way in which states tend to organise the protection of their citizens and economic infrastructure, through, for example, resilience- and civil-defence planning, as well as security of supply.[92] Nevertheless, military powers have carried out punishing attacks against civilians in numerous conflicts. This is also not confined to the past, as demonstrated by Russia in the armed conflict with Ukraine, as discussed above.

Figure 4: In 1944-1945, Nazi-Germany launched some 20,000 drones towards the British Isles. The V-1's were aimed at urban areas, the accuracy was low, and the drones hit civilians and military targets indiscriminately. The attacks were part of Hitler's attempt to coerce the British administration by frustrating the public and causing as much suffering and damage as possible. The attacks strained the British aerial defenses significantly.
Source: Wikimedia commons, (PD).
Note: The image has been cropped.

89 Black, *War and Technology*, 232–233.; Van Creveld, *Technology and War*, 319–20.

90 O'Hanlon, *Technological Change and the Future of Warfare*.

91 Pape, *Bombing to Win*, 22–27.

92 Pape, *Bombing to Win*; see also Vale, *The Limits of Civil Defence in the USA, Switzerland, Britain and the Soviet Union*.

The use of drones and drone swarms against civilians is therefore a likely eventuality in future conflicts that must be considered and understood, particularly as the proliferation of drone technologies for combat purposes continues and industrial production becomes cheaper.

3.2 Factual and fictional examples of swarm attacks against civilians and civilian infrastructure

How, then, might drones and swarms be used in the future against civilian and civilian infrastructure? There are several ways an adversary might utilise both socio-technically controlled and true swarms in civilian contexts in the future. Overall, the purpose of using swarm tactics will likely be the same as outlined in the previous section—that is, either for denial purposes to limit the opponent's military capability, or through punishing attacks against the state and its citizens to coerce and gain political advantage.

3.2.1 Size determines usage

Considering the size of drones is instructive in understanding how they might be used, as size affects the payload and range of the drones, and thus determines their effectiveness. Larger drones have greater range, can carry heavier payloads, and are more suitable for damaging infrastructure, especially when used in combination with aircraft, cruise missiles, or ballistic missiles. If civilian infrastructure were targeted, the advantage of using a swarm lies in tactics such as the saturation of aerial defences, as discussed in Chapter 2. Drones have been used in this way several times over the past decade, and the number of drones involved in such incidents is increasing. In a 2018 drone attack on a Russian base in Syria, 13 homemade aerial drones were used. Iran used 25 drones in a 2019 attack on Saudi oil facilities.[93] Since 2022, Russia has used Iranian Shahed-136 drones to saturate Ukraine's aerial defences and then strike civilian energy facilities and harbours. In November 2024, Russia used 120 missiles and 90 drones in a single attack against Ukrainian power systems in the Kyiv region, and news outlets reported that over 200 drones and 90 missiles were used in an attack on 13 December 2024.[94]

In these examples, socio-technical means were used to facilitate the attacks, rather than true swarms. However, the use of true swarms might make such *en masse* attacks with medium and large drones more effective in the future—for example, by avoiding aerial defences, saturating radar systems, or loitering until they detect buildings with lit windows or identify infrastructure sites.

93 Pledger, "The Role of Drones in Future Terrorist Attacks"; Kamminga and Veltman, "Drone Swarms: Fact or Fiction?"

94 Odell et al., *Russian Attacks*; see also AP, "Russia Targets Ukrainian Infrastructure."

Smaller drones and LMs, such as the Hero-120, Lancet-3, and smaller sized FPV drones, might not cause significant damage to infrastructure, but could still cause casualties and damage, for example, to vehicles and individuals.[95] These are more likely to be used for denial attacks in local contexts. There are plenty of examples today of small-sized LMs and FPV drones being used to hunt armoured vehicles and supply vehicles. However, it is not difficult to see how such drones might be used to attack civilian vehicles in order to cause panic for coercive purposes in punishing attacks. Smaller drones lack long range, but if dropped in large numbers near their intended targets by a larger carrier, they could target moving vehicles, guaranteeing casualties upon impact and disrupting traffic. Examples of this have already been seen in the armed conflict in Ukraine.[96] If true swarms are operated in this way, the process could be automated using algorithms to identify targets.

Micro aerial vehicles, which weigh less than one kilogram, are unlikely to cause significant damage to infrastructure or vehicles, but could be used to attack individuals.[97] In contrast to the potential use of larger and medium-sized drones, it is difficult to see how this kind of use in a civilian context could serve any purpose other than punishing attacks for coercive reasons. There are already numerous

Figure 5: Today, drones are often associated with the smaller rotary-wing aircraft type. These have a multitude of potential applications. The above image is from the British Ministry of Defence testing the TRV150 in 2021. These drones delivered ammunition and other supplies to special forces as needed.
Source: Ministry of defence, UK, (OGL).

95 Examples of existing LM systems that the manufacturers claim to have anti-tank capability include the Switchblade 600 system from AeroVironment, the Hero 90 and Hero 120 systems from UVISION, and the Lancet 1 and Lancet 3 from ZALA. All these systems are of fixed-wing design, with pusher propellers and a payload weight of 1–4.5 kg. The Switchblade and Hero systems are also man-portable, and tube-launched with foldable wings.

96 Brown, "Ukraine Modifies Domestic UAV Into FPV Strike Drone 'Aircraft Carrier.'"

97 Examples of such small drones include the Switchblade 300 and Hero 30. These are LMs with anti-personnel capabilities.

examples of individual first-person view UAVs being used in this fashion in Ukraine against infantry in military settings. From Ukraine, we also see how FPV operators have managed to sneak drones into vehicles or buildings, causing significant damage from within by detonating near ammunition storages or unprepared soldiers.[98] Using swarming technology in such circumstances could have a similarly destructive effect to that of a larger explosive, but with greater precision and autonomy through algorithmic feedback based on sensor data.

Range is a factor here, however. Micro aerial vehicles have short range and must be released from a vehicle or airdropped close to their intended target area. They can also be countered by obstacles, such as stationary nets or by people staying indoors.[99] Tactics such as using one drone to shatter a window may grant the rest of the swarm access to an indoor environment, but once indoors, the swarm would lack access to GNSS localisation and would have to rely on advanced algorithms for localisation, mapping, and exploration. In sum, the scenario of small drones being used to target civilians requires a great deal in terms of algorithms and software capability relative to the drones' light-weight construction, low power consumption, and limited computational hardware. It is therefore unlikely that this will pose a serious threat to civilians in the near future.

