Strategy Research Project

Swarms in the Third Offset

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Abstract

Advances in swarm technology is part of the Department of Defense's Third Offset Strategy which is a plan for overcoming reduced military force structure and declining technological superiority against potential U.S. adversaries. The components of the Third Offset represent the enabling capabilities of swarm behavior which could be adopted in the future force. Therefore, this paper investigates whether the U.S. military should focus greater research and development efforts on swarm-capable systems that are low-cost, numerous, unmanned, and fast. The first area of discussion includes swarm initiatives that could allow the military to transition away from expensive and heavy weapons platforms. Second, self-driving vehicles, automated logistics, and aerial drones in industry could translate to autonomous supply trains, reduced soldier error, and targeting missions in the military. Third, adversaries are pursuing swarm capabilities. While swarms show great promise, there are some major legal and ethical obstacles to swarm-capable systems. Lastly, recommendations are offered as a way ahead for swarm initiatives.

Swarms in the Third Offset

The fiercest serpent may be overcome by a swarm of ants.

—Admiral Isoroku Yamamoto[1]

During the 2017 Super Bowl 51 half-time performance, Intel demonstrated the control of 300 drones and broke the world record a few months earlier with 500 drones controlled by a single operator.[2] In October of 2016, the U.S. Military conducted the largest deployment ever of micro-swarms. Dubbed the Perdix micro drone, these small, inexpensive, battery-powered, propeller-driven air vehicles were launched by three F/A-18 Super Hornets.[3] Just over a year prior in 2015, the Advanced Robotic Systems Engineering Laboratory at the Naval Postgraduate School in Monterey, California, held the record with 50 simultaneous airborne unmanned aerial vehicles controlled by a single operator.[4] This author predicts that 500 drones will quickly increase to 1,000 and 10,000 agents in just a few a year's time while being scalable, adaptable, distributed, and collective.[5] Advances in swarm technology is part of the Department of Defense's (DoD) Third Offset Strategy which is a plan for overcoming ("offsetting") reduced military force structure and declining technological superiority against potential U.S. adversaries.[6] Key components of this strategy include dominance in artificial intelligence, machine learning, robotics, unmanned systems, and increased autonomy.

Collectively, the components of the Third Offset represent the enabling capabilities of swarm behavior which could be wholly adopted in the future force. Therefore, should the DoD focus research and development efforts on swarm-capable ISR (intelligence, surveillance, reconnaissance) and weapons systems that are low-cost, numerous, unmanned, and fast? This paper will provide an overview of swarms and explore three major areas to address this primary question. While the promise of swarm behavior appears great, there are some major obstacles to swarm-capable systems which will be presented. Lastly, recommendations will be offered as a way ahead for DoD swarm initiatives.

Swarms can offer multiple operational advantages in terms of speed, intelligence gathering, coordinated effects (kinetic and non-kinetic), and efforts. Humans typically cannot control more than four to five discrete elements at a time.[7] Swarm-based systems allow for collective and distributed control of hundreds and thousands of agents where the operator is executing mission objectives and not focused on individual agent control. Humans will maintain overall operational control but low-level decisions from individual agents within the swarm could be made autonomously to fulfill mission objectives within pre-defined rules of engagement.

The first area of discussion includes swarm initiatives that could allow the DoD to transition away from expensive, heavy, and human-centric weapons platforms such as legacy tanks, manned fighters, and submarines. These systems are difficult to deploy, require large amounts of maintenance and fuel, and may be out-matched in a many operator to one vehicle paradigm.

Second, the advent of self-driving vehicles, automated logistics, and aerial drones in the commercial sector could translate to autonomous supply trains, reduced soldier fatigue and error, and targeting missions in the military. Academia partnered with private industry could propel these innovations since the technology has dual-use capabilities in transportation, search and rescue, agricultural monitoring, and homeland security. The open source community has enabled these advances but has also allowed for their proliferation and use among enemy forces and terrorist organizations.

Adversaries from both state and non-state actors are pursuing swarm capabilities and autonomous weapons. U.S. military forces could quickly be overcome by enemy systems that can adapt faster without human input. In future war, overwhelming swarm intelligence gathering could require near instantaneous decision-making and effectively render current command and control mechanisms obsolete.[8] Artificial intelligence and machine learning algorithms could provide near-perfect sensing, accuracy, discrimination, and lethality leaving human operators incapable of making low-level, individual agent decisions. [9]

While swarms offer many potential advantages, there is significant risk with a rapid adoption of unproven technologies and the many legal and ethical issues associated with autonomous weapons. An unmanned systems algorithm race could ensue and lead to less costly wars in terms of human lives but also potentially increasing the likelihood of war since there is less risk to humans. The chain of custody and ability to act with impunity could also be problematic as currently seen with cyberattacks.

