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Are Drone Swarms Weapons of Mass Destruction?

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by

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Table of Contents

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Abstract

Public discussion has raised significant fears over armed drone swarms being used in a manner like weapons of mass destruction (WMDs). However, should they be considered WMDs? The first half of the article explores the question of comparing drone swarms to various conceptions of WMD. Overall, it finds that a subset of drone swarms, armed fully autonomous drone swarms (AFADS), are WMD. The second half examines the potential of drone swarms to serve in traditional WMD roles. Although drone swarms could be effective mass casualty weapons, they are likely to be a poor strategic deterrent. Drone swarms could be a useful anti-access/area-denial or assassination weapon in some contexts. The study has broad conceptual, legal, and policy implications. If drone swarms are WMD, then various international treaties apply, their use may justify military intervention in conflict, and new nonproliferation treaties should be developed.

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CHAPTER 1

Introduction

In 2017, the Future of Life Institute released *Slaughterbots*, a video depicting a theoretical drone swarm attack.[1] The swarm of microdrones was equipped with small charges and used facial recognition to seek out and strike targets. The video quickly went viral, receiving coverage from *The Economist*, *Fox News*, *CNN*, the *BBC*, and other major outlets.[2] By the end of 2018, the video received more than 70 million views across multiple social media platforms.[3] As Dr. Stuart Russell, the creator, describes, "What we were trying to show was the property of autonomous weapons [to] turn into weapons of mass destruction automatically because you can launch as many as you want."[4]

Slaughterbots technology is not theoretical. Numerous states are interested in drone swarms and the technology has advanced rapidly.[5] In January 2017, the U.S. Department of Defense tested a swarm of 103 unarmed microdrones that collectively and autonomously made decisions.[6] China and Russia are also pursuing drone swarm technology. China appears to have recently displayed a thousand-drone swarm during an air show.[7]

The low-cost and distributed nature of drone swarming technology enables its rapid growth. In 2013, Timothy Chung identified 13 test beds, primarily run by universities, experimenting with drone swarm technology.[8] Numerous others have been established since then. The barriers to developing swarming technology are sufficiently low that engineering students at the Massachusetts Institute of Technology (MIT) developed some of the first drone swarms.[9]

So, is Dr. Russell correct? Should these drone swarms be considered WMD?

Defining a Drone Swarm[10]

Exactly what are drone swarms? Drone swarms consist of multiple unmanned platforms and/or weapons deployed to accomplish a shared objective. The platforms and/or weapons autonomously alter their behavior based on communication with one another.[11] The interconnectivity of drone swarms enables them to exhibit more complex behaviors than their component drones. For example, during the 2018 Olympics, a thousand drones arranged themselves in complex, highly precise formations to create moving images of the Olympic rings, a flying dove, and a snowboarder.[12] Autonomy potentially enables highly sophisticated behaviors, such as self-healing, where a swarm adjusts its behavior in response to the loss of individual units.[13]

Drone swarms could involve novel platforms capable of launching attacks or existing weapon systems modified to allow communication and autonomous action. Drones within the swarm might be in close physical proximity or separated by miles. If the drones are deployed to accomplish the same objective and autonomously share information affecting their actions, they are part of a single swarm.

The number of drones possible within a swarm and their capacity to execute complex missions continue to grow.[14] Because drones involve proven, albeit evolving, technologies, the primary limitation on swarm size is the capacity to manage information exchanges between ever more drones. With computing power continuing to grow over the coming years, capacity to manage that information will likely continue to grow as well.[15] Further, energy-density research continues to increase the payload capacity and flight endurance of unmanned platforms.[16]

A drone swarm could consist of many drones of similar or identical size and capability or a heterogeneous mixture of platforms with different weapons and sensors.[17] Current drone swarms are typically designed as sensor platforms, conducting coordinated area surveillance.[18] These swarms are typically composed of small drones with limited range. However, as the technology matures, it will become increasingly viable to incorporate larger, more complex platforms able to carry weapon systems over large distances.[19] As the drone swarms and component drones increase in sophistication (better control algorithms, larger payloads, improved range and persistence), production costs are likely to increase as well owing to increased system complexity. Higher costs may mitigate some of the strategic value that drone swarms offer.

Role differentiation within heterogeneous swarms offers distinct advantages. Attack drones carry weapons payloads. Sensing drones carry sensors to identify and track potential targets or threats. Communications drones ensure stable communication links within the swarm and between the command system. Dummy drones may absorb incoming adversary fire, generate false signatures, or simply make the swarm appear larger.

The composition of a heterogeneous swarm could be modified to meet the needs of a particular mission or operational environment. The capability to swap in new drones has been demonstrated on a small scale.[20] In the future, providing a drone swarm to an operational commander could be akin to supplying a box of Legos. "Here are your component parts. Assemble them into what you need."

Role differentiation may also enable more complex behaviors. Sensing drones may be smaller and lighter than attack drones, enabling them to conduct reconnaissance ahead of the main swarm. Software architecture has been developed to coordinate teams of multi-mission unmanned aerial vehicles, including integrated intelligence and strike functions, weapon selection, and route planning based on identified adversary air defenses. (See *Figure 1)*.[21]

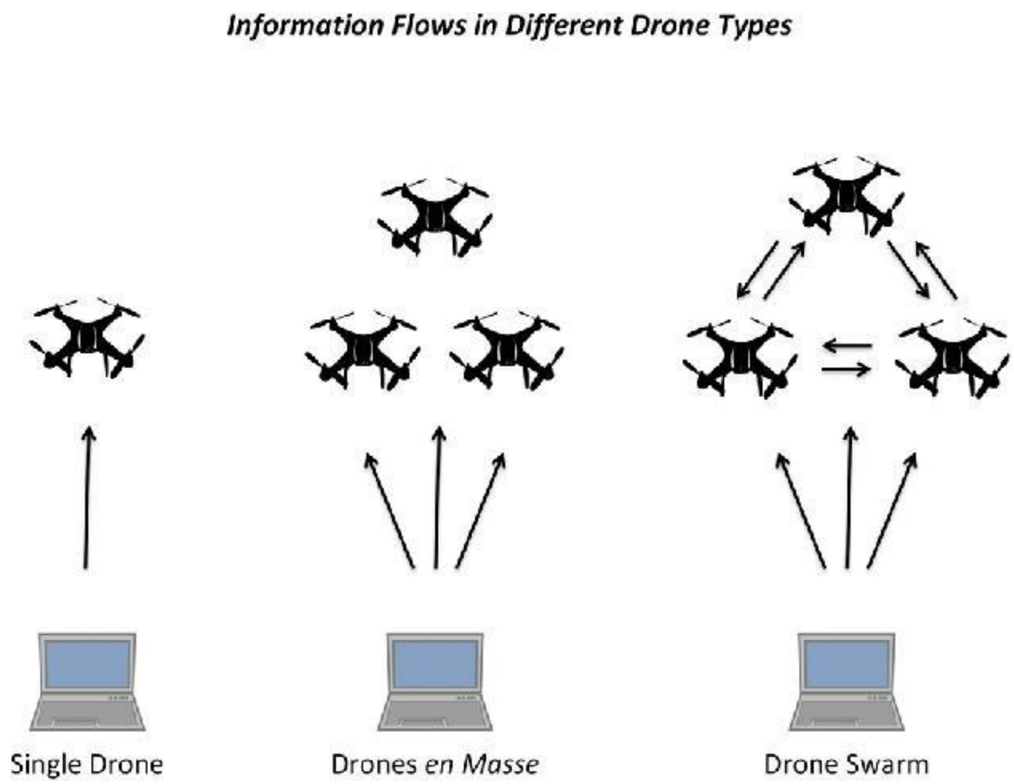

Figure 1 Information flows in different drone types.