3.2.2 Fear of the swarm

In fiction, the swarm is sometimes portrayed as a source of dread, such as in Alfred Hitchcock's 1963 film *The Birds,* and it holds significant terror potential. This is important, as the threat of punishing attacks must be taken into account.[100]

It has been suggested that drone swarms could be operated by non-state actors and terrorists for coercive purposes. The idea is that, since truly autonomous swarms are scalable, certain non-state actors could potentially operate a large number of drones in an autonomous swarm and use them for terror attacks. It has even been suggested that swarms could be used by terrorists as a sort of "weapon of mass destruction." (WMD)[101] The term is used here to signify the potential future scalability of swarms and their potential to cause mass civilian casualties on a scale comparable to WMDs, rather than to argue that drone swarms could be used to deliver such weapons.[102] As noted above, the potential use of smaller drones and swarms remains highly limited and cannot be compared to the destructive power of WMDs. However, these discussions do underscore that imaginative aspects of drone swarms, and that this, in itself, is a problem that must be addressed.

98 Axe, "A Ukrainian Drone Sneaked Up On Russian Troops In Their Sleeping Bags"; SVT, "SVT mötte soldaterna vid Pokrovsk"; Hambling, "The Fast And Furious FPV Drone Strikes On Russia's Supply Lines."

99 Levine and Hausman, "The Global Project to Make a General Robotic Brain—IEEE Spectrum."

100 Pape, *Bombing to Win*, 19.

101 Russell et al., "Why You Should Fear 'Slaughterbots'—A Response—IEEE Spectrum."

102 See also Kallenborn, "The Plague Beckons," 16–17.; and Kallenborn and Bleek, "Swarming Destruction."

An example of this imaginative component is the video *Slaughterbots*, posted on YouTube in 2017 and produced by the Future of Life Institute. The video portrays a fictional scenario aimed at contributing to discussions surrounding lethal autonomous weapons systems (LAWS). At the time of writing, the video has gained over 47 million views across various platforms.[103] In *Slaughterbots*, a company develops an autonomous micro aerial vehicle equipped with facial recognition software for targeting and a shaped charge, which it uses to kill a single person. The technology is then obtained by a terrorist group, which uses it to target civilians.

The video has sparked controversy and debate. Some argue that the technology portrayed is plausible, but that militaries are not building weapons to target civilians, and that terrorists would not be able to acquire large numbers of such weapons.[104] Others argue that autonomous weapons such as those depicted in the video should be banned, or that further regulations should be introduced to monitor manufacturers of drone technology and its precursors.[105] Concerns that such weapons could fall into the wrong hands have also been raised in international

Figure 6: Screenshot from the short film Slaughterbots. Thousands of small drones are being released from a "mothership" aircraft over an urban area. Screenshot taken by the author of this report.
Source: Screenshot from short film "Slaughterbots", https://www.youtube.com/watch?v=O-2tpwW0kmU&t=157s Accessed 2025-06-28.

103 Russel et al., "Slaughterbots Case Study."

104 Scharre, "Why You Shouldn't Fear 'Slaughterbots'—IEEE Spectrum."

105 This, they argue, might lead to the introduction of regulations that monitor manufacturers of drone technology and its precursors, and then state-actors will be able to notice whether terrorists begin mass production of drones; see Russell et al., "Why You Should Fear 'Slaughterbots'—A Response—IEEE Spectrum."

discussions on new regulations for LAWS, partly as a consequence of these debates.[106] Proposals have been made that a potential future instrument should require states to take legislative and other measures to prevent and suppress violations of international law within their jurisdiction.[107]

To date, such scenarios have only been discussed in political debates, and there are currently no real-world examples. There are, however, indications that the fear of the swarm already constitutes a palpable threat, and that fear itself can have disruptive effects on civilian society. Studies of the Obama administration's "drone wars" suggest that the presence of UAVs was highly distressing for civilians in those countries and areas where they appeared.[108] There have been multiple sightings of unknown drones in various situations that have caused traffic disruptions and alarm, as well as uncertainty and fear of antagonistic threats. In the Nordic countries, there have been several such incidents, and authorities have responded by urging the population to report sightings.[109] For three days in September 2024, there were disturbances at Sweden's Stockholm Arlanda Airport following consecutive drone sightings near runways.[110] In Norway, several individuals were apprehended and prosecuted for espionage in 2023 after flying drones near critical infrastructure.[111]

These were all singular drones, not swarms. Nevertheless, public reactions suggest that if a single drone can cause this level of fear and interference, an incoming and unidentified swarm of drones would likely be extremely disruptive to society. The context in which such swarms might appear could also intensify public fear—for example, if a swarm is sighted at a point of increased tension in a hybrid conflict situation, or in the initial phase of a conflict when civilians and politicians are not yet accustomed to continuous attacks and coercive behaviour by the adversary. If such swarms were sighted in the context of an international armed conflict, they could potentially have a significant coercive effect.

106 Meeting of the High Contracting Parties to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects, 13–15 November 2019, Final Report, CCW/MSP/2019/9, 12 December 2019, Annex III Guiding Principles affirmed by the Group of Governmental Experts on Emerging Technologies in the Area of Lethal Autonomous Weapons System (GGE LAWS Guiding principles), Guiding Principle (f).

107 See the informal proposal by the Chair of the CCW GGE LAWS 2024, *Rolling text*, status date: 26 July 2024. See further discussion in Chapter 4.

108 See, for example, Hijazi et al., "Psychological Dimensions."

109 YLE, "Police: Drone Threat Is 'Here to Stay.'"

110 SR, "Sources: Nato in the Loop about Drone Reports at Arlanda Airport."

111 Milne, "Norway Cracks down on Drone Flights after Arrest of Seven Russians."

3.3 Civil defence and swarms

Protective measures for civilians and civilian infrastructure have been instrumental in safeguarding against coercion through threats of, or actual, punishing attacks in the past.[112] But, how should states defend their civilian population against potential attacks by drones and drone swarms? Technological change has been an important factor in how states have developed their organisation of civil defence. Every technological change, or new technological fear, has led to some counter-technology or defensive method.[113] The introduction of drones and swarming capability will likely result in a similar shift. From a civilian threat perspective, this development need to be acknowledged, and new counter-UAS tactics should be developed to defend civilians, or existing techniques repurposed.[114]

It is important to note, however, that the protection of civilians will always involve both military and civil defence to some degree, and that these must be seen as complementary.[115] Military counter-UAS is thus the first line of defence against drone swarms. Subsequently, civil defence must also respond. Moreover, counter-UAS directed at swarms must be considered in the broader context of other types of weapons that may be used simultaneously.