Lastly, this author will put forth a number of recommendations and concluding remarks about how swarming capabilities, autonomy, and unmanned systems could provide the required overmatch sought after by the DoD and U.S. allies.

What are Swarms?

A swarm is a collection of agents (either homogeneous or heterogeneous) that can coordinate and adapt its activity to achieve an overall goal or direction.[10] Nature has many examples of swarming behavior as evident in ant colonies, bee hives, and termite nests. Typically swarms in nature involve homogenous groups where single agents outside of the group cannot attempt to accomplish the same task as the whole. Further, the direction or collective task of the swarm is not orchestrated by a centralize leader but rather by simple rules followed by all of the individual agents.[11] Elements within the swarm have little to no knowledge or ability to communicate with other elements that are not its immediate neighbor.[12]

In contrast, robotic swarms could involve centralized control, distributed control, or at a minimum overall task knowledge in the event that the human operator loses communications with any of the agents. These swarms can have near-perfect knowledge of their neighbors through the use of wireless communications (non-contested frequency spectrum) or on-board sensors such as vision and ranging payloads in a contested spectrum. Processing power and sensor packages should continue to increase in capabilities such that a swarm will be able to execute mission objectives even if there is no communication with the human operator or within elements of the swarm itself. Swarm agents that are within line of sight may still be able to 'sense' neighbors if communications are jammed or unavailable.

Swarms Leverage Autonomy[13]

Robotic swarms do have similarities with nature in that they leverage autonomy.[14] Humans will not be able to keep pace with the rapid decision-making required by the swarm such as maintaining formation and performing collision-avoidance tasks.

Autonomy is often misunderstood and a source of fear and mistrust. In the simplest terms, an autonomous machine can sense its environment, react, and execute a task without human input.[15] There is much debate about levels of autonomy and how much control to turn over to machines.[16] For example, intelligent automobiles range in features from breaking assistance, collision avoidance, and parking assistance to self-driving modes where the vehicle plans routes and navigates to a destination with or without a driver. These features are designed to improve safety, reduce congestion, and reduce personnel required to operate transportation, trucking, and shipping fleets. Much of this same technology could apply to military applications with similar benefits.

Perhaps the most controversial aspect of autonomy is the ability of a machine to engage and make lethal decisions without operator input immediately prior to the strike.[17] Released in November 2012, DoD Directive 3009.09, "Autonomy in Weapons Systems", establishes guidelines and policies on the development of autonomous weapons systems (AWS).[18] The directive states that AWS will have some level of human control. The topic of human control and even potentially banning AWS is heavily debated in the literature.[19] For this analysis, the policy, legal, and ethical considerations are beyond the scope of this paper. Yet, as what often occurs, the technology far outpaces the policy. While the implementation of AWS still has many unknowns, swarms leverage autonomy.

<u>Swarms Leverage Quantity</u>

Swarms in their very nature favor quantity with the typical sacrifice in quality.[20] Unmanned systems can have reduced weight, size, and design complexity which may in turn reduce their overall cost. Numerous agents that are low-cost can be expendable and overwhelm an adversary through sheer mass and exhaust their means to effectively defeat them. Simplicity leads to adaptability and dispersion creating multiple targets for an enemy to engage. Attrition is acceptable and survivability is sacrificed due to the concept of swarm resiliency, where the swarm can adapt to losses in numbers and still achieve the desired effect.[21] A loss of a single swarm agent will typically not have the same detrimental impact if a multi-purpose or main battle system is destroyed. Countering a swarm may prove difficult for any adversary, including the United States. Swarm agents that can react to enemy defenses faster and in a distributed manner may saturate adversary capabilities.

