OCTOBER 2020

U.S. Military Investments in Autonomy and AI

A Strategic Assessment

CSET Policy Brief

CENTER *for* SECURITY *and* EMERGING TECHNOLOGY

AUTHORS

Margarita Konaev
Husanjot Chahal
Ryan Fedasiuk
Tina Huang
Ilya Rahkovsky

Executive Summary

The Department of Defense aims to harness AI to support and protect U.S. servicemembers, safeguard U.S. citizens, defend U.S. allies, and improve the affordability, effectiveness, and speed of U.S. military operations.[1] To advance this strategy, the U.S. military is developing plans to use AI in physical systems—in the air, on the ground, underwater, and in space—as well as to operate virtually in cyber operations and electronic warfare. Policymakers need information about DOD's investments in AI to ensure these research efforts support broader strategic goals. Where exactly is this investment going? And what benefits and risks might result from developing and fielding autonomous and AI-enabled weapons and systems?

As the U.S. defense community implements its vision for AI, CSET offers a two-part analysis assessing the scope and implications of U.S. military investments in autonomy and AI. Drawing on publicly available budgetary data on DOD's science and technology program and an extensive review of strategic and operational literature and scientific research, these studies focus on three interconnected elements that form our analytical framework:

- The *technology* element addresses DOD research and development efforts in autonomy and AI;
- The *military capabilities* element speaks to the speed, precision, coordination, reach, persistence, lethality, and endurance enabled by advances in autonomy and AI;
- The *strategic effects* element analyzes how these technological developments and capability enhancements may affect key strategic issues—specifically, deterrence, military effectiveness, and interoperability with allies.

This report presents a strategic assessment encompassing the military capabilities and strategic effects elements, while the accompanying report, "U.S. Military Investments in Autonomy and AI: A Budgetary Assessment," covers the technology element. The following is a summary of our findings and recommendations for ensuring U.S. military leadership in AI in the short term and the long term.[2]

AI in the short term

Filling knowledge gaps: Effective human-machine teaming is at the core of applications that facilitate coordination and increase military endurance—in some situations, even mitigating the risks from machine complexity and speed. But gaps in research on trust in human-machine teams can stymie progress.

The U.S. military sees many benefits in pairing humans with intelligent technologies—improving coordination and decision-making, helping reduce the cognitive and physical burden on warfighters, and decreasing exposure to dangerous missions. The basic technologies that support human-machine collaboration already exist. Yet advances in AI could allow intelligent machines to function not only as tools that facilitate human actions but as trusted partners to human operators. Such breakthroughs could provide U.S. forces with a significant technological and operational advantage against opponents without similar capabilities.

Trust is essential for effective human-machine teaming. Yet research on human attitudes toward technology identifies tendencies for both mistrust and overtrust, with each presenting unique risks and challenges for military uses of human-machine teams. Without a contextualizing understanding of trust in human-machine teams, the U.S. military may not be able to fully capitalize on the advantages in speed, coordination, and endurance promised by autonomy and AI. This, in turn, could impede U.S. ability to use AI-enabled systems to deter adversaries from aggression, operate effectively on future battlefields, and ensure interoperability with allies.

To safely and effectively employ machines as trusted partners to human operators, the following steps may be necessary:

- DOD should increase investment in multidisciplinary research on the drivers of trust in human-machine teams—specifically under operational conditions and in different domains—by varying stress conditions and accounting for relevant dispositional, situational, and learned factors.

- U.S.-based researchers should collaborate with defense research communities in allied countries on joint research initiatives that assess how cross-cultural variation in trust in human-machine teams may impact interoperability.

Maximizing advantages: AI applications that enhance military endurance contribute to military effectiveness and readiness, as well as interoperability with allies.

Today's strategic and operational realities put a premium on both operational readiness—supported by elements such as personnel, equipment, supply/maintenance, and training—and endurance—the ability to withstand hostile actions and adverse environmental conditions long enough to achieve mission objectives.[3] There are great opportunities in leveraging existing and relatively safe technologies for logistics and sustainment to streamline personnel management and enhance the functionality and longevity of military equipment. But their potential value is understated.

- AI applications for logistics and sustainment are more than cost saving measures boosting back-office efficiency; they enable military readiness and effectiveness in combat.

- Gaps in endurance capabilities can impair interoperability in multinational coalitions like NATO and undermine the long-term health of U.S. alliances.

Therefore, we offer the following policy recommendations:

- DOD, with coordination support from the Joint Artificial Intelligence Center, should calibrate investment in AI applications for endurance as an enabler of military readiness.

    - JAIC should work with the centralized AI service organizations to assess the impact of AI programs related to logistics and sustainment on overall readiness.

- The United States should work closely with allies on AI applications in logistics and sustainment, including joint research and development programs and support for multinational public-private sector partnerships.

Minimizing risks: In the short term, the national security risks of AI have less to do with AI replacing humans and more to do with failure to deliver on technical expectations and with warfighters inexperienced with AI misusing it.