From a military perspective, and judging from how the Armed Forces Ukraine have worked to fend off large numbers of drones, a key element has been distributed defence. The Russian military has launched hundreds of drones alongside ballistic and cruise missiles against Ukraine, at varying altitudes. A distributed defence capable of wearing down these barrages has proven decisive. This includes early detection, sensing, tracking, electronic warfare, and kinetic measures operating across different altitudes.[116] This is likely what would be required to address swarming technology as well, and a future challenge will be to ensure that such measures can be adapted to track increasingly larger numbers of drones. The most effective solutions will also depend on the type of drones they are designed to counter, while simultaneously providing protection against other incoming threats such as ballistic missiles and cruise missiles.

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112 Pape, *Bombing to Win*, 23.

113 See, especially, Fridlund's analysis of the ages of fear; Fridlund, "Buckets, Bollards and Bombs"; Bennesved, *Sheltered Society*. For example, during the era of gas warfare, early civil defence organisations turned to gasmasks and evacuation routines to solve this new threat. During the age of flight and aerial warfare, they tried to counteract this by building makeshift basement shelters and practicing fire-fighting routines. As the nuclear age made the threat more all-encompassing, bordering on existential, states turned to even more extensive civil-defence planning in the form of massive fallout shelters or evacuation routines that included the movement of entire cities (as in Sweden and Switzerland), or abandoned it in favour of military deterrence- instead (as in the US and the UK). During the post-9/11 period, bollards and extensive airport security checks have been the means of controlling the environment, albeit in response to threats from terrorists rather than international armed conflict. In this way, civilian means for protection have adapted continuously.

114 Watling and Bronk, *Protecting the Force from Uncrewed Aerial Systems*; Petersson and Ahlberg, *Counter-UAS för säkerhet*; Lykou, Moustakas, and Gritzalis, "Defending Airports from UAS: A Survey on Cyber-Attacks and Counter-Drone Sensing Technologies."

115 For a discussion on the relationship between civil and military defence, see Vale, *The Limits of Civil Defence*; see also Bennesved, *Sheltered Society*.

116 Watling and Reynolds, "Tactical Developments During the Third Year of the Russo–Ukrainian War," 18–19.

In civilian environments, there may be a need for more diverse countermeasures to neutralise hostile drones, such as radio-based jamming and high-power microwave technologies.[117] In terms of kinetic countermeasures, technologies such as net guns are currently used to counter drones, but these are mainly used against individual small drones, not incoming swarms of medium or larger size.[118] It may become necessary to introduce temporarily positioned automated gun batteries to defend against low-flying UAVs near key civilian infrastructure—this is discussed further below. Such systems might prove decisive in complementing more advanced aerial defences (such as surface-to-air missiles, SAMs), which are adapted to counter larger and faster projectiles, such as cruise and ballistic missiles. These systems could also offer a potential solution against large and medium-sized UAVs used for denial and punishing attacks in local settings. The Armed Forces of Ukraine are currently engaging incoming Russian LM's in this way (see Fig. 6).[119]

In terms of non-military—or passive—measures for civilian protection against drone swarm attacks, communication and sheltering are key. Various forms of air raid shelters in public spaces would probably be effective against large and medium-sized drone attacks, as these type of drones rarely carry large warheads. Against smaller drones, staying indoors may be sufficient. Passive measures, however, necessitate effective communication between military sensors and civil-defence functions,

Figure 7: Incoming swarms of UAVs puts pressure on aerial defenses in a new way. Here, Ukrainian soldiers practice shooting down incoming UAVs from a pick-up truck with a mounted machinegun, December 2022. CC, Territorial Defense Forces of Ukraine.
Source: Ministry of Defence of Ukraine, (CC).
Note: The image has been cropped.

117 Petersson and Ahlberg, *Counter-UAS för säkerhet*, 23–24.

118 Zmysłowski, Skokowski, and Kelner, "Anti-Drone Sensors, Effectors, and Systems–a Concise Overview"; See "kinetic interdiction" in Lykou, Moustakas, and Gritzalis, "Defending Airports from UAS"; Petersson and Ahlberg, *Counter-UAS för säkerhet*, 24.

119 Watling and Reynolds, "Tactical Developments," 19.

especially if there is a risk that the swarming behaviour of incoming weapon carriers could result in the saturation of military defences.

Another passive measure against swarming small drones that could be used locally is the deployment of nets. Nets are already used to protect crowds during demonstrations involving drones and drone swarms. Small rotary drones can easily become entangled in sturdy netting. In the military context, nets were tested as an anti-aircraft method in the early twentieth century to ward off incoming, low-flying biplane bombers. Nets were abandoned during the 1930s, however, as aircraft models and bombing techniques evolved to permit bombing from higher altitudes. As noted, this method may once again prove useful in local environments, such as near energy and communication infrastructure or entrances to civilian buildings, particularly against smaller drones. There are also examples of nets being used against individual drones in military contexts in this way.[120] Against a determined enemy, however, it is difficult to see how passive measures of this kind could function effectively without being complemented by military aerial defences.

Figure 8: Mobile concrete shelter used in Ukraine during the Russo-Ukrainian war 2023. These have been placed in central areas to be used by civilians in case of attacks.
Source: Ministry of Defence of Ukraine, (CC).

120 Hambling, "Ukrainian Drone Pilots Unimpressed By Russia's Anti-FPV Tunnel"; "Can Nets Protect against Kamikaze Drones in Ukraine?"