Swarms Leverage Reduced Size and Increased Speed

The size of the swarm relates to the physical footprint of each agent in addition to the size in terms of number of agents. Perhaps the most significant benefit to a swarm mentality is the focus on small size which can be more deployable and easier to sustain logistically. Speed relates to shorter computational execution times as well as speed in movement and maneuver. In the future, swarms could collect vast amounts of data that will need to be processed on the agent itself and at times at a larger coordination cell. This speed in processing and execution may allow for reduced personnel to operate a swarm while at the same time overmatching adversarial weapons systems. Robotic swarms can be heterogeneous and could leverage interoperability between all air, land, and sea based agents. While humans will still maintain overall operational control of the swarm, the size will likely not involve human control at the agent level where lethal decision-making will be made. The redundancy of information could lead to near-perfect sensing providing unmatched discrimination in the engagement of targets.

DoD Swarm Initiatives

Future warfare will include operations that occur in large, densely populated, costal megacities. Over half of the world's population currently resides in urban areas and that percentage will likely increase drastically over the next 25 years. In recent remarks at the Association for the U.S. Army, Army Chief of Staff General Milley stated:

> In the future, I can say with very high degrees of confidence, the American Army is probably going to be fighting in urban areas … We need to man, organize, train and equip the force for operations in urban areas, highly dense urban areas, and that's a different construct. We're not organized like that right now.[22]

With the current focus on maneuver and fires in open terrain, the military will need to continue to shift to smaller, adaptable units that are distributed across the battlefield and able to operate in narrow, urban corridors. These types of challenges are currently being studied in Unified Quest 2017 and in the draft proposal of the Multi-Domain Battle doctrine.[23] Brigade Combat Teams do not have the requisite composition to maneuver in a megacity. However, a swarm mindset of smaller, faster, disposable, and precisely lethal weapons and ISR systems could offer the ability for small, distributed units to effectively operate in these vast, chaotic, urban areas.

The U.S. Military of 2035 will be even more reliant on robotics.[24] Recent combat operations in Iraq and Afghanistan have clearly demonstrated that ground and aerial robotic systems are able to increase standoff distances, provide valuable surveillance, and target enemy combatants. Due to their mission success, several strategic documents have recently outlined the vision and framework for increasing their numbers, enhancing their capability, and making robots more autonomous. For instance, TARDEC (Tank Automotive Research Development and Engineering Center), as part of their 30-year strategy to shape the future programs of record for the Army, has published two documents that indicate the increased emphasis to acquire autonomous robotic systems in the future.[25] In this strategy, TARDEC shows the progression of autonomous system capabilities through the year 2030, and it includes autonomous convoy operations and unmanned battle tanks exercising combined maneuver.[26] Further, TRADOC (Training and Doctrine Command) more formally published TRADOC Pamphlet 525-3-1 U.S. Army Operating Concept (AOC), which prioritizes robotics and autonomous systems (RAS) requirements across all formations. The AOC integrates RAS as a key to the Army's differential advantage over adversaries.[27] The U.S. Air Force's Small UAS (Unmanned Aircraft System and sometimes UAV or Unmanned Aerial Vehicle) Roadmap calls for the increased use of small drones while the U.S. Navy's Unmanned Systems Roadmap shows a similar focus to guide acquisition programs and budgets.[28] [29]

As a result of the increasing acquisition and integration of autonomous systems into the force structure, the understanding of robotics and its underlying technologies will continue to be more important across the full spectrum of operations: from humanitarian assistance, to disaster relief, to crisis intervention, to counter-terrorism challenges, to conventional warfare. The systems employed by the U.S. Military of 2035 will require leaders with an increased understanding of technical capabilities along with the ability to integrate them into small unit operations. While humans will continue to fight wars and warfare will always be a human endeavor, technology continues to provide increased stand-off, control, and protection for operators.

Current ground combat systems (M1 Abrams Tank, M3 Bradley Fighting Vehicle, and M109 Paladin Self-Propelled Howitzer among others) are large, heavy, difficult to airlift, and are human-centric. The F-35 Joint Strike Fighter represents the largest defense program in history and submarines and aircraft carriers are even more expensive. Looking at the top ten DoD programs for FY2017, the single year cost for the F-35 is well over $10 billion.[30] The Virginia Class Submarine comes in second place at over $5 billion. These exquisite, major DoD programs represent a more of the same mentality that serve Cold War era mindsets and force structures. If the DoD seeks to reduce costs in the future, it could move towards numerous and cheap rather than few and expensive. With shrinking budgets and long, cumbersome acquisition cycles, the DoD could leverage these disruptive capabilities to become more innovative and agile. But much of this vision depends on both the DoD advocating for it and the defense industry adopting these changes.