Many of the current U.S. military autonomy and AI research and development projects will never reach fruition; others will fail to scale or be fielded yet rarely used. There are significant technological, organizational, and budgetary barriers to innovation and adoption of new military technologies. As such, a healthy degree of skepticism and tolerance for technical failure are needed.

At the same time, there is also the risk of over-eager adoption. This could result in premature use of AI systems that cannot grasp context or make strategically intricate judgments by warfighters who may not fully understand the potential failure modes of these systems, possibly leading to inadvertent escalation. For instance, employing increasingly autonomous unmanned surface vehicles for military deception, while technically possible, could be destabilizing in highly militarized areas such as the South China Sea. As a result, we recommend the following:

- Security and technology researchers, particularly those affiliated with or advising DOD, should be more explicit about the uncertain pace of progress in specific areas related to autonomy and AI technologies (e.g., autonomous ground combat vehicles and unmanned undersea vehicles).

- The same researchers should differentiate between two types of risks: short-term risks associated with the use and misuse of technologies already in the pipeline, and long-term risks arising from more advanced technologies which are likely to face development and fielding barriers.

- DOD should coordinate with federally funded research and development centers and university-affiliated research centers to conduct risk assessments and wargames focused explicitly on near-term AI technologies and risks from human-machine interactions.

- JAIC should coordinate with the services and relevant operational commanders to provide thorough training to units operating autonomous and/or AI-enabled systems on the potential failure modes and corresponding risks.

AI in the long term

Robust, resilient, trustworthy, and secure AI systems are key to ensuring long-term military, technological, and strategic advantages.

Numerous science and technology programs focus explicitly on strengthening AI robustness and resilience, fortifying security in the face of deceptive and adversarial attacks, and developing systems to behave reasonably and reliably in operational settings (DARPA's "AI Next Campaign" is a prominent example). Yet in our assessment, most S&T programs on autonomy and AI don't mention safety and security attributes. Failure to advance reliable, trustworthy, and resilient AI systems could adversely affect deterrence, military effectiveness, and interoperability:

- **Deterrence:** The unpredictability and opaqueness of current AI technologies amplify risks of unintended escalation due to the speed of autonomous systems, as well as miscalculations and misperceptions surrounding their potential use.

- **Military Effectiveness:** AI applications that improve situational awareness, decision-making, and targeting processes can enhance precision capabilities and operational effectiveness. But the need for new data input and validation of AI systems deployed in uncertain operational environments raises concerns about unpredictable behavior.

- **Interoperability:** Safety, security, and privacy concerns could stall progress toward AI-enabled coordination between the United States and its allies and undermine the effectiveness of coalitions like NATO.

Based on these findings, we propose the following policy recommendations:

- DOD research, development, testing, and evaluation programs should emphasize safety and security across all stages of the AI system lifecycle—from initial design to data/model building, verification, validation, deployment, operation, and monitoring.

- DOD should collaborate with private sector leaders on safety research in areas such as automated and autonomous driving systems, while prioritizing robustness and resilience research in areas understudied in the private sector.

- DOD should focus on traceability for assurance with ML systems that continue to learn on dynamic inputs in real-time.
- The United States should collaborate with allies on common standards for safety and security of AI systems, including AI-enabled safety-critical systems.
- The United States should pursue opportunities for collaboration with China and Russia on AI safety and maintain crisis communications protocols to reduce the risk of escalation.

Table of Contents

Introduction

The United States faces a complex and volatile security environment. China is a strategic competitor with robust economic and technological capabilities its authoritarian government uses to stifle domestic dissent and pressure its neighbors. Russia is a revisionist power that violates the sovereignty of nearby nations and attacks the electoral integrity of Western democracies. North Korea's nuclear posture threatens peace and security on the Korean peninsula, while Iran's nuclear ambitions further destabilize the already restless Middle East. All the while, the COVID-19 pandemic is devasting the U.S. economy, undermining military readiness, aggravating tensions between the United States and China, and causing friction with U.S. allies.

Rapid technological change accompanies this reemergence of long-term strategic competition. The U.S. National Defense Strategy posits that technologies such as artificial intelligence, autonomy, and robotics will ensure the United States military can fight and win the wars of the future.[4] The FY2021 U.S. defense budget request allocates $1.7 billion to autonomy to enhance "speed of maneuver and lethality in contested environments" and the development of "human/machine teaming," as well as $800 million to AI, building on previous funds directed to the Joint Artificial Intelligence Center (JAIC) and Project Maven.[5] Yet other nations—particularly China and Russia—are also investing in military applications of AI, threatening to erode U.S. "technological and operational advantages and destabilize the free and open international order."[6]