There is a significant distinction between drone swarms and drones en masse. Drones en masse is the use of multiple drones without autonomous communication between the drones. Rather, one or more human decision makers coordinate all their actions, either in real time or in advance via preprogrammed behaviors. This distinction is significant for three reasons. First, the limits of human cognition are likely to limit the size, complexity, and behaviors of drone swarms generally, and they are exacerbated significantly with drones en masse. As Amy Hocraffer and Chang S. Nam note, "[Aerial drone] swarms pose several human factors challenges, such as high cognitive demands, nonintuitive behavior, and serious consequences for errors."[22] They also find that the level of autonomy of the swarm is the main factor in whether the human controller is a strength or weakness for management of large drone swarms.[23] While drone swarms have at least limited autonomy to limit the cognitive demands, that does not necessarily apply to drones operated en masse.

Second, drones en masse, unlike drone swarms, will not be vulnerable to countermeasures that seek to disrupt inter-drone communication or exploit weaknesses in control algorithms. Drones en masse will still be vulnerable to disrupting connections between the drones and the operator, though this communication may use different frequencies or different types of communication methods than inter-swarm communication. Although a central hub to collect and disperse data could limit this risk, the use of a central hub would likely impose range and responsiveness costs and create a vulnerable target to disrupt the drone swarm. Third, drone swarms will incorporate additional technological complexity over drones en masse. While commercial off-the-shelf or do-it-yourself drones can easily be used en masse, enabling them to communicate and alter behavior autonomously is a significant technical challenge. This challenge is likely to be particularly acute for non-state actors, who are likely to have more limited capabilities.

Drone swarms are also distinct from swarming as a tactic. John Arquilla and David Ronfeldt define tactical swarming as "seemingly amorphous, but it is a deliberately structured, coordinated, strategic way to strike from all directions at a particular point or points, by means of a sustainable pulsing of force and/or fire, close-in as well as from standoff positions."[24] Given the rich history and apparent importance of swarming as a tactic, it is striking that the literature on it appears to be rather limited. Swarming has been employed as a tactic throughout history, long before contemporary development of unmanned systems. For example, during the 12th and 13th centuries, Mongols "combined the mobility of the horse with the rapid, long-range fire of their horn bows to create an imposing ability to swarm either fire or forces."[25]

Drone swarms are highly suited to employing swarming tactics, but do not necessarily need to do so. Members of a drone swarm rapidly share information and coordinate their actions, enabling them to attack from all directions. The ability of drones within a swarm to act either individually or collectively also enables drones to concentrate or disperse as needed.

Armed, Fully Autonomous Drone Swarms

Overall, a subset of drone swarms – armed, fully autonomous drone swarms (AFADS) – qualify as WMD because of both their potential to cause mass casualties and inability to adequately distinguish between civilian and military targets. Although drone swarms do not need to be fully autonomous, the difficulty of operating a truly massive swarm is likely to require autonomous movement and targeting. Further, because AFADS are a subset of lethal autonomous weapon systems (LAWS) writ large, this conclusion also implies any LAWS capable of mass casualty could qualify as a WMD.

Drone swarms can also serve in traditional WMD roles. They would be highly effective as mass casualty weapons, especially against soft targets. They could also be strategic deterrent weapons, though the variety of defenses means nuclear weapons are likely to continue to be more reliable deterrents. Drone swarms could be effective in assassination attempts due to the ability to overwhelm defenses. However, the lack of stealth means they are likely to only appeal to actors unconcerned with (or desire) their role being known. In some circumstances, drone swarms could function as anti-access, area-denial (A2/AD) weapons.

Two other studies have touched on these issues. They are Jeremy Straub's "Analysis of Mutually Assured Destruction-Like Scenario with Swarms of Non-Recallable Autonomous Drones" and Zachary Kallenborn's and Philipp C. Bleek's "Swarming Destruction: Drone Swarms and Chemical, Biological, Radiological, and Nuclear (CBRN) Weapons."[26] Straub's article considers a few potential scenarios where non-recallable autonomous drone swarms could be used in a WMD-like manner. However, he does not engage with the theoretical literature on WMD and what it means for a weapon to be categorized as WMD. Although Kallenborn and Bleek examine numerous WMD-relevant applications of drone swarms, they devote no analysis to whether drone swarms could be categorized as WMD and only briefly examine the ability of drone swarms to serve in WMD roles.[27]

The remainder of the paper proceeds as follows. First, the paper explains why WMD categorization is significant and the major challenge in categorizing novel weapon systems. Then it explores whether drone swarms could be categorized as WMD based on general rationales for separating WMD from conventional weapons. Next, it examines the question of full autonomy and whether states will ever develop AFADS. Finally, the article concludes with an analysis of whether drone swarms can serve in WMD roles.

Why WMD Categorization Matters

Categorizing drone swarms as WMD has important theoretical, legal, and policy implications. Theoretically, an understanding of whether drone swarms constitute WMD is tied deeply to the conceptual problem of understanding WMD generally. Drone swarms share some commonalities with traditional WMD, such as their ability to inflict largescale death and destruction against civilian populations. However, drone swarms do not incorporate non-kinetic means of actions, such as disease or asphyxiation. Unlike other conventional weapons, drone swarms may be inherently indiscriminate between civilian and military targets.

Legally, the categorization of drone swarms as WMD affects the applicability of certain international laws. Three international treaties ban certain uses of WMD without defining WMD.[28] The Seabed Treaty prohibits "nuclear weapons and other weapons of mass destruction" from being placed on the "sea-bed and the ocean floor, and in the subsoil thereof."[29] That could pose a challenge for undersea drone swarms that may station on or utilize the seabed.[30] Similarly, the Outer Space Treaty prevents signatories from placing "nuclear weapons and other weapons of mass destruction" on the moon and other celestial bodies.[31] The Strategic Arms Reduction Treaty (START) reiterates these commitments and expands the Outer Space Treaty's scope to include fractions of Earth's orbit.[32] Drone swarms, like other robotic systems, could be quite useful in this domain as they do not require costly life-sustainment equipment.[33] If drone swarms are WMD, these treaties apply. If they are not, the treaties do not apply to them.

Categorization also may impact international treaty policies. The nascent movement to ban LAWS would necessarily cover armed, autonomous drone swarms.[34] Alternatively, categorization could justify the development of new arms control treaties because arms treaties are traditionally an important component of WMD non-proliferation. At minimum, this categorization would justify further analysis and study to understand the global security implications of proliferation.

In addition, categorization could affect policy calculations on interventions in conflicts in which drone swarms carry out military strikes, especially against civilian targets. In recent history, the use of WMD has drastically altered considerations on conflict intervention. In 2012, President Barack Obama issued a so called "red line" that any attempt to use chemical weapons in the conflict in Syria would change the administration's calculus on direct American intervention.[35] Although President Obama ultimately elected not to intervene, President Donald Trump ordered military strikes against Syria in April 2018 after additional chemical weapons usage.[36]

The use of WMD, including chemical weapons, also significantly affects public support over military intervention. In 2012, during debates over whether the United States should be militarily involved in the Syrian Civil War, a *Washington Post* poll found that chemical usage drastically shifted public opinion in favor of military intervention. In general, only 17 percent of respondents believed the United States should be involved militarily.[37] However, if Syria used chemical weapons against its people, support for military intervention jumped to 63 percent.[38] Similarly, when asked whether they supported intervention in Syria if Syria lost control of its chemical weapons, 70 percent supported military involvement.[39] Thus, the use or loss of control of chemical weapons alone was sufficient to radically change public support for military intervention.

While the categorization question is quite important, an answer is hard to find. In a study by Seth Carus on the term WMD, he identified 20 different definitions of WMD used by the United States government alone.[40]

The definitions fall into six general categories:[41]

1. WMD as nuclear, biological, and chemical (NBC) weapons.

2. WMD as chemical, biological, radiological, or nuclear (CBRN) weapons.

3. WMD as CBRN and high-explosive (CBRNE) weapons.

4. WMD as CBRN weapons that cause massive destruction or kill large numbers of people.

5. WMD as weapons that cause massive destruction or kill large numbers of people, and do not necessarily include or exclude CBRN weapons.