DoD Swarm Research and Development

The DoD recognizes that the rise of megacities increases the likelihood that future battles are urban. Therefore, DoD swarm initiatives across all services are integrating the technology with man-unmanned teaming mechanisms to allow soldiers the ability to control swarm systems. One recent example is the DARPA OFFSET (Offensive Swarm-Enabled Tactics) program which seeks to overcome the difficulties in managing and interacting with hundreds of swarm agents.[31] Focused on urban environments, OFFSET involves swarm tactic implementation using combinations of unmanned air and ground robots. In its early stages, OFFSET aims to bring swarm system integrators (akin to an end-to-end operating system like iOS or Android) and swarm tactic sprinters (application developers) together to realize 100, 150, and 250 agent swarms together with an intuitive user interface for squad-sized elements on the ground. A more mature program and related to OFFSET is another DARPA initiative called Squad X. A recent test at Camp Edwards in Massachusetts demonstrated the ability of a small drone using computer vision and artificial intelligence algorithms that can detect and discriminate targets carrying replica AK-47s in a mock village.[32] While unarmed, the small UAS can identify and track human targets that meet certain criteria while also ignoring non-combatants. The services are all heavily invested in swarm research and development.

U.S. Air Force Initiatives

Perhaps the service with the most visible integration of unmanned technology is the U.S. Air Force and its wide-spread use of Remotely Piloted Aircraft (RPAs). The Air Force already has a RPA manpower deficit and the ability for pilots and operators to control and interact with 100s and 1000s of UAS would provide a much higher level of manpower efficiency. A recent GAO (Government Accountability Office) report on Unmanned Aerial Systems found that the Air Force must tailor its strategy to meet UAS pilot shortages and that it does not have effective human capital planning.[33] The current paradigm of a ground control station consisting of two to four pilots and operators controlling a single aircraft is not sustainable with the demand and increase of ISR and targeting missions globally. The Air Force Small UAS Roadmap calls for an increased use of small drones that could eventually replace larger ones, reduce costs, reduce manpower, and provide redundancy in the event of the loss of aircraft.[34] This redundancy allows for a greater probability of mission success. In addition to unmanned aircraft, the user interface will also have to allow high-level human control and input to synchronize intelligence gathering and effects.[35] An improved ground control station would replace multiple operators while allowing a single pilot/operator to perform the same functions.

The Air Force is most likely a decade away from developing a fully independent robot that can decide on its own when to kill, stated General Paul J. Selva, Vice Chairman of the Joint Chiefs of Staff.[36] Efforts involving a loyal wingman could be a bridge for traditional fighter aircraft to become autonomous and unmanned while accompanying manned aircraft. But lessons from the F-35 acquisition will most likely direct future systems to be less human-centric while moving to unmanned and small.[37] The MQ-9 Reaper costs approximately $12 million per unit while the F-35 Lightning II exceeds $100 million per aircraft with variants in the $200 and $300 million figure.[38] While current RPAs are not designed for air to air combat or for surviving anti-aircraft defenses, it is foreseeable that future RPAs could achieve numbers that would overwhelm air defenses and incorporate sophisticated air to air weapons systems to defeat enemy aircraft. It is the opinion of this author that the future air superiority campaign will not be a dogfight but achieved by slow, small, large numbered unmanned vehicles with the most advanced sensors and missiles while maintaining stand-off.

U.S. Navy Initiatives

The Navy is currently testing the ability to launch drones out of a tube-based launcher where up to 30 drones could be deployed in one minute. [39] The program is called LOCUST (Low-cost UAV Swarming Technology) and will include armed and unarmed versions that can join together, break apart, and conduct missions individually, collaboratively, and spontaneously.[40] The Navy will also invest $600 million over the next 5 years in unmanned undersea vehicles of various sizes and payloads.[41] Part of this effort is to build systems that provide ISR, conduct anti-submarine warfare, and perform mine and counter-mine operations.