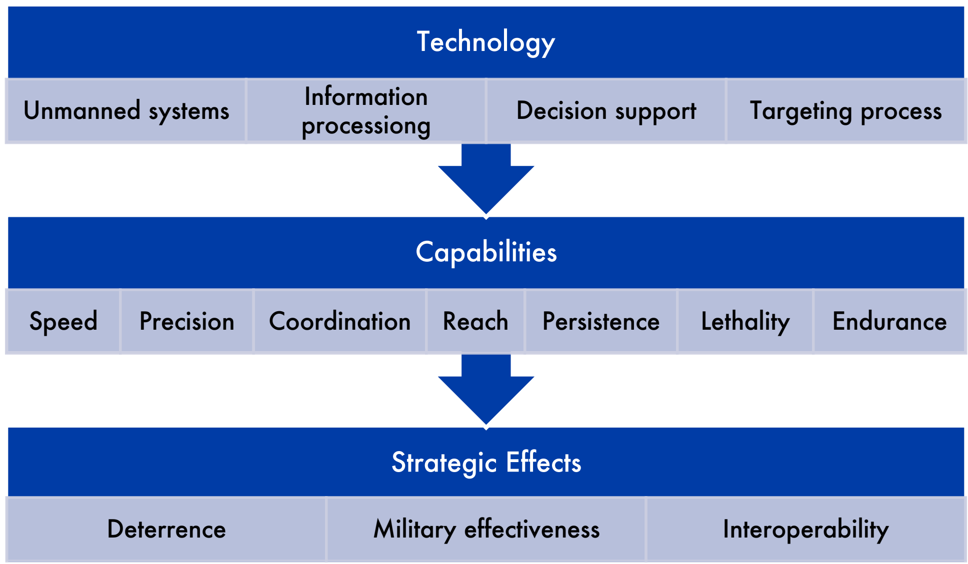
This report is the second of two CSET studies examining the scope and implications of U.S. military investments in research and development related to autonomy and AI. We sought to better understand the science and technology investments in autonomy and AI, and how they may affect the military capabilities and strategic interests of the United States. Toward that end, we developed the following analytical framework, which focuses on three interrelated elements:

Technology: Mapping the landscape, type, and monetary value of U.S. military research and development programs related to autonomy and artificial intelligence, particularly in areas like unmanned systems, information processing, decision support, and the targeting process.

Capabilities: Assessing the critical capabilities enabled by advances in autonomy and AI, with specific attention to speed, precision, coordination, reach, persistence, lethality, and endurance.

Strategic Effects: Analyzing how these technological developments and capability enhancements may affect U.S. strategic objectives, specifically, deterring adversaries, conducting effective military operations in line with the Law of War, and ensuring interoperability with allies.

Figure 1. Analytical framework



Whereas the first report, "U.S. Military Investments in Autonomy and AI: A Budgetary Assessment," centered on the technology component of our tripartite analytical framework, this report offers a strategic assessment covering the military capabilities and strategic effects portions. To illustrate some of the dynamics and implications identified in our research, we also include a short vignette on the role autonomous and AI-enabled weapons and systems could play in the South China Sea.

Strategic Assessment

To ensure the U.S. military retains its operational and technological advantage, the Department of Defense is investing in a wide range of research efforts using autonomy and AI in unmanned vehicles and systems, information processing, decision support, targeting functions, and other areas. This research cuts across different warfighting functions, including command and control, information, intelligence, fires, movement and maneuver, and protection and sustainment—clearly demonstrating the broad vision DOD has for AI in both combat and non-combat situations. Ultimately, at a strategic level, investments in autonomy and AI are meant to provide the U.S. military with the AI-enabled capabilities needed to deter adversaries from aggression, fight and win the wars of the future, and cooperate effectively with allies.

Building on an extensive review of strategic and operational literature and scientific research, the following discussion addresses the military capabilities enabled by autonomy and AI, and analyzes how these technological developments and capability enhancements could affect U.S. strategic objectives, specifically as they pertain to deterrence, military effectiveness, and interoperability. The research and development programs we reference throughout the report draw on data from the FY2020 research, development, test, and evaluation (RDT&E) budget justification books of the Army, Air Force, Navy, Marines, and DARPA. We focus specifically on basic, applied, and advanced research—known jointly as the Science and Technology (S&T) program, which supports the development of new technologies imperative to U.S. military superiority.

Before we proceed, however, there are a number of pertinent findings from the budgetary assessment report that have a bearing on the current discussion:

- **Most AI-related research efforts are also related to autonomy:** A large portion of the U.S. military AI research is geared toward AI applications enabling greater autonomous functionalities in unmanned systems, such as robotics and different semi-autonomous and autonomous vehicles. Meanwhile, AI research unrelated to autonomy—and especially autonomy in unmanned systems—receives a much smaller share of the S&T budget.
    - Advances in AI research related to unmanned systems and unmanned vehicles can expand the reach and persistence

    - capabilities of missions in hostile and contested environments, with implications for deterrence; increased automation of ground and air resupply and casualty evacuation can strengthen endurance, improving military effectiveness.
    - That said, the potential gap in non-embodied AI research is concerning, given the proliferation of malicious cyber operations and the vulnerability of critical infrastructure.