6. WMD as weapons of mass destruction or effect, potentially including CBRNE weapons and other means of causing massive disruption, such as cyberattacks.[42]

However, these six categories really reflect two general classes of definition, based on weapons type and on weapons effect. All six definitional categories fall into one or both of these two classes. Categories 1 through 4 define WMD based on the type of weapon, varying what types are included. Categories 4 through 6 define WMD based on their effect, focusing on the ability to literally cause mass destruction or death.

Neither Class of Definition Is Sufficient

While definitions of the first class offer ease of categorization, they do not offer guidance as to what separates these types of weapons from others. Nor do they offer any hint of what justifies expanding the term to include other types of weapons. This is problematic because weapon systems may emerge in the future that requires special attention akin to WMD. Therefore, because drone swarms could be one such weapon, this class of definition is not useful.

The second class of definition is incomplete. As others have noted, definitions based solely on effect would encompass large explosives, as well as non-weapons, such as the use of airplanes in the Sept. 11, 2001, attacks.[43] This definition would also imply that, for example, chemical facilities holding potentially lethal gasses should be qualified as WMD. While such facilities may be used to inflict mass casualties via a terrorist attack on the facility, they are not inherently WMD.[44]

Carus also disagreed with these alternatives, instead arguing that the definition passed by the United Nations General Assembly in 1946 is authoritative:

> *"[WMD are] . . . atomic explosive weapons, radioactive material weapons, lethal chemical and biological weapons, and any weapons developed in the future which have characteristics comparable in destructive effect to those of the atomic bomb or other weapons mentioned above."*[54]

Although this definition recognizes the potential for future WMD, it does not adequately separate WMD from conventional weapons. Chemical and biological weapons can vary significantly in their destructive effects. Toxins, such as ricin, have been effectively and typically used for the assassination of single targets. Most famously, Georgi Markov was assassinated with a pellet containing ricin injected by an umbrella. If WMD are weapons "comparable in destructive effect" to chemical and biological weapons, every weapon from handguns to tanks are WMD. The term would be analytically useless.

Various authors have also argued that "weapons of mass destruction" should be abandoned entirely.[46] These authors argue that the term conflates fundamentally different types of weapon. CBRN weapons all operate based on different physical principles, vary significantly in their capacity to inflict mass destruction, and require different policies to counter them. Further, the normative nature of the term enables WMD to be co-opted for political purposes to encourage intervention.

However, alternatives such as CBRN, NBC, and CBRNE retain the same problems as WMD. Each still squishes together different types of weapon.[47] Binding them together in one term implies a similarity. If they are all different, why use a single term? Further, little reason exists to believe these terms cannot also be appropriated for political purposes. After all, most of the public is not steeped in international relations issues.[48] They are most likely to encounter these alternatives in the context of weapons capable of mass destruction that drive popular news attention. Although these alternatives lose the explicit association with mass destruction, the term could implicitly gain the association, especially when each alternative and WMD overlap substantially.

The *Washington Post* poll regarding American intervention in Syria unintentionally tested the argument of political support for intervention. The use or loss of control of chemical weapons alone was enough to radically change public support for military intervention. For critics of the term WMD, the poll is particularly problematic. Critics are concerned that the term increases support for inappropriate intervention because WMD implies the destructiveness of chemical and nuclear weapons are equivalent. Because WMD includes both weapons, the public interprets "WMD usage" to include nuclear weapons, which are capable of reliably inflicting far more damage. However, if the use of chemical weapons, specifically defined, is sufficient to change public perception, then this concern is unfounded.

CBRN and alternatives also have a significant weakness compared to WMD. It's unclear under what circumstances one alternative should be used over another and what shared proprieties justify combining the weapon systems together. These weaknesses encourage the proliferation of alternatives to WMD with seemingly arbitrary usage. Why should radiological or explosive weapons be included in some alternatives such as CBRNE, but not in others like NBC? The terms do not offer an answer. That's a problem because it makes cross study and cross-organizational comparisons difficult. To what extent can a study on NBC weapons be combined with a study of CBRNE weapons? It also makes deciding whether to include new weapons systems impossible because there is no identified common denominator, which is particularly important for the present study.

Thus, while the WMD categorization is important, current definitions of WMD and alternatives such as CBRN do not provide clear guidance.

CHAPTER 2

Are Drone Swarms WMD?

Given the definitional challenges of WMD, I will evaluate drone swarms based on various rationales for separating WMD from conventional weapons. This avoids a messy debate, which cannot be resolved here, while addressing the debate's underlying question. Why do scholars, analysts, and government officials separate these weapons from others?

The creation of distinct government agencies and policies to combat WMD suggests differences exist. The U.S. Defense Threat Reduction Agency (DTRA) is responsible for preparing for and combating WMD for the military.[49] DTRA develops novel detection and response measures across the full range of WMD. Also, the U.S. Department of Homeland Security Countering Weapons of Mass Destruction Office is responsible for domestic WMD detection and supporting federal, state, local, and international governments.[50] Likewise, the Cooperative Threat Reduction program after the Cold War focused on preventing the proliferation of WMD, and only WMD, material and knowledge out of the Soviet Union.[51]

WMD can be considered distinct from conventional weapons based on their degree of harm, morality, and method of action. WMD are literally "weapons of mass destruction." They can cause significantly more harm than traditional weapons. The public and policymakers have significant moral concerns with WMD, due to the degree of harm and the often horrific nature of death by WMD. WMD also have unique methods of action, relying on disease, asphyxiation, and radioactivity to cause harm. Unique methods of action demand unique defenses from protective gear to vaccines.

Overall, drone swarms are akin to WMD in the degree of harm. Some drone swarms raise moral concerns, and drone swarms, unlike WMD, do not rely on unique methods of action. The scalable nature of drone swarms means they can pass any arbitrary threshold for "mass harm," although their lethality is lower than traditional WMD. Drone swarms with meaningful control over targeting decisions do not raise significant risk of indiscriminate harm. However, a subset of drone swarms – AFADS – do. Drone swarms do not have distinct methods of action.

Degree of Harm

Nuclear, biological, and chemical weapons, though not radiological weapons, are distinct from conventional weapons because they can easily cause mass casualties. During World War I, the use of chemical weapons including phosgene, mustard gas, and chlorine resulted in more than 1.3 million casualties and approximately 90,000 deaths.[52] New chemical agents developed in later years are even deadlier. Just 2.04 grams of pure sarin on the skin represent a median lethal dose for a 73-kilogram (160.9-pound) person and 0.146 milligrams of pure sarin taken orally is enough to have a toxic effect.[53]

While not used on the same scale as chemical weapons, biological weapons are also highly deadly. Former Secretary of Defense William Cohen famously held up a five-pound bag of sugar to represent the amount of *Bacillus anthracis* that could kill half of Washington D.C. if dispersed properly.[54] The equivalent explosive power of nuclear weapons ranges from 20 tons to 50 megatons of TNT.

On this dimension, drone swarms could be theoretically categorized alongside WMD. Drone swarms could meet or exceed any arbitrary capability threshold to inflict mass casualties. For example, a swarm of 10,000 drones each equipped with large bombs and missiles would meet virtually any threshold for mass casualty capability. The primary limit on drone swarm size is the development of algorithms and systems to coordinate drones receiving increasingly complex information flows. Although that is a non-trivial technical challenge, extensive research is on-going in industry, academia, and government to develop drone swarm control systems.