In addition to undersea vehicles, the Navy is also investing in unmanned surface ships. The U.S. Office of Naval Research conducted a demonstration off the coast of Virginia in the Chesapeake Bay to autonomously patrol a 4x4 nautical mile area using 'drone boats' for potential harbor defense missions. The advantage of these systems is that they are augmented with an autonomy package onto existing boats rather than developing ones from scratch.[42] Similar to the F-35, the Navy's Virginia Class Submarines, AEGIS Cruisers, and Ford Class Aircraft Carriers cost multiple billions per major weapons systems as described previously. In addition to the thousands of personnel required for manning, the operating costs of these systems are orders of magnitude greater than their unmanned counterparts. One promising program is the recently christened Sea Hunter autonomous unmanned surface vehicle. [43] [44] While currently not weaponized, future versions could add anti-ship and anti-submarine capabilities in addition to cruise missiles. In a recent interview, Deputy U.S. Defense Secretary Robert Work stated: "I would like to see unmanned flotillas operating in the western Pacific and the Persian Gulf within five years."[45] Smaller and cheaper than conventional ships, multiple unmanned surface vehicles could provide the necessary deterrence and check on Russian and Chinese surface vessel and submarine technological advances.

U.S. Army and Marines Initiatives

Finally, the Army and Marines are also investing into swarm capable systems. The Army's Robotics and Autonomous Systems Strategy focuses on three key areas: autonomy, artificial intelligence, and common control.[46] Mid-term objectives (years 2020-2030) would emphasize human and machine teaming with the ability to achieve swarming capabilities. One potential project is to repurpose the Army's current MLRS

(Multiple Launch Rocket System) launchers with munitions that would carry swarms of tank-killing quadcopters each fixed with the ability to detonate a payload on top of enemy tanks.[47]

The Marines could leverage existing Navy programs such as LOCUST to support amphibious operations using drone swarms. Both the Army and Marines are currently drafting the Multi-Domain Battle concept which is how many believe that future conflict will be conducted. Marines could see the use of drones in the very near future. Marine Corps Commandant Gen. Robert Neller said he wants every infantry squad to carry a drone by the end of 2017. “At the end of next year, my goal is that every deployed Marine infantry squad had got their own quadcopter … they’re like 1,000 bucks” said Neller at an exposition in Quantico, Virginia.[48]

Where the Army and Marines differ greatly from their sister services is in major weapons systems cost. Neither service have systems that fall in the top ten acquisition programs for FY2017. Tanks and assault amphibious vehicles are relatively inexpensive compared to strike fighters and submarines. Ground forces have the advantage of proximity to whatever vehicle they are controlling and thus not requiring elaborate, global communication systems. In the near-term, the unmanned combat vehicle will likely involve a robotic wingman in a similar manner to the Air Force loyal wingman. Current ground weapons platforms are being modified to remove the crew members who would tele-operate the vehicle from a nearby one. Thus, the next generation unmanned combat vehicle could sacrifice survivability, maintain lethality, and achieve greater deployability as compared to legacy systems. Further in the strategy, small

UAS, sensors, non-line-of-sight fires, unmanned vehicles, and human operators would all operate on the same operating picture in a large, heterogeneous swarm.

Academic and Commercial Initiatives with Swarms

The field of aerial swarms has seen great advances just in the past few years with movement from out of the laboratory environment to outdoor experiments with tens to hundreds of vehicles. Society is just at the beginning in developing swarms. This technology will have a profound impact on the global economy, commerce, transportation, safety, and efficiency. Two industries that are changing the landscape are self-driving automobiles and commercial UAS.

Self-Driving Automobiles

This author believes that the self-driving car industry will provide much of the underlying technological advances in swarm autonomy and capability. Advances in collision avoidance, parking assistance, and congestion detection and re-routing are already improving safety and efficiency. High-profile self-driving fatalities by Tesla, Google, and Uber self-driving vehicles make headlines but with over 35,000 U.S. automobile deaths per year, autonomy in vehicles will greatly reduce human error in driving. These trend will occur gradually with improvements and advances made after multiple failures and tests. Drivers will most likely control the vehicle in narrow, congested areas such as cities and then move to autopilot features on the highway. The trucking industry will also benefit from these developments where most of the driving is conducted on interstates. For communications, vehicles are already connected through mobile phones and future models will have on-board devices to connect to cellular networks or using short-range radios to communicate directly to other vehicles. The vehicles on the roadways will become a defacto swarm capable of learning and adapting to the number and density of vehicles on the roads.

Self-driving technologies are already present in military research and development efforts. TARDEC's ARIBO (Applied Robotics for Installation and Base Operations) program is using self-driving vehicles to transport wounded soldiers from their barracks to hospitals at Fort Bragg, NC. Autonomy in individual vehicles lead to multiple self-driving vehicles that can form convoys. TARDEC is also experimenting with driverless trucks to remove soldiers from hostile areas during logistics operations. Many predict that autonomous convoys will be serving in conflict zones by the year 2030.[49] Self-driving features could also be applied to weapons platforms to allow fire and maneuver without the presence of a human operator. Self-driving tanks and missile systems could apply the same autonomy and swarm behavior found in the private sector.