- **Trust in Human-Machine Teams:** Effective human-machine collaboration is key to harnessing the full promise of AI. But gaps in our understanding of trust in human-machine teams can impede progress.
    - Human-machine teaming is a crosscutting theme across the different U.S. military research initiatives related to autonomy and AI. Yet there are notable gaps in research on trust, which is an essential aspect of effective human-machine teaming.
    - Without a contextualized understanding of trust in human-machine teams, the U.S. military may not be able to fully capitalize on the advantages in speed, coordination, and endurance promised by autonomy and AI. This, in turn, could undermine U.S. ability to leverage AI for its broader strategic goals.

- **Trustworthy, Robust, Responsible, and Secure AI**: Several U.S. military S&T programs focus explicitly on increasing AI system robustness and resilience, strengthening security against deceptive and adversarial attacks, and developing systems that behave reliably in operational settings. In our assessment, however, most of the research programs related to autonomy and AI don't mention safety and security attributes such as such as robustness, resilience, reliability, trustworthiness, traceability, explainability, interpretability, or assurance.
    - In the short term, these gaps could hinder efforts to scale AI for decision support and undercut effective human-machine teaming; over the long term, they could also stall the development and fielding of AI systems in operational environments.

These findings from the first report reinforce some of the key takeaways from the following strategic assessment. Throughout this report, we identify both short- and long-term opportunities and risks in AI. In the short term, DOD should increase investment in research on trust in human-machine teams, while United States and its allies should capitalize on AI applications in logistics and sustainment to enhance endurance and readiness; doing so will improve military effectiveness and interoperability. National security experts and decision-makers should also pay closer attention to near-term risks from using increasingly autonomous and AI-enabled systems in roles that could trigger inadvertent escalation. In the long term, fielding AI systems in operational environments will require overcoming their unpredictability, brittleness, and vulnerability to adversarial attacks. Investing today in reliable, resilient, trustworthy, and secure AI systems could cement U.S. military and technological advantages into the future.

Military Capabilities

As U.S. Secretary of Defense Mark Esper notes, "whichever nation harnesses AI first will have a decisive advantage on the battlefield for many, many years."[7] The U.S. military is investing in research and development that incorporates autonomy and AI into unmanned systems, information processing, decision support, and targeting functions, among other applications. What specific capabilities does the U.S. military need to remain dominant, and how do advances in autonomy and AI affect them?

Security and technology experts usually highlight capabilities such as speed, precision, coordination, reach, persistence, and lethality.[8] The Department of Defense Artificial Intelligence Strategy also envisions using AI to reduce the risk to fielded forces, maintain equipment, reduce operational costs, and improve readiness.[9] AI applications for force protection, logistics, and sustainment can then enhance what we refer to as endurance.[10]

These capabilities should be viewed as complementary, rather than separate, concepts. The following subsections elaborate on these seven capabilities, briefly identifying some of the ways in which they relate to the strategic issues in this report—i.e., deterrence, military effectiveness, and interoperability. The subsequent section on strategic effects offers a more detailed discussion of how these capabilities, enabled by technological advances in autonomy and AI, affect the aforementioned strategic issues.

Speed

Speed is a critical capability for decision-making and operations in a competitive and complex security environment, as well as a key advantage promised by autonomy and AI. Autonomy allows weapon systems to execute the so-called observe, orient, decide, act (OODA) loop much faster than a human can; time-critical missions such as air and missile defense already incorporate varying degrees of autonomy into their systems.

AI-enabled speed in decision-making and operations has implications for deterrence and escalation control. The ability to process information with machine speed and distill real-time actionable intelligence also applies to the effective conduct of military operations. At the same time, AI-enabled speed in information processing and decision-making could widen the military capabilities gap between the United States and its allies, potentially impairing interoperability.

Precision

The ability to apply force accurately and discriminately is a hallmark of American military power. Precision strike capabilities can achieve a range of U.S. strategic objectives across the competition continuum, allowing the United States to conduct low-visibility operations and maintain a small footprint in politically or diplomatically sensitive environments. Precision capabilities also reduce the risk to U.S. servicemembers by insulating them from the dangers of the battlefield. Moreover, the United States can use such force in compliance with the Law of War and rules of engagement protecting civilians and civilian objects from unnecessary harm.

AI can enhance precision capabilities by automating the processing and analysis of data from intelligence, surveillance, and reconnaissance (ISR) platforms and missions, and by automating target identification, tracking, selection, and engagement. AI-enabled precision capabilities may affect the conduct of military operations by increasing military effectiveness, while helping to reduce the risk of civilian casualties and collateral damage.

Coordination

Modern warfare is a complex endeavor requiring coordination of forces and assets across multiple domains. Command and control architectures may differ depending on the mission and operational environment. But effective coordination is key to joint warfighting functions such as movement and maneuver, use of fires, protection, and sustainment.

The difficulty of developing a unified, real-time operating picture poses major coordination challenges. Soldiers at different levels of command receive information in various formats and from multiple sources and platforms. Moreover, the extensive network of U.S. alliances, joint interests, and common threats often means military operations unfold in concert with allies and partners, each bringing a diverse set of capabilities, procedures, and systems into the fight. The proliferation of unmanned vehicles in the air, sea, and on land means both human-machine teams and multiple autonomous systems must now coordinate. Taken together, AI-enabled coordination capabilities have implications for the conduct of military operations and interoperability.