States seek drone swarms for military use. Every leg of the U.S. military, as well as the militaries of other states, is pursuing drone swarm technology. The U.S. Strategic Capabilities Office tested a swarm of 103 drones.[55] The U.S. Navy recently tested a swarm of four drone boats.[56] The U.S. Air Force Small Aircraft Systems Flight Plan: 2016-2036 envisions a broad array of roles for drone swarms, including attacking targets, providing intelligence, surveillance, and reconnaissance (ISR), and suppression of enemy air defenses (SEAD).[57] Besides the United States, China is making extensive investments in swarming and artificial intelligence.[58] Chinese companies have tested swarms of a thousand rotor-wing drones and swarms of 119 fixed-wing drones.[59] Russian companies are also pursuing swarming technology. Armen Isaakyan, the chief executive officer of the Kronstadt group, has hinted at secret Russian swarming programs.[60]

Non-state actors are not known to have developed drone swarms. However, they have clear interest in drones. During the Battle of Mosul, ISIS carried out more than 100 drone attacks in one month.[61] Likewise, unknown persons in Great Britain used two drones to shut down London's Gatwick airport, grounding flights for 30 hours.[62] Although the author could not identify commercial software allowing true drone swarms with drone-to-drone communication, control software to use drones en masse is increasingly available. For example, the Naval Postgraduate School used the open-source software, Ardu-Pilot, in their live 50 vs. 50 drone live flight testing.[63]

Unfortunately, examples do not exist to judge how much harm a true drone swarm can inflict. As a nascent, highly advanced military technology, a true swarm does not appear to have been used against either military or civilian populations. At best, only one real-world example exists of drones being used en masse. In January 2018, 13 drones made of plywood and tape and strapped with bombs attacked two Russian bases in Syria en masse.[64] The Russian military claimed they destroyed or disabled all the drones with no injuries. However, the Free Alawite Movement that claimed responsibility also claimed they destroyed an S-400 missile launcher, which costs approximately $400 million.[65] I could not find an independent confirmation of this claim, nor supporting evidence. The claim nevertheless merits mention as a real-world example of drones used en masse.

Nonetheless, the potential for massive combat swarms is clearly there. Drone swarms are low-cost, enable the development of new military tactics, and enable the integration of distributed, mobile sensor systems.[66] In particular, drone swarms enable the use of mass by bombarding adversary defenses with overwhelming numbers of drones.[67] This creates significant upward pressures to create larger swarms. If the goal of drone swarms is to overwhelm the enemy, more drones are better.

Of course, the degree of harm will vary significantly based on swarm size and armament. A drone swarm incorporating a single armed drone equipped with small arms is unlikely to meet any meaningful threshold of mass casualty capability. Evaluating the casualty potential of a drone swarm would require some measure that combines both the number of the drones and the type of weapon. While important for assessing a particular drone swarm, this is not relevant to the overall categorization because almost all traditional WMD can be reduced to trivial sizes.

Morality

WMD are distinct from conventional weapons on moral grounds. Under the Geneva Convention, combatants must "take all feasible precautions in the choice of means and methods of attack with a view to avoiding, and in any event to minimizing, incidental loss of civilian life, injury to civilians and damage to civilian objects."[68] However, minimizing the loss of civilian life from WMD is impossible. Chemical and biological weapons are susceptible to changes in wind patterns that may blow the agents into non-targeted populations. Further, biological and chemical weapons are likely to be employed in an indiscriminate manner, because they are useful in countervalue strikes, but less so against military targets who may be equipped with countermeasures.[69] Nuclear weapons are likely to cause significant civilian casualties because of the sheer size of the blast. The Hiroshima attack killed approximately 20,000 soldiers and between 70,000 and 126,000 civilians, while the Nagasaki attack killed between 39,000 and 80,000 people. The radioactive fallout may also blow into untargeted civilian areas. As C. A. J. Coady wrote regarding the bombing of Dresden and Tokyo, "conventional bombing need not be as indiscriminate as this, whereas it seems inherent in the idea of a WMD that it is geared to violation of the principle of discrimination."[70]

On this dimension, drone swarms, as a category, would not qualify. An unarmed drone swarm is clearly no weapon, much less a WMD. If the swarm is armed, human decisionmakers may elect to only fire at recognized military targets. With human control over targeting, drone swarms are not morally different than any other form of long-range munition.

However, a certain subset could qualify in the short run: drone swarms that are armed and fully autonomous (e.g. self-targeting and self-mobile). Current technology cannot provide AFADS (or any fully autonomous LAWS for that matter) with an effective ability to discriminate between combatants and non-combatants generally, except for specific pre-defined targets.

In large part, the ability of AFADS to discriminate between civilian and military targets depends on the quality of the AFADS' object recognition ability. AFADS requires the ability to effectively recognize indicators that the target is a military one. For example, the weapon needs to recognize whether a target is carrying a rifle or a rake. Accurate assessment depends heavily on image resolution and target visibility.[71] Obscuring conditions such as rain, snow, or shadows may prevent civilian-military discriminators from being perceived accurately.[72]

AFADS must also identify and evaluate context. Even if a target is holding a rifle, the person may be a farmer, not a solider. In addition, guerrilla or unconventional forces blur the line between farmer and soldier, because they lack clear indicators of military affiliation. Even if a target is a soldier, the person may be considered a noncombatant due to illness or injury.

In theory, AFADS and other autonomous weapons could discriminate between civilian and military targets. Debate is ongoing over whether autonomous systems could ever effectively accomplish this. However, both sides agree that discrimination on the battlefield is not likely to be possible in the near term.[73] Discrimination requires an explicit effort by the developer to create and incorporate such a capability. AFADS would require a software-based method of doing so, because, by definition, they cannot rely on humans to make that decision.[74]

While software could be developed to account for every hypothetical, it would be extremely challenging. As the roboticist Dr. Noel Sharkey noted in 2012, "We may move towards having some limited sensory and visual discrimination in certain narrowly constrained circumstances within the next 50 years."[75] Any autonomous weapon system must consider numerous possible variations and situations. Requiring such situational analysis may also slow down the AFADS' decision-making ability, creating opportunities for adversary counterattack. So, states may elect not to incorporate robust ethical decision making.

However, others disagree with Sharkey's views. As Ronald Arkin argues, ethical discrimination may be possible in the future and may lead to robots that are better than humans at discriminating between civilian and military targets.[76]

Arkin supports this through six arguments:

1. Robots are expendable and therefore can be more conservative in choosing to fire.

2. Advanced sensors may provide better sensing capability than humans.

3. Robots would not be clouded with human emotions that could impact judgment.

4. Robots are less susceptible to confirmation biases.

5. Robots can integrate more information sources, faster.

6. In human-robot teams, autonomous systems could report human ethical violations.[77]

While Arkin's arguments are intriguing, several of them depend on technological capabilities that are not yet possible or have other problems. For example, Arguments 3 and 4 are only relevant if robots can achieve near-human levels of judgment. This does not appear to be possible in the near future. Further, while robots are expendable, they are also a valuable military asset, so their loss would still harm overall military capabilities. So, robots are unlikely to be significantly more conservative in their fire than humans. Argument 6 is only applicable to a specific usage for robots and would not apply to robots as independent weapons. Nonetheless, Arkin compellingly shows that discrimination challenges may be mitigated by future technology. However, technology is not the only challenge in adequate target discrimination.

Effective moral discrimination depends on military decisions about when and where to employ AFADS. If AFADS are employed in areas with little likelihood of civilian presence, the likelihood of civilian casualties is inherently low. For example, autonomy is already used in a limited way in anti-tank mines, the Navy MK-60 sea mines, and Patriot anti-aircraft systems. However, the context of their use makes accidental civilian harm unlikely.[78] Similarly, the SGR-A1 automated gun turret is only employed in the demilitarized zone (DMZ) between South Korea and North Korea, where potential targets can be assumed to be hostile.[79] However, fully autonomous systems as defined here – systems that are both self-mobile and self-targeting –must also remain in an area with limited to no civilians.

Self-mobile autonomous weapon systems are inherently more difficult than non-self-mobile weapons to confine to military targets. The South Korean SGR-A1 gun turret is self-targeting, but not self-mobile. Because the DMZ has few civilian targets, that means the turret is highly unlikely to accidently shoot a civilian target because civilian movement is highly confined and controlled. The gun turret cannot move itself, so the South Korean military can be confident it will stay there. However, if the gun turret were self-mobile, it could move into a civilian area in pursuit of a target or simply due to an error. This makes self-mobility especially significant from a law of war perspective.