Commercial UAS

The factors that allow almost anyone to build a quadcopter for under $100 could enable 1000s and tens of 1000s small to medium sized drones simultaneously controlled by a single operator in the next 5 to 10 years. The commercial sector is already poised to leverage these technologies to provide goods in under 30 minutes (probably most famously is Amazon's desire to deliver goods using UAVs). As previously mentioned, Intel currently holds the record for the most air vehicles controlled by a single operator at 500. This demonstration is primarily used for artistic purposes but other applications could be in search and rescue and disaster response scenarios. The largest robotic ground swarm to date was performed at Harvard University using over 1000 agents.[50] Commercial swarms could eventually be used for construction, mining, and other labor intensive tasks. As discussed in DoD Swarm Initiatives, the military, private industry, and academia collaborate on these capabilities. While beneficial, most of the hardware and software resides in the open-source community that foreign competitors and adversaries can also access.

Adversarial Capabilities with Swarms

Low-cost, asymmetric threats have proven dangerous for U.S. military forces and homeland security. The proliferation of improvised explosive devices of all types in the Iraqi and Afghan theaters has demonstrated that inexpensive, commercial off-the-shelf technology and some electronics knowledge can be combined to significantly impact high tech operations. Autonomous GPS-guided and semi-autonomous unmanned aerial vehicles are changing the paradigm in their employment now and in the future. While a single attack might be insignificant, a swarm of robotic devices could prove a credible threat. Wired magazine reported that the Department of Homeland Security pitted $5,000 worth of drones against a convoy of armored vehicles and the drones won.[51] In addition to state actors developing swarm capabilities, non-state actors such as the Islamic State are doing the same.

Russia and China

Russian development in autonomous weapons has produced among others drones, tele-operated tanks, and humanoid robots.[52] Recent reports by the Russian paper Komsomolskaya Pravda detail a robot soldier that could one day operate in hazardous areas threatened by explosives and radiation.[53] The Platform-M combat robot and Uran-9 are also sophisticated weapons systems that can deliver hundreds of rounds per minute.[54] Russian unmanned ground vehicles equipped with heavy caliber machine guns and grenade launchers have conducted drills with mechanized infantry units.[55] The recently released ‘Flight’ robot can use radar, thermal imaging, and video imaging to detect and kill humans from over four miles away.[56] Developers state that the intent for this robot is to be able to distinguish friendly and enemy forces using long-range missiles and artillery.[57] Ultimately this system would be able to operate independently without human commands and shoot down a drone for example. While these systems are still in their early stages, the Russian military is incorporating these robotic capabilities into their doctrine and tactics.

Russia has long been an expert in military espionage and this pattern has continued in its desire to obtain autonomous systems.[58] Most evident in this intellectual property theft is the similarities in the Russian drone program to the U.S. one.[59] But in addition to stealing technology, the Russian industrial complex has been performing domestic production of drones to reach the same level as the U.S. military’s Reaper and Global Hawk platforms. Most notable, the success of the Russian intervention in Syria has allowed for field testing of many of their new unmanned aerial vehicle systems. It was the first major Russian utilization of UAVs in a conflict and a capability that is only likely to continue to grow. [60]

Russia’s entrance into autonomous weapons and robotics is not surprising due to the wide-scale proliferation and democratization of software, inexpensive components, and open-source algorithms that can easily be downloaded online. The sale or unintentional transfer of autonomous weapons to U.S. adversaries could pose a threat. Further, Russia has demonstrated its reluctance to admit involvement such as in the Ukraine. As Russia continues to acquire these systems, the cost of commitment will decrease and their ability to deny involvement will become easier.[61] Russia’s hybrid approach in the Ukraine could be applied to other theaters potentially using autonomous robots without proper checks and safety mechanisms.[62]

China is also rapidly pursuing drone and swarming technologies. The People's Liberation Army sees autonomous systems as having a "huge impact" on future operations.[63] In addition to UAVs, the Chinese are pursuing unmanned surface and underwater vehicles for reconnaissance operations and to maintain a constant presence in the South China Sea. One particular UAV is the BSK-005 which is a medium-altitude long-endurance system that has conducted patrols in the East and South China Seas.[64] During a Chinese airshow, a formation of a few dozen drones conducted a coordinated search mission. While currently unarmed, these models could be weaponized for strike missions.[65]