Reach

The U.S. military must stand ready for a range of missions, including in denied, hostile, and austere environments. Such missions may entail operations in anti-access / area denial (A2/AD) environments near potential adversaries, contested airspace, densely populated urban areas, and underground environments with unreliable or nonexistent access to GPS navigation and communications. Greater autonomy and AI in unmanned systems vastly expand reach without placing servicemembers at risk, which has critical implications for deterrence.

Persistence

Whether in competition below the level of armed conflict or in active military engagements, the U.S. military relies on systems' persistence—that is, their consistent and continuous performance over time. Persistence enabled by advanced autonomy and AI is best captured by a system's ability to perform dull, dirty, or dangerous missions. Dull missions include persistent surveillance or identification of objects of interest from imagery and video from ISR platforms; dirty and/or dangerous missions refer to things like countermine operations and logistics resupply in enemy territory. Greater persistence capabilities—often coupled with reach and speed—have implications for deterrence.

Lethality

The shift to strategic great power competition has been accompanied by a renewed emphasis on lethality. Building a more lethal force is the Department's principal goal. The National Defense Strategy explains that the United States must make difficult choices to ensure that, above all else, it can "field a lethal, resilient, and rapidly adapting Joint Force."[11] The U.S. Army Modernization Strategy is also geared toward making "soldiers and units more lethal to deploy, fight, and win our Nation's wars."[12]

While lethality is not clearly defined, it means more than the ability to kill.[13] On a strategic level, lethality is closely linked to combat credibility. Advances in autonomy and AI increasing the speed and accuracy of decisions and improving situational awareness can bolster the lethality of individual warfighters and small close-combat units.[14] On a strategic level, new weapons and systems enabled by AI can strengthen military readiness and signal greater combat credibility. Lethality enabled by AI has implications for deterrence.

Endurance

Endurance is the ability to withstand hostile actions or environmental conditions for as long as it takes to achieve mission success. As a concept, endurance combines insights from the protection and sustainment warfighting functions, which focus on preserving combat power and supporting readiness through force protection, logistics, and personnel services.[15] Endurance affects the extent to which the force can conduct decisive operations and seize, retain, and exploit the initiative.

Autonomy and AI applications that enhance endurance include partial automation of ground and air resupply, casualty evacuation, predictive maintenance, and logistics.[16] Endurance is closely tied to the effective conduct of military operations; by lightening the physical and cognitive workloads and shifting dirty and dangerous tasks from humans to machines, the U.S. military can increase survivability and reduce military casualties. To operate effectively together, allies need comparable endurance capabilities, which is pertinent to interoperability.

U.S. military investments in research and development related to autonomy and AI can enhance capabilities such as speed, precision, coordination, reach, persistence, lethality, and endurance. In the next section, we discuss ways in which these technological advances and capability enhancements affect U.S. strategic interests.

Strategic Effects

Developments in emerging technologies have profound implications for the intensifying strategic competition with China, resurgent tensions with Russia, and the increasingly complex and unpredictable geopolitical landscape of the 21st century. But how exactly will these technological developments and capability enhancements affect the U.S. ability to preserve deterrence, conduct military operations effectively and in compliance with the Law of War, and ensure interoperability with allies?

Table 1. Analytical framework

	U.S. Strategic Interests		
Autonomous and AI-enabled Capabilities	Deterrence	Military Effectiveness	Interoperability
Speed	X		X
Precision		X	
Coordination		X	X
Reach	X		
Persistence	X		
Lethality	X		
Endurance		X	X

Tying together the technology, capabilities, and strategic effects elements of the analytical approach outlined in Figure 1, Table 1 highlights key examples of how capabilities augmented by investments in autonomy and AI could affect U.S. strategic interests.

How autonomy and AI will affect deterrence and strategic stability is one of the most urgent questions in national security. AI technologies that increase the speed of decision-making and operations, coupled with autonomous functions in weapon systems augmenting lethality, could deter potential aggressors. AI for ISR applications, unmanned aerial vehicles (UAVs), unmanned surface vehicles (USVs), and unmanned undersea vehicles (UUVs) that expand reach and persistence capabilities in contested and inhospitable environments may also reinforce deterrence by increasing situational awareness and strengthening early warning mechanisms.[17]

That said, the very same capabilities could also fuel misperceptions and miscalculations leading to intentional or inadvertent escalation. The risks associated with the brittleness, unpredictability, and opaqueness of current AI technology are especially alarming in the context of nuclear weapons systems. Assessing the implications of autonomy and AI for deterrence then calls attention to balancing speed and human control in autonomous systems, understanding the drivers of trust in human-machine interactions, and addressing the limitations of current unmanned undersea and surface technologies.