Expressed another way, a self-targeting gun turret on the Antarctic sea ice does not present a significant threat to human life. However, give the turret wheels, and it could wander into a civilian research station.

The difficulty of reducing risks to civilians may also vary based on domain and target. While foliage, buildings, and other objects may hide land-based platforms, ships on the open ocean have limited to no obstructions, other than camouflaging weather conditions and the curve of the Earth. Military ships also may be easier to distinguish from civilian ships, owing to much larger sizes and the presence of distinctive cannons and other equipment. Alternatively, AFADS could be restricted to only anti-drone warfare where only robots would be harmed.[80] In practice, this is likely to entail a few challenges, such as appropriately differentiating between manned and unmanned craft. That might be easier than differentiating between combatants and noncombatants, but certainly not a trivial task. So, varying domain and target may reduce, but not resolve, the challenge of adequate civilian-military discrimination.

Thus, AFADS will be morally indiscriminate in the near term. Future technological advances may allow them to be morally discriminate, but until then AFADS could be categorized with WMD on moral grounds.

Method of Action

WMD are distinct from conventional weapons because they depend on, or significantly incorporate, nontraditional methods of inflicting harm. Conventional weapons rely on conventional mechanisms of inflicting harm, such as the momentum of the bullet or the pressure of an explosion. However, biological weapons rely on the transmission of disease. Chemical weapons depend variously on asphyxiation, disruption of neurotransmitters, or chemical burn depending on the agent. Radioactive and nuclear weapons incorporate significant radioactivity that can damage or mutate cells.

The mechanism of action also means that harm may continue well after an attack. Diseases may spread to new people. Chemical agents may persist for days or weeks, causing continual harm. Nuclear fallout can cause radioactive harm years later. This creates significant postattack cleanup challenges.

Distinct methods of action give rise to unique countermeasures. Respirators and hazardous material (HAZMAT) suits cannot stop bullets, but can prevent harm from chemical, biological, and radiological agents. States have also developed detectors to identify signatures of WMD agents. The multibillion-dollar BioWatch program deployed air filtration systems across the United States to help identify biological weapons agents.[81] Likewise, nuclear and radiological weapons detectors sense either natural or stimulated radiation emitted by such weapons.[82]

Drone swarms do not have unique methods of action. While the platform is novel, the payloads are not. Drone swarms may be equipped with conventional arms that inflict damage through traditional kinetic means. Although drone swarms could be armed with WMD agents, a drone swarm attack does not change the nature of the WMD agent being used nor does this change with full autonomy.[83]

CHAPTER 3

The Question of Autonomy

Will drone swarms ever become fully autonomous? Whether states will allow full autonomy is unclear. The Department of Defense policy on autonomy in weapon systems prevents autonomous systems to select humans as targets without appropriate human control.[84] However, the "Summer Study on Autonomy" by the Defense Science Board concluded that the U.S. military "must accelerate its exploitation of autonomy – both to realize the potential military value and to remain ahead of adversaries who also will exploit its operational benefits."[85] Exploiting the benefits of autonomy may ultimately require adoption of full autonomy, especially if adversaries do so.

The incentives are mixed. While full autonomy offers clear benefits for drone swarms, clear risks exist too. However, because states may calculate their interests differently, especially when it comes to their security, AFADS emergence should not be discounted.

Incentives for full autonomy

More autonomous drone swarms are easier to control. Autonomy may allow multiple drones in the swarm to follow a single leader, maintain fixed distances from one another, dodge obstacles, and carry out strikes against targets. Each function autotomized is one less function requiring operator focus.

Larger, more complex drone swarms place more cognitive demands on human operators. Large swarms have more operational demands and more sensors sending information to the operators.[86] Overworked operators may respond more slowly. Heterogeneous swarms comprised of drones of different sizes and payloads require even greater attention.[87] The operators must coordinate complex actions, such as deploying one drone to search for targets and another to carry out strikes.

Even restricting humans to only use of force decisions would be a challenge as swarm size increases, due to the large number of inputs. An operator must maintain awareness of the inputs from numerous sensors in a remote area. The challenge is exacerbated if the swarm has multiple attack drones because the operator must monitor the activities of each. Although multiple operators could be used to control the swarm, this would offset any cost benefits. For a truly massive swarm of tens or even hundreds of thousands of drones, an operator for each attack drone would be infeasible.

A combat environment creates significant additional complexity. In a military context, the operator must also detect, avoid, and counter potential adversaries. Any communication delays from the drones to the operator raise the risks of adversaries defeating the swarm.[88] As drone swarms are fundamentally information-dependent weapons, adversaries are also likely to attack inter-swarm and operator to drone communications too.[89]

Already, drone operation places significant stress on operators. A 2017 RAND Corporation study found extensive stress and dissatisfaction among Air Force drone operators, contributing to an inability to staff drone units.[90] The RAND Corporation study notes approximately one third of the operators in their focus group displayed signs of burnout, viewing their stress as greater than other career fields.[91] Greater swarm autonomy would combat all of these challenges, and also may offer military benefits.

Greater autonomy may offer greater survivability. A human-controlled drone swarm would be vulnerable to loss of the human operator. As the famous military theoretician Sun Tzu implores, "To advance without the possibility of being checked, you must strike fast at the enemy's weakest points."[92] For a human-controlled drone swarm, the human operator is a significant weak point because killing or incapacitating the operator would disable the swarm.[93] The human operator could also fall sick or become injured unrelated to adversary attack. A fully autonomous drone swarm has no such risks.

Greater autonomy also allows the drone swarm to make decisions faster. For a remotely operated swarm, an operator must receive information from the drones in the field, interpret that information, decide to fire a weapons payload, and send a command back to fire. The added delay may be enough for an adversary to fire first, move positions, or take any other form of defensive action. The delay will be even longer with more drones in the swarm because the operator's focus may be elsewhere. Delegating decision making to artificial intelligences in the field could shorten the decision-making loop, and thereby increase the swarm's survivability, and capacity to cause harm.

Greater autonomy also allows swarms to be used in novel ways. Drone swarms could be programmed to carry out multiple strikes over a longer period, dispersing between attacks. This approach could be particularly appealing for homeland defense with drones separated and stored in different areas around a city. When activated, the drones come together and carry out strikes. The defender would not need to worry about the loss of any fixed operating site, but full autonomy has significant disadvantages.

Disincentives for Full Autonomy

Concerns over loss of control are likely to significantly inhibit the creation of AFADS. An uncontrolled drone swarm could potentially kill friendly civilians or military personnel simply due to an error in coding. Domestic and international audiences may pressure states to refrain from developing fully autonomous weapon systems generally – and AFADS specifically – over these concerns. Domestic audiences may be concerned about potential risks to friendly soldiers and civilians. Both domestic and international audiences may be concerned about the potential violations to international laws of war on non-civilian targeting. International audiences may also be concerned that a rogue swarm may wander into their territory, harming their citizens despite not being part of a conflict. As of November 2018, 28 nations endorsed a complete ban on fully autonomous weapons.[94]

Interested militaries may also be dissuaded from AFADS for the same reasons. A rogue swarm that wanders into another state could create a crisis that distracts time and resources from resolving an ongoing conflict and harms the state's soft power. If the rogue swarm causes significant casualties, it could risk drawing another adversary into the conflict. The military using the swarm would be in a much more difficult position to manage the conflict and achieve victory.

Giving over complete control to an artificial intelligence could induce new vulnerabilities that weaken the reliability of AFADS. Inherently, full autonomy requires software and/or hardware to support more sophisticated decision making. That software and/or hardware may make mistakes or adversaries may introduce error via cyberattack. System complexity might make deliberate or accidental errors difficult to identify. The lack of human control could exacerbate these fears under the belief they are unexpected or uncontrollable. More mundane concerns exist as well.