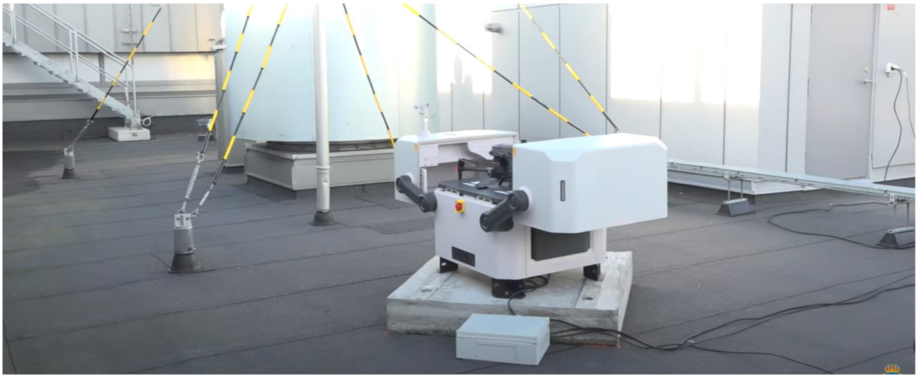

Figure 9: Swedish police demonstrating how drones might be used from the rooftops in urban areas. The box containing the UAV is placed on the rooftop beforehand to be activated when a crime is reported in.
Source: Screenshot from Swedish Police https://polisen.se/aktuellt/nyheter/syd/2024/mars/dronare-ska-bli-forst-pa-plats-vid-allvarliga-brott-i-malmo/ (accessed 2025-06-28).

3.3.1 Using swarms for protective purposes

There are also ways in which swarms themselves could be used for civil defence and emergency management purposes. In emergency management research, drones have been a recurrent topic for some years and are already used by rescue services today.[121] In general, the role of swarming in this context would be to enhance existing methods of drone use.[122] UAVs and UGVs can be used, for example, for wildfire and fire surveillance, search and rescue (SAR), crowd control, damage assessments, and the detection of CBRN materials, agents, and explosives.[123] A drone could also perform a preliminary assessment to diagnose a casualty before the rescue team arrives. These applications are, of course, useful in both warfare and emergency management situations.

Swarming capability does not necessarily introduce fundamentally new functions in this context, but it can enhance emergency-management functions, for instance by enabling faster coverage of a given area more than a single drone. That kind of capability can be very important for relaying information during casualty evacuation and SAR missions. A swarm can also help to map an area and identify a viable route for personnel to travel along. A swarm of UAVs may patrol an area in order to detect intruders. Once an intruder is detected, nearby civilians can be alerted if they need to take shelter. In the city of Malmö, Swedish police have placed drones on roofs to be ready to film incidents of crime as they are reported.[124]

121 Jin et al., "Research on Application and Deployment of UAV in Emergency Response"; Khan, Gupta, and Gupta, "Emerging UAV Technology for Disaster Detection, Mitigation, Response, and Preparedness"; see, also, FOI's research on this topic, including Wingfors, Forsberg, and Landström, *Drönare med CBRNE-sensorer för räddningstjänst*.

122 See, for example, Javed et al., "State-of-the-"; Gkotsis et al., "Swarm of UAVs."

123 Javed et al., "State-of-the-Art"; Wingfors, Forsberg, and Landström, *Drönare med CBRNE-sensorer för räddningstjänst*.

124 Collier, "Swedish Police Pioneer A Trial Drone First Responder System"; see also Mohamed et al., "Unmanned Aerial Vehicles Applications in Future Smart Cities."

Most of these suggestions, however, remain at the experimental level. The limitations on the use of drones for protective purposes are, in essence, the same as those in military contexts. Improved coordination and control systems are needed. The problems of limited range and endurance also persist for civilian drone applications.[125]

125 The different functions that drones can carry out require different types of search patterns and software to be effective. Further research in this area is needed, however. See Wingfors, Forsberg, and Landström, *Drönare med CBRNE-sensorer för räddningstjänst*; See also Javed et al., "State-of-the-Art."

4. International humanitarian law on drone swarms and civil defence

It might seem that the easiest way to protect civilians and civilian infrastructure from drones and drone swarms would be for states to prohibit their development, stockpiling, and use through international law, as they did in the Biological Weapons Convention and Chemical Weapons Convention.[126] However, drones are already shaping contemporary battlefields and offer distinct advantages for armed forces, such as enabling engagement at a distance and in conditions of electronic warfare. There is, therefore, little support for a complete ban. There are, however, ongoing international efforts to discuss regulation of these weapons. This discussion is progressing, and concrete formulations are being considered. It is thus likely that autonomous weapons systems, such as drone swarms, will be subject to new and specific regulation in the future. It must also be borne in mind that already existing international law is applicable to the use of drones and drone swarms. As such, international law is also a key factor in how drones and swarming technologies may develop and be used now and in the future.[127]

4.1 Existing international humanitarian law

There are currently no specific rules on drones or drone swarms under IHL. However, it is clear that existing IHL applies fully to all existing and future weapons used in armed conflicts.[128] As such, regardless of how a party to a conflict uses drone swarms, their use must always comply with IHL. Over history, IHL has proven to be resilient and adaptable to new technology, including drones. In that sense, drone swarms, be they true swarms or socio-technical swarms, do not constitute something conceptually

126 Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction, adopted 16 December 1971, opened for signature at London, Moscow and Washington, 10 April 1972, entered into force 26 March 1975 (BWC), and Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction, adopted 3 September 1992, opened for signature in Paris 13 January 1993, entered into force 29 April 1997 (CWC).

127 Given the report's focus on civil defence and drone warfare, this part focuses on IHL applicable in international armed conflicts, i.e. armed conflicts between states. Note that other areas of international law also apply to the development and use of drones and LAWS, such as *jus ad bellum* and human rights law.

128 UNGA resolution 78/241, *Lethal autonomous weapons systems*, A/RES/78/241, 22 December 2023, first preambular paragraph; Meeting of the High Contracting Parties to the CCW, 13–15 November 2019, *Final Report,* CCW/MSP/2019/9, 12 December 2019, Annex III *Guiding Principles affirmed by the GGE LAWS* (Guiding Principles)*,* Guiding Principle (a); GGE LAWS, *Report of the 2023 session of the GGE LAWS, 6–10 March and 15–19 May 2023*, CCW/GGE.1/2023/2, 24 May 2023, para. 21(a); ICJ, *Legality of the Threat or Use of Nuclear Weapons*, Advisory Opinion, 8 July 1996, I.C.J. Reports 1996, p. 226, para. 86.

new or problematic for IHL. However, the technology underlying drone swarms does give rise to new legal questions. This is primarily because of its reliance on autonomous functions, which may change the role of humans in warfare. This raises questions about how to interpret and implement IHL in relation to these weapons.