The U.S. defense community is also betting on emerging technologies to enhance military effectiveness by strengthening capabilities such as coordination, precision, and endurance. Across the services, research efforts focus on improving situational awareness and decision-making through autonomous and AI-enabled systems. These advances facilitate coordination between leaders, warfighters, and machines—central for military effectiveness. Research applying AI for intelligence analysis, battlespace sense-making, and certain targeting functions can enhance precision capabilities, improving effectiveness while reducing the risk of civilian casualties and collateral damage. Concurrently, investments in autonomy and AI supporting force protection, logistics, and sustainment bolster endurance, thereby improving both readiness and effectiveness.

But the integration of more autonomous and AI-enabled weapons and systems into military operations is not without pitfalls. AI tools and systems are being developed to augment human intelligence and allow for new forms of human-machine collaboration. Yet, there are outstanding questions about the role of trust and human attitudes toward technology in high-risk situations. Using AI systems to enable greater precision in military operations raises concerns about risk and unpredictable behavior of complex and opaque systems in uncontrolled environments. And while enterprise AI applications that increase endurance are more attainable than operational systems, the challenges of scaling these efforts across the DOD are not trivial.[18]

Finally, sustaining technological and operational advantages in an era of strategic competition requires close cooperation and interoperability with allies and partners. AI-enabled tools and systems enhancing coordination will be particularly useful for deepening interoperability and information sharing in coalitions like NATO. Comparable endurance capabilities are also pertinent to interoperability and the long-term health of U.S. alliances. The United States then also has a strong interest in ensuring its allies benefit from advances in AI, including adapting some commercial applications for logistics and sustainment.

That said, security and privacy concerns, as well as divergences in technological and military capabilities, could stall progress toward AI-enabled coordination between allied nations. The advantages that autonomy and AI offer for decision-making and operational speed may adversely affect multi-national coalitions where some allied forces cannot maintain the tempo dictated by machine speed. Moreover, as unequal technological advances magnify the gaps in logistical support, survivability, and endurance between allies, coalitions like NATO will struggle to work and fight together.

The following subsections elaborate on these dynamics, paying attention to both the short-term and long-term opportunities and risks of autonomous and AI-enabled weapons and systems.

Deterrence

Deterring adversaries from aggression against vital U.S. interests is a strategic priority for the United States. There is no "one size fits all" approach to deterrence, but successful strategies often depend on convincing the potential aggressor that one is both committed and capable of using lethal force to prevent unwanted actions.[19] Speed, lethality, reach, and persistence in denied and hostile environments are all capabilities influencing the adversary's risk and cost calculus, making them essential to deterrence.

Speed and Lethality

The speed of modern warfare has outpaced the speed at which humans can orient, understand, and act. Countries that integrate autonomy and AI into their information processing, decision-support, and targeting functions and systems could have a significant advantage over adversaries relying on human operators in crisis and conflict scenarios.[20] The possibility of losing at machine speed amplifies the costs of aggression. This assessment, in turn, could dissuade the potential aggressor from taking unwanted action, strengthening deterrence.

The decision-action speed of autonomous and AI-enabled systems is fueled by technologies that not only process information from diverse sources, but also weigh information significance to guide decision-making. Research into decision-support technologies—motivated in part by the need for an advantage in speed—is prevalent across the services. The Air Force's basic research on decision-making, for instance, focuses on "mathematical modeling of cognition and decision making, development and testing of advanced representations and processes for high-level artificial intelligence, trust between humans and autonomous agents," as well as "mixed human-machine decision making."[21] Navy "Applied Information Sciences for Decision Making" research seeks to "develop enablers for decision making and mission execution," through technologies that "automate understanding of the battlespace by identifying objects, determining relationships among the objects, assessing intent, and automatically generating courses of action with associated risks and uncertainty."[22]

Successful deterrence rests on the ability to credibly threaten using lethal force. Lethality, which is closely intertwined with combat credibility, is therefore necessary for deterrence. The potential aggressor must believe that the deterrent state would follow through on its threat even if the risks become high. Deterrence scholars therefore advocate for creating commitments that are effectively unbreakable. By removing humans partially or entirely from the decision to engage targets, autonomous weapon systems may signal a state's credible commitment to use lethal use. Because automation connotes certain reprisal, adversaries are likely to back down during a crisis; this dynamic, according to some scholars, conveys stronger deterrence.[23]

Notably, at least 50 weapon systems around the world today can engage targets without direct human involvement—mostly defensive weapon systems protecting ships, ground installations, or vehicles from incoming projectiles. Typically described as "human-on-the-loop" weapons, these systems have different modes of engagement and generally only operate autonomously when humans cannot respond quickly enough because of the limited and fast time of engagement. [24]

Reach and Persistence

Reach and persistence are essential capabilities for direct deterrence—defending the homeland—and extended deterrence—discouraging attacks against U.S. allies and partners. Greater autonomy and AI in UAVs, USVs, and UUVs expand reach and persistence through improved remote-sensing and ability to operate safety, persistently, and at scale in inhospitable environments, such as deep water or areas protected by A2/AD systems. Such technological advances and capability enhancements can buttress deterrence by improving situational awareness, strengthening early-warning mechanisms, and providing overmatch capabilities that dissuade adversaries from aggression against U.S. interests. [25]

Advances in autonomy and AI that increase the reach, persistence, speed, and endurance of unmanned maritime vehicles could be particularly consequential. Nuclear deterrence hinges on the survivability of strategic assets in the face of an enemy's first strike, and currently, nuclear-powered ballistic-missile submarines (SSBNs) are considered the most survivable of nuclear platforms.[26] Some observers, however, argue that rapid improvements in autonomous weapon systems—particularly in unmanned and autonomous undersea vehicles that can locate and shadow adversary submarines for weeks or months—make these nuclear delivery systems vulnerable. Such technological advances and capability enhancements then have significant implications for deterrence and strategic stability.