Military services might possess cultural inhibitions against granting full autonomy to drone swarms. For example, the U.S. Air Force tends to refer to drones as "remotely piloted" as opposed to simply "autonomous vehicles," likely because of the U.S. Air Force's cultural focus on pilots.[95] Similarly, DOD policy preventing autonomous weapons from targeting humans may establish normative prohibitions over the long term.[96] Long-term prohibitions are especially likely if the systems are unreliable.[97] Full autonomy just may not be worth it.

Nonetheless, because of the potential incentives, it is certainly possible that *a* state or military will believe the benefits outweigh the costs. Thus, the emergence of AFADS is plausible.

CHAPTER 4

Drone Swarms in WMD Roles

Traditionally, WMD have been used as weapons for mass casualty, assassination, and A2/AD. WMD are also appealing as strategic deterrents, either for counterforce or countervalue targeting, though only nuclear weapons are particularly effective in this regard. If certain forms of drone swarm can be considered WMD, how well do they perform in those roles?

As strategic deterrent weapons, states use the threat of WMD usage to discourage other states and non-state actors from taking certain actions. For example, the United States used threats of nuclear retaliation – both explicit and implicit – to discourage a potential Soviet invasion of Western Europe. Generally, strategic deterrents may be targeted at either adversary military forces (counterforce) or civilian populations (countervalue). While counterforce targeting is regarded as more ethically acceptable and diminishes an adversary's ability to retaliate, countervalue targeting may destroy economic and political systems, inhibiting the will of a target state to continue the conflict and ability to operate as a coherent unit.

States and terrorist organizations have pursued and used WMD to cause mass casualties. During the Syrian Civil War, the government of Bashar al-Assad used chemical weapons to inflict extensive casualties on Syrian civilians. Similarly, Aum Shinrikyo in Japan sought to use chemical, biological, and potentially even nuclear weapons to cause mass death and incite an apocalyptic civil war.[98] The radical environmental group RISE sought biological weapons to kill off most humans to repopulate the earth with enlightened, environmentally conscious revolutionaries.[99]

Both states and terrorist organizations have used WMD for assassinations. The South African chemical and biological weapons program, Project Coast, was geared created, in part, to assassinate the regime's adversaries.[100] Similarly, North Korea is believed to have employed the chemical warfare agent VX in the assassination of Kim Jong-nam, North Korean leader Kim Jong-un's half-brother.[101] Moreover, the October 2001 *Bacillus anthracis* (the causative agent of the disease anthrax) terrorist attacks targeted American Senators Patrick Leahy and Thomas Daschle, as well as various media organizations (whether the attacker sought to kill the senators or simply draw attention is unclear).[102]

Both states and terrorist organizations could pursue WMD for A2/AD purposes. Radiological weapons can be used against sea- or airports to cause economic harm or inhibit military operations.[103] As a RAND Corporation report notes, nuclear weapons can be used to strike ships at sea, fixed military assets, civilian infrastructure, U.S. forces inside adversary territory, or to disrupt command and control systems.[104]

The potential of drone swarms to fill WMD roles is a function of four attributes:

1. Their capacity to inflict harm.
2. Availability of defenses.
3. Stealth
4. Persistence.

Each WMD role depends on some combination of these factors, though their relative importance may differ. All factors are relevant for strategic deterrence. Most factors are relevant for mass casualty weapons, though persistence is less relevant. As an assassination weapon, the stealth of a drone swarm is likely to be most important, although the availability of defenses may play a role. The area-denial role depends primarily on a weapon's persistence because an area can be denied only if the weapon poses a threat. However, the availability of defenses and capacity to inflict harm will affect an adversary's calculation on occupying or passing through an area despite the threat.

Overall, the analysis of drone swarm attributes shows that:

1. Drone swarms are quite capable of inflicting mass harm and the size of the swarm can be varied to increase or decrease the likely damage caused.
2. Defenses against drone swarms abound, though their efficacy will depend on the concept of swarm operation.
3. Stealth is likely to be a significant challenge for swarms and individual drones are likely to be far more efficacious on this dimension.
4. Swarms could serve as persistent threats, limited by their power capacity, operating concepts, and environmental conditions.

This implies that drone swarms could be highly effective as mass casualty weapons, especially against soft targets. Infantry units are likely to be ideal targets in this role. A swarm could easily disperse to target infantry spread out over an area. Infantry are also unlikely to have native air defense capabilities in any significance. Unfortunately, massed civilians are also likely to be ideal mass casualty targets. Civilians will have little to no protection and certainly no sophisticated counter-drone systems.

Particularly nefarious states may be drawn to drone swarms and AFADS as genocidal weapons. Ethnic indicators are often physical and therefore highly visible, which may enable autonomous detection. Racial biases already creep into artificial intelligence systems inadvertently.[105] In addition, drone swarms lack the normative and legal constraints that inhibit development and use of traditional WMD agents.

Swarms could serve as strategic deterrent weapons, but the availability of defenses make them less ideal for this role, especially compared to nuclear weapons. Strategic deterrent weapons must be reliable. If the United States communicates a threat that the adversary does not believe the United States can carry out, the adversary is unlikely to be deterred. Although drone swarms offer clear military advantages, a wide range of traditional arms can counter them, and information warfare attacks can disable or destroy even massive swarms.

States are unlikely to pursue drone swarms as assassination weapons due to the lack of stealth and relative availability of defenses. An assassination target is likely to observe a massive swarm of drones coming towards them and respond. The drone swarm user would also lose any plausible deniability, especially if any drone was downed during the attack. Of course, actors may be unconcerned about their affiliation being known, such as during an active conflict, assassinating a domestic dissident, or deliberately seeking media attention or psychological harm. Terrorist organizations may even see the lack of stealth as advantage in addition to potentially overwhelming often much better-armed states.

Drone swarms could be useful in A2/AD. However, it is likely to be context dependent. The ability of the drones to remain in the area is likely to be both highly variable and highly challenging. Solutions to mitigate power limitations, such as recharging stations and motherships, also create new vulnerabilities to attack.

The remainder of this section breaks down the properties of drone swarms that underlie these overall conclusions.

Capacity to Inflict Harm

The capacity to inflict harm on either human beings or military equipment is critical for all four WMD roles. Strategic deterrent weapons must inflict enough harm to adversary civilian and military populations and equipment to deter the adversary from taking an otherwise desirable action. By definition, a mass casualty weapon must be capable of inflicting significant harm. An assassination weapon must cross the minimum threshold of being lethal and A2/AD weapons must impose a threat to adversaries seeking access to a defended area. Drone swarms can inflict harm either directly or indirectly.

Drone swarms can inflict direct harm as explosive devices or as weapons platforms. Drones within the swarm can be equipped with explosives to kamikaze into adversaries. Drones could be dedicated military systems or off-the-shelf drones modified to allow swarming. Such weapons could be used to strike crowded public areas, buildings, or adversary weapons platforms, striking from many different directions. The lack of human operator makes the drones within the swarm readily disposable, allowing the swarm to potentially overwhelm adversary defenses through sheer numbers. As weapons platforms, drone swarms could be equipped with guns, airdropped bombs, or missiles.

The capacity of a drone swarm to inflict harm is highly variable, depending on the size of the swarm, drone armament and armoring, range, the speed of the drones and their control algorithms, as well as adversary defenses (explored in depth in the next section). A larger swarm can incorporate more bombs or guns, incorporate more sensor drones for more precise targeting and better situational awareness, or more control drones to manage the swarm. Larger swarms may also better survive some target defenses, because the swarm will be more resilient to drones being downed. The type and degree of armoring – if any – will also make it better able to resist defenses. Physically faster drones can better avoid adversary defenses, while algorithmically faster drones may more rapidly identify and respond to threats and coordinate actions.[106] For example, researchers recently developed drones capable of dodging thrown objects.[107] The type of munitions payload – gun, explosive, or missile – will also affect the swarm's killing capacity and the type of target it can strike. With larger munitions, swarms can inflict more damage against harder targets.