It should be borne in mind that IHL aims to protect victims from the effects of armed conflicts.[129] Violations of IHL may also bring about State responsibility under international law,[130] and the responsible State may be liable to make reparations in various forms.[131] Violations may also constitute war crimes, genocide, or crimes against humanity and thus be subject to individual criminal liability under international and domestic criminal law.[132] Historical and contemporary conflicts are full of examples in which civilians suffer serious harm from the effects of hostilities, including those involving drones. Some of these examples are the result of violations of IHL and may also constitute war crimes. The introduction of autonomy in critical combat functions is likely to make war crime investigations and eventual prosecutions for crimes committed in the use of a weapon even more complicated than they already are today, however.[133]

4.1.1 Obligations to be taken by the attacker

States must determine whether the weapon would, in some or all circumstances, be prohibited by international law in the study, development, acquisition, or adoption of a new weapon.[134] Any future drone and drone swarm must therefore be subject to this legal review before it is employed. While any weapon could potentially be used in an unlawful manner, the objective of the legal review is to ensure that it can be used in line with international law. The forward-looking nature of this obligation thereby forms a link between technological development and IHL's rules on the conduct of hostilities.[135]

As with the use of any other weapon, the use of drones and drone swarms is regulated by IHL's rules on the conduct of hostilities. Three of the fundamental principles are essential to consider in this, namely the principles of distinction, proportionality, and precautions.

129 AP I, preamble para. 4. This is relevant, as treaties should be interpreted in good faith and in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose, according to Article 31 of the 1969 Vienna Convention on the Law of Treaties (VCLT).

130 International Law Commission (ILC), *Articles on Responsibility of States for Internationally Wrongful Acts*, Reports on the Work of its Fifty-third Session (23 April–1 June and 2 July–10 August 2001), GA, Official Records, Fifty-sixth Session, Supplement No. 10, (A/56/10). See also *Gaeta, ,* "Who Acts When Autonomous Weapons Strike?: The Act Requirement for Individual Criminal Responsibility and State Responsibility."

131 AP I, Article 91, and ICRC, CIHL database, Rule 150.

132 See, for example, Rome Statute of the International Criminal Court 1998, Articles 6, 7 and 8. See further the Swedish Act on certain international crimes (2014:406) (*Lag (2014:406) om straff* **för** *vissa internationella brott*).

133 Bo, "Autonomous Weapons and the Responsibility Gap in Light of the Mens Rea of the War Crime of Attacking Civilians in the ICC Statute"; See further discussion in Pocar, Pedrazzi, and Frulli, *War Crimes and the Conduct of Hostilities*.

134 AP I, Article 36.

135 Pilloud et al., *Commentary on the Additional Protocols*.

Under the principle of distinction parties to an armed conflict must at all times distinguish between civilians and civilian objects on the one hand, and military objectives, including combatants, on the other, and only direct their operations against military objectives.[136] A civilian person is any person who does not fall within the definition of a combatant, and in case of doubt, the person should be considered a civilian.[137] Civilian persons are protected from direct attack, unless and for such time as they take direct part in hostilities.[138] As such, civilians who do not take part in hostilities must never be the object of attack. Furthermore, indiscriminate attacks and acts that are intended to spread terror among the civilian population are prohibited.[139] Indiscriminate attacks are those that are not directed at a specific military objective, employ a method or means of combat that cannot be directed at a specific military objective, or employ a method or means of combat that cannot be limited as required by IHL.[140]

The principle of proportionality requires that an evaluation be made of the expected military advantage of attacking the military objective in relation to the anticipated, incidental civilian harm prior to the attack. Incidental harm to civilians or civilian objects must not be excessive in relation to the anticipated military advantage.[141]

The principle of precautions requires that feasible measures be taken both in the planning and during the execution of an attack to avoid, and in any event minimise, incidental civilian harm. Such measures include verification that the objective is military, choice of means and methods of attack, issuing warnings, and cancelling the attack if it becomes apparent that the objective is not military or that it would be disproportionate.[142] Accordingly, even though civilians must never be the object of attack and all feasible precautionary measures must be taken to avoid civilian harm, incidental civilian harm is nevertheless not necessarily unlawful in armed conflict.

Some of the technical developments described previously in this report—such as the use of UAVs for surveillance in relation to targeting by other means—potentially increase the information available to commanders, resulting in improved situational awareness. This offers opportunities for better-informed evaluations, judgments, and decisions in line with the principles described above. New technology, such as drone swarms, may thus provide possibilities to enhance IHL compliance. However, more complex legal questions arise when drones or drone swarms are armed and

136 Articles 48 and 51(2) AP I and ICRC, CIHL database, Rules 1 and 7.

137 AP I, Article 50(1).

138 AP I, Article 51(3) and ICRC, CIHL database, Rule 6.

139 AP I, Article 51(4) and ICRC, CIHL database, Rule 11; and Article 51(2) and ICRC, CIHL database, Rule 2.

140 AP I, Article 51(4). See also ICRC, CIHL database, Rule 11.

141 AP I, Articles 51(5)(b) and 57(2)(a)(iii) and 57(2)(b) and ICRC, CIHL database, Rule 14.

142 AP I, Article 57.

can perform additional critical combat functions, such as identifying, selecting, and engaging targets with force. This is because the principles described above involve a number of evaluations, judgments, and decisions that must be made in the planning and execution of an attack. The rules apply to parties to armed conflicts and humans, and are based on the assumption that humans perform these actions.[143] Depending on the context, it may be possible to design weapon systems to perform combat functions autonomously in line with IHL, but many legal issues still remain unsolved.[144]

Notwithstanding challenges relating to autonomy and law, it is clear that drones and drone swarms must never be used to target protected civilians or civilian objects. This is both prohibited under IHL, and a war crime.[145] It is also prohibited to use a drone swarm to terrorise a civilian population. Accordingly, the portrayal of the intentional targeting of civilians similar to the video *Slaughterbots* mentioned above could amount to a war crime under international criminal law.