The current state of some of these technologies suggests such claims are likely overstated. According to a 2019 RAND survey of unmanned maritime vehicles (178 UUV platforms and 89 USV platforms), the majority were small- to medium-sized with relatively slow maximum speed and endurance. These platforms are used for surveillance, mapping, and monitoring or inspecting; mine countermeasures are their most common military-specific mission. Most of the antisubmarine warfare and security platforms surveyed were capable only of detecting and identifying targets, making them more akin to platforms performing generic survey or monitoring missions. [27]

The state of the current technology, the complexity of antisubmarine warfare, and the sheer scale and physics-based challenges of undersea sensing and communications all suggest these systems have a long way to go.[28] That said, the U.S. military is working to address these challenges. The Navy's "Force Protection Advanced Technology" applied research project, for example, provides "the undersea energy and communications infrastructure necessary to assure undersea dominance; extend the reach of undersea assets; enhance situational awareness (SA) and standoff advantage without reducing forward presence and; provide endurance for unmanned systems necessary for force multiplication in an anti-access/area denial (A2/AD) environment."[29]

Challenges and Risks

The implications for deterrence and strategic stability of autonomy and AI advances enabling speed, lethality, reach, and persistence remain a matter of debate. Potential effects are highly contingent on nuclear postures, state perceptions of their own vulnerability, and technological capabilities of relevant platforms and systems. Yet the use and misuse of these systems could be detrimental to U.S. interests in several areas.

Speed and Lethality

The unpredictability, opaqueness, and speed of AI technologies amplify the risks of unintended escalation. Part of the danger stems from misperceptions and miscalculations around the use of these systems. The argument that credible reprisal strengthens deterrence, for example, rests on a state's ability to clearly signal its decision to deploy fully autonomous weapon systems. But the distinction between supervised autonomy and fully autonomous weapons remains blurry (if not irrelevant) in situations where the OODA loop cycles too fast for human intervention.

Moreover, from an engineering perspective, a particular weapon occupies a range rather than a point within the continuum of autonomy. The operations mode may therefore be altered from a semi-autonomous to supervised autonomous or fully autonomous system (e.g., AEGIS).[30] Given the technical barriers to distinguishing between different levels of autonomy and the high degree of distrust between adversaries, states may not believe adversaries who threaten autonomous reprisal.

In addition to the technical barriers to credibly signaling autonomous reprisal, findings from a RAND wargame illustrate that the speed of autonomous systems can lead to inadvertent escalation. In the wargame, the players representing the United States and Japan set their air defense systems to fully autonomous and linked them to signal resolve to China. But when North Korea unexpectedly fired a missile over Japan, the autonomous system not only engaged the missile, but also launched counterbattery fire against North Korea in a move that escalated the crisis.[31] Relying on machines to accelerate decision-action cycles in operational settings can therefore have destabilizing effects.

Effective human-machine teaming can moderate some of the risks from increased speed and system complexity. The evidence is contradictory, however, on whether humans do not trust machines to perform effectively or whether humans trust machines too much, especially in complex and high-risk situations.[32] Investments in research on trust in human-machine teams are therefore vital. Particularly important is research enhancing understanding of the factors that influence human-machine trust under operational conditions, in different domains, across varied stress, stimulation, and complexity levels, and in reference to cultural, social, and demographic variables that shape human behavior and attitudes toward technology.

Reach and Persistence

The United States has a strong interest in technologies facilitating situational awareness and persistent surveillance in strategically important environments. Still, greater reach and persistence could also improve the ability to find, track, and target adversaries' nuclear arsenals. Although such capabilities remain elusive, in the future, robotics and AI providing real-time tracking of adversary nuclear arsenals and accurate, rapid targeting may enable counterforce operations. Countries such as Russia and China have traditionally feared "bolt from the blue" precision-guided or nuclear strikes against their nuclear arsenals and delivery systems, such as road-mobile ICBM launchers or SSBNs. If these countries perceive their arsenals to be vulnerable due to enhanced U.S. persistence and reach capabilities, it could upset first-strike stability, causing inadvertent escalation or preemptive use of force.[33]

Taken together, the risk of inadvertent escalation due to advances in and misperceptions around AI-enabled speed, lethality, reach, and persistence reiterate the need for robust, trustworthy, and reliable AI systems. Given their shared interest in preventing catastrophic outcomes, the United States and its allies can and should engage with China and Russia on issues of AI safety and security, as well as crisis communications protocols.[34]

Military Effectiveness

To ensure effective conduct of military operations, U.S. forces need to maintain an advantage in all seven capabilities discussed in this report. Yet current strategic and operational conditions elevate the significance of coordination, precision, and endurance. We focus on the how autonomous and AI-enabled weapons and systems affect these specific capabilities for the following reasons.