The nature of drone swarms makes them inherently scalable. The number, type, and payloads of the drones within the swarm can be varied depending on the objective. A handful of drones may be deployed to signal hostile intent or to achieve discrete objectives such as attacking a target. Or hundreds of thousands of well-armed drones could be deployed against a strategic or operational objective, such as a city or military base. This would allow a state to control the ladder of escalation in a crisis.

Alternatively, drone swarms may strike commercial or military planes, nuclear power plants, or chemical plants either by colliding with them or with carried explosives to cause indirect harm. Terrorist organizations could seek to cause mass casualties by flying drones into the engines of commercial or military planes.[108] This method of attack would likely lower the terrorist's operational risk because they could be launched from outside the airport without needing to bypass a security checkpoint.[109] The use of drones may also carry symbolic value because of Western nations' use of drones against Muslim nations.[110]

Terrorist or state actors could instead attack a chemical or nuclear facility using an aerial drone swarm, either a true swarm or drones en masse.[111] Drones could search the area for and strike target containers to release contained gases over a population. Launched from outside the facility, no terrorist would need to bypass access controls.

In addition to casualty numbers, the speed and reliability of achieving them are relevant for strategic deterrent weapons. While chemical and biological weapons are theoretically capable of inflicting horrendous numbers of casualties, they rarely achieve that effect. Many variables including wind, temperature, and humidity affect their reliability.[112] Even if a biological attack is successful, symptoms may not manifest for several days.[113] By contrast, a successful nuclear weapon delivery can reliably inflict massive damage immediately.

Drone swarms armed with conventional weapons could inflict damage far more quickly than biological weapons and are generally less affected by environmental conditions than chemical or biological agents. However, environmental conditions still pose significant challenges. Even modest winds can make air photography difficult for small fixed-wing drones.[114] Drone swarms with high degrees of autonomy may rely on visual sensors from small drones to identify natural hazards, adversary defenses, and targets. More significant than environmental conditions are adversary defenses.

Availability of Defenses

Defenses limit the ability of drone swarms to inflict damage. Effective defenses can undercut the ability of a weapon to successfully deter an adversary because the weapon can less reliably impose costs. Similarly, effective defenses make it harder to inflict mass casualties and lower the likelihood of a successful assassination or targeted killing. If a weapon can be easily defended against, it is unlikely to be effective at controlling an area to prevent adversary movement.

As Paul Scharre discusses, a broad variety of defenses against swarms are possible.[115] Low cost-per-shot weapons such as lasers, rail guns, and machine guns provide cost effective ways of striking many drones.[116] High-powered microwaves can be used to disrupt or destroy the electronics within the drones.[117] Swarms could be used to defeat other swarms.[118] Alternatively, defenders may seek to jam communications between the drones or between the swarm and its control system, take control of the swarm via cyberattack or fake data, or exploit the decision-making algorithms of the swarm to draw it into a problematic position.[119] In addition, defenders may just hang a net to catch the drones and inhibit movement.[120]

Nonetheless, the relative efficacy of these defenses is still uncertain. Some drone swarm defenses are still in development (e.g. counter-swarm swarms) or not widely used (e.g. laser weapons). Others are unique to specific drone swarm characteristics. Nets are not useful against ground or surface drones. The success of algorithm manipulation depends on the degree of human control and any built-in error detection mechanisms. As a consensus report by the National Academies of Science, Engineering, and Medicine notes, "Today's consumer and customized (small, unmanned, aerial systems) can increasingly operate without radio frequency command and control links by using automated target recognition and tracking, obstacle avoidance, and other software-enabled capabilities."[121] These developments make electronic warfare jamming significantly more difficult.

Existing open-source analyses are mixed. Loc Pham's modeling of a hypothetical attack with drones en masse on an American destroyer found eight drones (four advanced Israeli Harpy drones and four off-the-shelf drones) were sufficient to overwhelm current destroyer defenses and would likely achieve four hits.[122] However, the number of hits can be significantly reduced with currently available technology, such as electronic warfare jamming technology.

The efficacy of defenses will depend on the concept of drone swarm employment and the countermeasures available to the swarm. Nets and simple countermeasures might be effective against small aerial drones equipped with short-range weapons.[123] However, larger aerial drones or ground-based drones with long-range weapons may be able to evade these measures, though larger drones are also more vulnerable to conventional anti-air weapons. Alternatively, unarmed sensing drones within the swarm may be dedicated to searching for, identifying, and relaying information about potential incoming threats.[124] Drone swarms may also adopt irregular, unpredictable flight paths, fly at low altitude, or use the natural environment to evade detection.[125] Drone swarms may also vary their method of communication, use multiple communication frequencies, and adopt other jamming defenses.

Far more drone swarm defense options exist compared to WMD defenses and some are more readily available. At best, sheltering in an extremely hardened area might protect against some nuclear weapons effects (assuming sufficient warning to retreat). Although civilian populations can defend themselves against chemical and biological weapons attack with protective gear, that gear is not broadly available. While basic protections such as gas masks may work against some chemical and biological agents, many agents can operate based on skin contact. By contrast, the Drone Center at Bard College inventoried 537 systems on the market for countering aerial drones.[126] Likewise, a wide range of simple countermeasures may be effective against some drone swarms from nets to small arms. Traditional, broadly available anti-air and anti-tank weapons may be useful too.

Persistence

The persistence of a weapon refers to its ability to continue inflicting harm over a long period. Persistence is primarily relevant for a weapon's ability to serve in an A2/AD role. It may also affect the weapon's role as a mass casualty weapon, because it could continually cause casualties. Generally, persistence is not significant for an assassination weapon, though the attributes that allow persistence may be relevant for assassination purposes (e.g. high loiter time would allow an assassination drone to wait for a target to appear.)

The persistence of a drone swarm depends on the onboard power of its component drones, the swarm's operating concept, and the operational environment. Overall, because the effectiveness of drone swarms stems from the cooperative behavior of its member drones, the persistence of the drone swarm likely will be equivalent to its least persistent member.

Onboard power is the primary limitation to drone swarm persistence. Without power, the drones cannot function. Large drones such as the Predator may have an onboard engine that can generate energy for a long period, but smaller drones must rely on battery life. Although the drone swarm could simply shed out-of-power drones, an adversary may intercept and exploit fallen drones to gather intelligence on the underlying technology, identify the user, or use the fallen drone to track the rest of the swarm.

Other drone improvements can increase persistence. Battery technology is improving with greater energy storage.[127] Likewise, improvements to machine learning and artificial intelligence (AI) may help drones better utilize available power.[128] More broadly, new technologies like inductive charging could allow drone swarms to recharge on flat platforms or powerlines.[129]

The drone swarm's operating concept may increase or decrease the swarm's power usage, thereby affecting its persistence. Unarmed sensor drones may actively rove over an area searching for potential targets or sensor-carrying drones may disperse passive sensors then lay at rest. Attack drones may accompany sensor drones or wait at rest to be called to attack. The swarm could also incorporate manned or unmanned support systems for recharging, such as a large mothership with recharging stations. Of course, such a mothership would also be an obvious target.

The environment can create hazards that limit the ability of the swarm to remain in the area. Rain, snow, and other weather conditions may force a premature swarm retreat or prevent the swarm from entering an area at all. Other conditions such as smoke, wind buffeting, and severe cold may also limit swarm persistence.[130] This will particularly affect swarms of small, aerial drones, but environmental conditions certainly could inhibit swarms in different domains and larger, aerial drones. For example, if a ground drone drove into a snow bank, a human might not be available to extract it. Overall, these factors mean drone swarms have potential for high persistence, but the persistence is likely to be highly variable. Except for A2/AD purposes, the persistence of drone swarms is less important than their stealth.