4.1.2 Obligations to be taken by the defender

In IHL, attacks are defined as "acts of violence against the adversary, whether in offence or in defence."[146] Hence, the rules described above must be upheld whether a party is using violence offensively or defensively to protect its own civilian population from approaching enemy attacks, including those carried out with or by drone swarms. In addition, IHL obliges parties to the conflict to take measures on their own (and occupied) territory aimed at protecting civilians from the effects of armed conflicts, sometimes referred to as "passive precautions."

IHL obliges states to endeavour to remove the civilian population, individual civilians, and civilian objects from the vicinity of military objectives, avoid locating military objectives within or near densely populated areas, and take other necessary precautions to protect the civilian population, individual civilians, and civilian objects from the dangers resulting from military operations "to the maximum extent feasible."[147] These obligations apply regardless of how the opposing party acts and respects the law, and can significantly enhance the protection of civilians.[148] However, the feasibility caveat has in practice "devalue[d] the character of the obligation in modern conflicts."[149] It is possible that drone technology will provide a tool to improve compliance with these obligations. Drones used for surveillance may give the defending state

143 Lewis and Sweeney, "Exercising Cognitive Agency: A Legal Framework Concerning Natural and Artificial Intelligence in Armed Conflict," 17, 21–23.

144 See for example, Kwik, *Lawfully Using Autonomous Weapon Technologies*; Geiß and Lahmann, *Research Handbook on Warfare and Artificial Intelligence*; Mauri, "Autonomous Weapons Systems under International Human Rights Law"; McFarland, *Autonomous Weapon Systems and the Law of Armed Conflict*.

145 For IHL, see Articles 48 and 51(2) AP I and ICRC, CIHL database, Rules 1 and 7. For the war crimes see Rome Statute 1998, Article 8(2)(b)(i) and (ii) and (iv).

146 AP I, Article 49(1).

147 AP I, Article 58.

148 Bothe, Partsch, and Solf, *New Rules for Victims of Armed Conflicts*, 413.

149 See, for example, Jensen, "Precautions against the Effects of Attacks in Urban Areas," 154.

better knowledge of where civilians are located, and increase the capacity to engage in defensive attacks against incoming enemy attacks to protect civilians who may not be removed.[150] The available information and increased capacity should affect what is considered "feasible."[151] As such, drone technology may enhance contemporary understanding and application of obligations to defend civilians,[152] that is, how civilians and civilian objects must, should, and can be protected on a party's own territory.

Chapter 3 highlighted that drones may contribute to civil defence's performance of humanitarian tasks. Drones that belong to civil defence organisations and are used for these purposes are civilian objects, and must not be destroyed or diverted from their proper use, except by the state to which they belong.[153] In situations of occupation, the Occupying Power must not destroy them or use them for other purposes.[154] However, there may be a risk that an opposing party does not perceive such drones as civilian in nature, but rather as drones that are intended or used to commit acts harmful to it. This has been noted in reports discussing experiences from the war in Ukraine.[155] If, albeit wrongfully, understood as such, this could result in these drones being classified as military objectives by nature, use, or purpose. A State using drones for civil defence purposes is likely to keep those drones in the vicinity of civilian objects and the population. The civilian population and civil defence personnel located nearby such drones could then be exposed to a real risk arising from this potential legal risk—namely, the risk of being incidentally affected by an attack that would not necessarily be unlawful. Civil defence organisations may therefore need to consider possible measures to avoid or minimise these risks, for example through marking or other measures. Parties to armed conflict are obliged to endeavour to ensure that civilian defence matériel is identifiable, including through displaying the international distinctive sign of civil defence.[156]

Unlike the literature on IHL's obligations of the attacker, there is little written on the obligations of the defender and on civil defence, and even less so with regard to the impact of new technology on those rules. As this is underexplored, further research is needed on how drone technology could affect the interpretation and implementation of IHL's regulation of defensive protection measures and the rules governing civil defence.

150 Compare Jensen, 172 on other types of technologies.

151 See Jensen, 172.

152 See, for example, Jensen, "Precautions against the Effects of Attacks in Urban Areas."

153 AP I, Article 62(3).

154 The Occupying Power may requisition or divert these resources subject to conditions set out in AP I, Article 63(5), but not if such diversion or requisition would be harmful to the civilian population in the occupied territory. The Occupying Power is also prohibited from diverting or requisitioning shelters provided for the use of the civilian population or needed by such population under AP I, Article 63(6).

155 Räkköläinen, Sundblom & Juutinen, Lessons from Ukraine:
Impact of the war in Ukraine on civil society and protection of the population during the war. 25, 56.

156 AP I, Article 66.

4.2 Discussions on new international law

The concerns raised about drones and drone swarms have sparked multilateral discussions on whether existing IHL is sufficient, or whether there is a need for further regulation or prohibitions. Recently, these discussions have intensified, and concrete formulations are being discussed. The following section describes the current status of the discussion on new international law as of January 2025. It is centred on LAWS, as it is likely that drone swarms will be understood as such.

4.2.1 Background to the discussion

In 2012, a number of civil society organisations voiced concern about risks to civilians by the increased use of drone warfare and formed the "Campaign to Ban Killer Robots."[157] The following year, the UN's Special Rapporteur on Extrajudicial, Summary or Arbitrary Executions presented a report on "lethal autonomous robots" that analysed the human rights concerns of the use of drones by militaries.[158] These two events were key catalysts for states to initiate a formalised process to hold multilateral discussions on the potential need to develop new law.[159] These discussions are taking place in the format of the Group of Governmental Experts on Lethal Autonomous Weapons Systems (GGE LAWS) of the 1980 Convention on Certain Conventional Weapons (CCW). In addition, there are informal discussions within the UN General Assembly on the same topic.[160]

The central questions in this discussion are whether international law sufficiently regulates LAWS, or whether new international law is needed, and if so, how a new instrument should regulate the development and use of LAWS. Over a decade after it was initiated, the discussions are still ongoing, with little substantive outcome. However, there was a turning point in 2023, after which the discussion has intensified.[161] In 2025, concrete formulations of a future instrument are being discussed, although the status remains to be decided.