Violent Extremist Organizations

The Islamic State (ISIS) and other non-state actors are also actively developing swarm capabilities. In Iraq and Syria, ISIS is already using commercially available drones carrying small explosives.[66] While an individual agent is not a credible threat, if tens or hundreds of small drones converged on a target, defenders would be quickly overwhelmed. [67] These attacks have occurred in Mosul where as many as five commercial quadcopters have been modified to carry small grenades or artillery rounds.[68] The risk is not only with attacks but from feigning operations to distract or disrupt defenses.[69] Autonomous capabilities are built into most commercial UAS giving adversaries the ability to launch multiple systems without requiring pilots. The same would apply for a scenario in Europe or the United States. Home-grown terrorists have easy access to commercial drones and could assemble a swarm of explosive-carrying agents to attack a fixed installation.

The Risk of Autonomous Weapons and Swarms

Swarms offer potential advantages in future warfare but also present many legal and ethical challenges in addition to the inherent risk in turning over decision-making to machines. The literature contains many examples of legal and ethical considerations with AWS.[70] There are also many petitions from individuals, states, and non-governmental organizations supporting an international ban on 'killer robots'.[71] The amount of risk and probability of unexpected or errant behavior is perhaps the greatest concern such as collateral damage or the inability to control the AWS once enabled. If an AWS engages and kills civilians, who is responsible? What role does the military perform in making ethical decisions if machines and algorithms are executing them? Autonomous agents in close proximity to adversarial ones could quickly escalate a conflict without a human involved in the decision. The current debate within the DoD is the 'Terminator Conundrum': given the potentials risks of AWS, the DoD should not develop them.[72] However, U.S. adversaries do not have the same hesitations with AWS and could achieve a decisive advantage in the future. Therefore, the debate does not necessarily lie with whether or not to develop AWS as much as deciding what aspects of warfare to automate and those to leave in control by humans. Many of these decisions will involve a scenario where there is a loss of communications with the AWS and how much autonomy is provided to engage targets of opportunity and the ability of it to defend itself if attacked.

Recommendations

This author puts forth a number of recommendations. First, the DoD should adopt a 'swarm mindset'. This change would largely be seen in the movement away from the single, exquisite weapons platforms to those that are small, cheap, unmanned, expendable, and fast. There are many operational advantages of swarms in terms of autonomy, quantity, and speed. Unmanned systems can take greater risk by reducing survivability while maintaining lethality and increasing deployability. A swarm mindset could lead to reduced costs and could potentially avoid extensive research, development, and long acquisition cycles as with current weapons platforms.

Second, DoD Directive 3000.09 should be re-evaluated and perhaps relaxed. In almost every case, the technology far outpaces the policy. Swarms do not allow for any meaningful human control over individual agents. These agents will make targeting decisions once they are deployed. While the 'Terminator Conundrum' continues to be debated in the Pentagon, it is already apparent that our adversaries are developing, improving, and integrating autonomous weapons into their doctrine and force structure.[73] The DoD should continue to monitor AWS development by Russia, China, Violent Extremist Organizations, and others. Again, swarm-capable systems will not realistically allow control at the agent level and policy should be adapted to account for this reality.

Finally, the DoD should increase research and development spending on swarm capable systems, sensing, and C2 (command and control) mechanisms. Acquisition programs should be tailored to rapidly develop and field these devices. The DoD should continue to leverage academia and commercial innovations in self-driving cars and commercial UAS among other private sector initiatives.

Conclusions

Robotic swarms will soon only be limited by the number of agents available to participate in the collective. Current software and artificial intelligence control algorithms already allow swarm formations to easily scale and adapt with increased numbers. The components of the Third Offset represent the enabling capabilities of swarm behavior. Thus, the DoD should focus greater research and development efforts on swarm-capable systems that are low-cost, numerous, unmanned, and fast. While the benefits of swarm systems appear unlimited, there are some major ethical and legal obstacles to swarm-capable systems as related to autonomous weapons and in particular the risk associated with their employment. While the development of AWS is likely forgone, there are many decisions on the balance between human control and automation in the use of these offsetting technologies.

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