Stealth

Stealth allows actors to place WMD covertly, mount an attack without the target being aware, or achieve plausible deniability. Stealth is useful for strategic deterrent weapons because stealth lowers the likelihood of the weapon being eliminated in an adversary's first strike and from being eliminated by adversary defenses while en route to attack. Strategic nuclear bombers incorporate stealth technology, while Trident missile submarines hide in the vastness of the ocean. Like with strategic deterrence, stealth aids mass casualty weapons in evading adversary defenses. In addition, stealth is critical for assassination because a failure of stealth may allow the target to escape or take protective action. Stealth has some utility for A2/AD roles by generating adversary uncertainty about whether an area is under threat, but stealth is not critical. In fact, a lack of stealth may be desirable to discourage an adversary from entering a given area.

Drone swarm stealth and capacity generally have an inverse relationship. Although more drones in the swarm offer greater capacity, they also lower the swarm's stealth. The great strength of drone swarms – their numbers – makes stealth difficult. Large numbers of drones are likely to draw significant attention, especially because large numbers of drones will be quite noisy. Both the sight and sound of the swarm may offer warning to a target to prepare defenses or escape the area. Similarly, in attempting to overwhelm adversary defenses, some drones will likely fall. Those fallen drones will provide clues on the source of the attack, weakening any plausible deniability. Drone swarms may be placed in a covert manner that may mitigate some stealth inadequacies. For example, drones could be preplaced on the roofs of buildings near a planned attack area, coalescing at the time and place of attack.

The use of drones generally, swarms or otherwise, limit postattack traceability. Drones can be controlled from a discrete location far from the location of an attack. Responders would likely have a significant challenge locating where the attack stemmed from. Further, distance from the target would ensure the attacker is not at risk if the attack is interrupted prematurely.

In general, individual drones are likely to be much better suited to stealthy operations. A single drone would draw far less attention than a large swarm. If advanced stealth technology is needed, equipping a single drone is much cheaper than equipping thousands.

Drone swarms are far less stealthy than traditional WMD. Both chemical and biological weapons can cause lethal effects with very little material. The small material size makes these weapons highly stealthy, and therefore highly useful for assassination because the material may go undetected prior to, during, and potentially even after an attack. Although nuclear weapons are not stealthy themselves, nuclear delivery platforms already incorporate expensive and sophisticated stealth technologies.

CHAPTER 5

Conclusion

Drone swarms, as a class, should not be considered WMD. However, a subset of drones, AFADS, should be. Drone swarms are capable of inflicting mass harm and AFADS are likely to be inherently indiscriminate for the foreseeable future. Drone swarms may also serve in traditional WMD roles, especially as weapons of mass violence against soft targets, but what remains unanswered is this question. What should be done?

Policy options fall into two general categories – preventative and responsive. Preventative policies seek to prevent AFADS from ever emerging, while responsive approaches seek to mitigate their negative impacts. In both categories, separating fully autonomous and non-autonomous drone swarms is critical. Without full autonomy, drone swarms should not be considered WMD.

The two are related, but not mutually exclusive. Certain policies that mitigate the harms of AFADS may also encourage their development. For example, global governments could seek to develop ethical targeting software and, in so doing, encourage proliferation through reduced moral opposition to fully autonomous weapons, including AFADS. However, approaches that limit or discourage the use or trade in AFADS disincentivize their creation in the first place. For example, if the use of AFADS against civilians motivates the United States to intervene militarily, rogue actors may be discouraged from developing AFADS as a mass casualty weapon.

The United States government should consider:

1. Issuing statements of compliance – The United States and global governments should officially assert a general belief that AFADS fall under the scope of applicable WMD treaties. This would encourage adoption by other states, signaling the intention of the United States and others to treat usage of AFADS the same as another WMD system. Of course, states must establish thresholds for when a swarm becomes a WMD, but the general principle can be established with the explicit intention of determining such a threshold.

2. Evaluating swarms – States should establish thresholds for when AFADS cross the line to WMD. A fully autonomous drone swarm with only one armed drone would technically qualify as an AFADS, but is unlikely to meaningfully inflict mass casualties. Drone swarms could be evaluated based on a "swarm score," a quantitative measure based on the number of armed drones and the type and size of munitions. In general, the more armed drones, the deadlier the swarm. Similarly, the larger and deadlier the carried munitions, the deadlier the swarm. Such analysis, for example, could rely on firepower scores as used in war games that combine weapon lethality and rate of fire.[131] While the actual number of casualties inflicted will depend on a complex interaction between offensive swarm, supporting offensive capabilities, and adversary defenses, evaluating only the drone swarm could provide a generalizable method of comparing capabilities between and within states.

3. Preventing emergence – Advancing policies, laws, international norms, and even treaties against fully autonomous weapons may prevent AFADS from emerging. DOD directive 3000.09 disallows autonomous weapon systems to target humans without appropriate human judgment, effectively disallowing AFADS.[132] However, this policy could change relatively easily because 3000.09 is not codified in law and "appropriate human judgment" is vague. Similarly, the nascent movement to outlaw LAWS would necessarily outlaw AFADS. Success in such efforts is likely to depend significantly on the perceived military value of AFADS and LAWS writ large.

4. Developing ethical targeting – The United States and global governments could seek to develop ethical targeting systems for autonomous weapons. Software could be developed that can integrate with AFADS targeting systems that checks for whether a given target is civilian or military. Of course, states may resist the adoption of ethical targeting systems or adopt, but cheat. Even if states and global society cannot verify the adoption of ethical systems, an overt, costly commitment communicates genuine interest. Embedded ethical systems are also likely to be a significant technological challenge. Embedded ethics may also have unexpected, pernicious effects such as encouraging the proliferation of autonomous weapons by minimizing moral opposition.

5. Debating intervention policy – The National Security Council, defense universities, think tanks, and other national security community organizations should debate the merits of whether AFADS use is sufficient to justify military intervention. Such debate should include discussion of why WMD usage merits intervention in the first place and whether such intervention (or not) is justified. It should also include debate over what scale of usage is sufficient to justify intervention: does the size of the swarm matter? Does the target matter? Although the categorization of AFADS as WMD suggest intervention is merited, ontological categorization is one of many considerations in military intervention policy.

6. Adopting new restrictions in UN Resolution 1540 – UN 1540 attempts to prevent WMD terrorism through imposed requirements on states to, inter alia, prevent sharing of WMD with non-state actors and adopt appropriate laws against terrorists developing and using WMD. As written, UN 1540 focuses on nuclear, chemical, and biological weapons. The treaty may need to be updated to include restrictions on AFADS, specifically on pre-built AFADS and software that allows drone collaboration and self-targeting weapon systems. In the near term, only states with advanced militaries are likely to successfully develop drone swarms and AFADS of any meaningful sophistication. The development of sophisticated military drones generally requires significant industrial, organizational, and infrastructural capacity.[133] Nonetheless, non-state actors could develop basic drone swarms over the longer term, especially as open-source software already allows multi-drone control.

7. Expanding scope of counter WMD organizations – National security organizations charged with countering WMD should consider whether AFADS fall within their scope. Such organizations should particularly focus on their rationale for separating WMD from conventional weapons. Some organizations may focus on WMD because of the unique technical capabilities involved with defending against them, such as the development of protective gear. Incorporating AFADS would not make sense. However, organizations focused on preventing mass casualty terror attacks would be well justified in including AFADS and potentially drone swarms writ large.

8. Developing verification methods – If AFADS are WMD, but drone swarms are not, states must be able to tell the difference. Verification could focus on the number of armed drones within the swarm, because large swarms will require higher levels of autonomy and more armed drones generally implies greater capacity for destruction. University and government researchers could identify thresholds at which human control of the swarm becomes virtually impossible. Cyber forensics is also likely to be a fruitful approach. The military advantage of drone swarms stems from the use of large numbers of relatively low-cost drones that can overwhelm adversary defenses. Inevitably, some drones will be defeated. States may be able to assess fallen drones to assess their degree of autonomy.

The United States and the international community should take strong actions to minimize the risks of drone swarms and AFADS to national and global security.

Notes

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