Many states are actively engaged in this topic. States advocating for a legally binding instrument with strict regulations have several times gathered in different *ad hoc* settings outside of the CCW to build regional consensus.[162] Some of the most active states working toward this end are Austria, Costa Rica, and the Philippines.[163] Major

157 Dube and Wareham, "State Positions on Autonomous Weapons Systems," 315.

158 Heyns, Report of the Special Rapporteur on Extrajudicial, Summary or Arbitrary Executions, A/HRC/23/47, 9 April 2013.

159 Dube and Wareham, "State Positions on Autonomous Weapons Systems," 315 and following.

160 UNGA resolution 79/62, *Lethal autonomous weapons systems*, A/RES/79/62, 2 December 2024.

161 See Andersson, *Utveckling av den folkrättsliga regleringen av autonoma vapensystem*.

162 Communiqué of the Latin American and the Caribbean Conference of Social and Humanitarian Impact of Autonomous Weapons, La Ribera de Belén, 23 – 24 February 2023, CARICOM Declaration on Autonomous Weapons Systems, Port of Spain, 5 – 6 September 2023, Republic of the Philippines, Ministry of Foreign Affairs, *Philippines calls for Indo-Pacific Voices to Address Lethal Autonomous Weapons Systems,* Communiqué of the regional conference on the peace and security aspects of autonomous weapons systems: an ECOWAS perspective, Freetown, 18 April 2024.

163 Andersson, *Utveckling av den folkrättsliga regleringen av autonoma vapensystem*, 40–42.

military powers are also actively engaged. For example, the US opposes a legally binding instrument but has put forward a proposal for a non-legally binding instrument and launched the Political Declaration on Responsible Military Use of Artificial Intelligence and Autonomy.[164] China has repeatedly expressed support for a legally binding instrument with a prohibition of certain types of LAWS, while remaining sceptical of regulating other types of autonomous weapons systems.[165] Notwithstanding the challenges presented by these diverging views, the active engagement of so many states and the progress made since 2023, indicates that it is likely that the LAWS discussion will result in a legal or political instrument.

The substance of the discussion is based on and shaped by legal, ethical, societal, and security concerns related to increased remoteness and autonomy in weapons and warfare.[166] Ethical concerns involve questions such as how these weapons affect concepts such as human dignity and whether they further a dehumanisation of warfare.[167] Therefore, the role of the human in relation to autonomy in targeting is at the core of the discussion. Requirements of human involvement would be a key component of a potential instrument.

4.2.2 The LAWS discussion related to swarms

Drone swarms per se have seldom been explicitly raised in the LAWS discussion. There are at least two critical issues related to LAWS that should be addressed.

The first issue is that although the discussion on LAWS has been ongoing for over a decade, there is no set definition of what it includes. It is therefore unclear whether drone swarms would fall under this term, and consequently, under a potential future instrument. Despite the lack of a legal definition, there is a common understanding of the term between states, practitioners, and academics in the field. LAWS can be described as weapons systems that, once activated, can identify and/or select and apply force without further human involvement.[168] It could possibly be useful to explore characterisation in relation to swarms through the question of what is considered as a "weapons systems." For example, whether individual entities in a swarm should be considered as separate LAWS or whether such entities could be seen as a whole collective unit (consisting of several entities) that constitute a LAWS.

164 Andersson, 40–42. See further Political Declaration on Responsible Military Use of Artificial Intelligence and Autonomy, February 2023, https://www.state.gov/bureau-of-arms-control-deterrence-and-stability/political-declaration-on-responsible-military-use-of-artificial-intelligence-and-autonomy.

165 Andersson and Winther, China's Position on Developing New International Law on Autonomous Weapons Systems, in Weidacher Hsiung, *Strategic Outlook 10: China as a Global Power*. See further Qiao-Franco and Bode, "Weaponised Artificial Intelligence and Chinese Practices of Human–Machine Interaction".

166 See, for example, UNGA resolution 78/241 (2023).

167 Hagström, "Autonom våldsutövning – hot eller möjligheter: För en strukturerad debatt."

168 See, for example, ICRC, "ICRC Position on Autonomous Weapon Systems"; Bruun, Bo, and Goussac, "Compliance with International Humanitarian Law in the Development and Use of Autonomous Weapon Systems." This is also reflected in the work of the GGE LAWS to formulate a characterization for a potential future instrument. See, for example, the informal proposal by the Chair of the CCW GGE LAWS 2024, *Rolling text*, status date: 26 July 2024.

It follows from the common understanding that the discussion focuses on the use of force. This means that unarmed drones and unarmed drone swarms would fall outside the concept of LAWS, unless they are weaponised. Armed drone swarms could constitute LAWS provided they possess sufficient autonomy in critical combat functions. Notably, remotely operated drones that cannot perform critical combat functions without the involvement of a human operator would be excluded from the definition of LAWS. As such, if a new legal instrument on LAWS is adopted, different legal rules will apply to different systems depending on their autonomous functions and whether they are weaponised.

The second critical issue in the LAWS discussion is that the notion of "meaningful human control" has been frequent in proposals, but also lacks a clear definition.[169] Over time, other wordings have also been introduced, such as "appropriate human control," "adequate human control," or merely "control." The latter suggests that control could be exercised through software. Proposals that focus only on "control" instead of being coupled with "human" tend to emphasise the role of humans in relation to judgment, such as "appropriate human judgment." The proposals to use "adequate" or "appropriate" add more flexibility than "meaningful," reflecting a context-dependent requirement. The formulation of requirements for human control or judgment is one of the most challenging issues in the ongoing discussion. How these requirements should be formulated will have significant implications for swarming capabilities.[170]

The issue of control of drone swarms has come up briefly in the GGE LAWS discussion.[171] In 2016, the Chairman of the Group held that "where swarms of LAWS act as force multipliers, it would be unclear how meaningful human control could be maintained over the use of force."[172] This illustrates the difficulty of formulating requirements of human control in relation to entities that are not meant to be controlled individually, but collectively. It may be easier to develop mechanisms for human control and/or human judgment for a single LAWS or a limited number of LAWS operating together, rather than for swarms.

It follows from the inherent characteristics and purpose of a swarm that the units act with a large degree of autonomy. As discussed above, the whole point of the swarm is that it performs tasks that no single individual could do by itself. The formation, flight path, task distribution, etc., of an envisioned drone swarm is based on AI algorithms that allow the drones a large degree of autonomy, and the operator is aided by a human-machine interface for giving aggregate control commands. Therefore, direct human control of each unit could be seen as undesirable, counterproductive,

169 Mauri, "Autonomous Weapons Systems," 239–240

170 Ekelhof and Paoli, "Swarm Robotics," 3.

171 Ekelhof and Paoli, "Swarm Robotics," 3.

172 Ekelhof and Paoli, 1–2.

Figure 10 Figurrubrik in här. Figure 10: The Warmate loitering munitions system as displayed as a swarm during an exhibition in Poland, 2024. The Warmate system is described as a "“self-contained” fully autonomous system that can be transported over land by special forces units or installed on vehicles".
Reference: "WB Group WARMATE Loitering Munitions."
Source: Michał Derela (CC BYSA), via Wikimedia Commons.
Note: The image has been cropped.

or an impediment to the development and use of swarms.[173] Conversely, requirements of human control of the swarm as a collective or a holistic entity (i.e. a system) would be possible.

If states seek to formulate elements that require human control or judgment of drone swarms that fall under the definition of LAWS, the term LAWS would need to be considered as including several entities operating together as integral to the system. The requirement of control and/or judgment would therefore need to be considered as controlling the swarm as a whole and not controlling each individual unit in it. It may therefore be beneficial to further explore whether swarms need to be addressed specifically in any instrument resulting from the LAWS discussion.

To summarise, there is no prohibition on the development or use of drones or drone swarms in international law. There is, however, detailed existing regulation, and it is likely that more specific regulation will be adopted in the future for how drones and drone swarms may lawfully be used in armed conflict. The emerging technology of drone swarms poses both challenges and opportunities for IHL compliance. It is still unclear whether, and if so, how armed drone swarms could be used in compliance with existing IHL. In addition, while much is written on IHL, drones, and autonomous weapons, issues relating to how the use of this emerging

173 Ekelhof and Paoli, "Swarm Robotics"; Jenks, "The Gathering Swarm."

technology may affect obligations on passive precautions and civil defence are currently underexplored in the legal literature.

The legal, ethical, societal, and humanitarian concerns raised by emerging drone technology that led to the multilateral discussion on LAWS have slowly progressed to a constructive state where concrete formulations are discussed. If states manage to conclude an instrument on LAWS, this will affect the development and use of drone swarms. As noted, it is likely that some kind of legal instrument will be adopted in an international forum. However, as the process within the CCW requires consensus among the states involved in the discussion, nothing is agreed until everything is agreed.

5. Concluding discussion

It is clear that enabling technologies are developing quickly, the battlefield use of drones is proliferating, and that swarm technology is the next step in this development. Recent scholarship on drones suggests that drone swarms will be a lasting feature of modern warfare, across all domains. The technological prerequisites for swarms are already present, and although examples of true swarms used in actual warfare are scarce, efforts are underway. Military powers and parties to ongoing armed conflicts are working towards producing swarm-like behaviour for their aerial weapon carriers. A key issue for the future of drone swarm technology, however, is the financial aspects. Much will depend on the kind of capabilities they can offer and whether countermeasures to swarms will be sufficiently cost efficient.

However, an important conclusion from this study is that it is difficult to separate the development of drone swarms from other types of aerial weapons and precision-guided munitions. All in all, the heart of the problem from a civilian perspective is really the increase in mass, although swarming technologies are at the core of this development. Moreover, there might be technological overlaps that eventually result in a separation of swarming technology from drones. Developments within the area of drone swarms might spur development in other fields and offer means of making other types of attacks and weapons carriers more effective. In that sense, autonomous swarming as a general capability is perhaps more alarming than swarms of drones specifically.

With regard to potential effects on civilians and civil infrastructure, our study suggests that drones and drone swarms, regardless of whether they are true swarms or socio-technically controlled, are likely to be used in the same way as aircraft and missiles have been used during the twentieth century. In that sense, drone swarms and related technology offer nothing new per se, only new ways of doing the same things, but with the side note that it might offer the means of making mass more efficient and more difficult to defend against. Moreover, as noted in Chapter 4, IHL applies to drones and drone swarms in the same way as it does to other weapons, and existing laws apply to both weaponised drones and drone swarms. Drone swarms do, however, underscore the problem of the relation between autonomy and human control, an area that has proven to be difficult in ongoing discussions about the regulation of LAWS.

In conclusion, civil defence organisations must expect that various forms of drone swarms, or a mixture of drones and other weapon carriers used in a swarming fashion, will be a common feature in future wars. Major military powers already demonstrate such capabilities, and others may develop them in the future. On the positive side, swarm technology could also benefit civil defence-related functions, as well as emergency management more generally. Drone swarms do not necessarily offer entirely new solutions, but, similar to the military sphere, swarm technology might make existing roles, such as in rescue operations, more effective. The use of swarms in ISR roles could particularly benefit civilians in warfare situations. Drone swarms might also aid states in fulfilling some of their obligations under IHL to evacuate civilians and protect them from the dangers resulting from military operations.

5.1 Suggestions for future research

Four areas of future research have been identified that would be beneficial in the short term (0–5 years).

Firstly, methods for identifying and communicating information about incoming drone swarms, or mixtures of drones and other weapon carriers, in civilian contexts should be developed. This includes development of surveillance and warning systems for drones and drone swarms, with the aim of protecting civilians and civilian infrastructure. Related to this, research is needed on how to physically protect or mitigate the risks posed by incoming drone swarms and mixtures of weapon carriers. Examples include continued technical development of electronic countermeasures and kinetic defences against drone swarms, with a focus on civilian needs.

Secondly, there is a need to develop methods for using drone swarms in civil defence operations and emergency management. This would include the development of methods for surveillance and rescue tasks using drones and drone swarms, both in peacetime crises and for the protection of civilians during war.

Thirdly, research into public attitudes and potential risks of disinformation and political coercion through asymmetric threats involving drone swarms would also be beneficial. In a similar vein, social science studies on risk awareness, public fear, and asymmetric warfare associated with technological leaps, such as drones with swarming capability, would further our understanding of the potential coercive effects of swarms.

Finally, there are several areas related to IHL that should be further examined. This includes the role, mandate, and protected status under IHL of civil defence and their equipment when employing drone technology in carrying out their functions. In addition, further research is needed into how obligations under international human rights law and IHL to protect the civilian population from the direct and indirect effects of warfare may be affected by the availability of drone technology. ■

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