First, according to the U.S. Joint Operations doctrine, the current strategic environment is "uncertain, contested, complex, and can change rapidly."[35]

These complexities are multiplied in joint operations, multi-domain warfare, in dense urban environments, and in multi-national coalition missions. Moreover, these challenges will worsen with technologically advanced near-peer competitors. Such strategic and operational realities put a premium on effective coordination between leaders, warfighters, and machines, as well as the ability to withstand hostile actions and adverse environmental conditions (i.e., endurance).

Second, the strategic and technological competition cannot be separated from ethical and legal considerations around the use of advanced technologies on future battlefields. The Department of Defense Artificial Intelligence Strategy expresses a strong commitment to ethics, humanitarian considerations, and AI safety, including an emphasis on using AI to reduce the risk of civilian casualties and collateral damage.[36] Precision capabilities are necessary for ensuring compliance with the Law of War. Moreover, the failure to minimize civilian casualties and collateral damage can undermine mission success and weaken the U.S. position in the world.

Coordination

Effective coordination improves situational awareness, accelerates decision-making, and ensures optimal use of manpower and resources to meet mission goals without exposing friendly forces to unnecessary risk. As previously noted, building a common operating picture is critical for coordination, but complicated by the complexity of modern warfare. Information overload and system failures undermine coordination. When command and control cannot keep up with operational environment complexity, that lack of situational awareness leaves forces vulnerable to adversary attack and fratricide.[37]

Research and development of AI/ML techniques—such as deep learning, natural language processing, anomaly detection methods, information fusion techniques, automated analysis support, visualization aids, and decision-support technologies—will help process and combine information to build a common operational picture.[38] The U.S. Air Force, for instance, is currently developing a Multi-Domain Command and Control (MDC2) system to centralize the planning and implementation of air, space, cyberspace, sea, and land-based operations. The MDC2 will eventually allow "any sensor to provide data to any shooter from any service, ally, or partner in any situation to achieve effects against any target."[39]

With a common operating picture, commanders and headquarter staff, platform operators, dismounted combatants, and mission support staff will be able to select and converge on a course of action more quickly. Improved situational awareness, better coordination, and more precise and accelerated decision-making processes combine to provide U.S. forces an advantage in future operations.

Coordination in modern warfare extends beyond the orchestration of human teams to include coordination between humans and intelligent agents, as well as coordination between machines and other non-human agents and systems. Human-machine teams have broad applications in military organizations, including providing greater situational awareness, extending reach, increasing lethality, and improving survivability and endurance. Much of the research and development into human-machine teaming stems from the premise that humans and intelligent agents are not comparable or interchangeable, but rather complementary.[40]

Multiple research and development programs across the services seek to improve human-machine teaming for coordination. Navy basic research on "Human Systems," for instance, centers in part on "attention and decision making in human and human-machine teaming tasks related to Naval missions, including command decision making, cognitive systems for human-machine teaming; computational neuroscience, human interactions with autonomous systems, attention and sensory processing."[41] The Air Force "Human Dynamics Evaluation" project is investing in applied research related to human trust and interaction. It "seeks to advance human language technologies to benefit military linguists and analysts, as well as to understand, quantify, and calibrate trust factors influencing airman interaction with autonomous systems that can be applied to airman-machine teaming in future weapon systems."[42]

With greater autonomy in unmanned systems and the integration of AI into decision-making, different permutations of human-machine teaming will become increasingly common on future battlefields. As the very essence of coordination in military operations evolves, advanced human-machine collaboration will enable not only situational awareness but situational understanding. Such advances could help mitigate human fallibility, reducing the incidence of misidentification leading to fratricide and unintentional targeting of civilians, as well as ensure mission success more broadly.[43]

Precision

The use of excessive and indiscriminate force is costly, inefficient, and can have adverse strategic consequences undermining U.S. influence and position. When weapons are more accurate, fewer are needed and smaller warheads can be used, improving lethality and reducing civilian casualties and collateral damage.[44] Civilian protection is "fundamentally consistent with the effective, efficient, and decisive use of force in pursuit of U.S. national security interests."[45]

Precision capabilities are tied to accurate, real-time intelligence about the capabilities, location, and activities of the adversary, as well as factors such as terrain, weather, and characteristics of the civilian population in the area of operations. AI is particularly well suited for culling images and information from platforms operating in multiple domains and analyzing the massive amount of ISR data involved in modern warfare.[46] DARPA's "Urban Reconnaissance through Supervised Autonomy (URSA)" program, for instance, "seeks to create a system of autonomous ground and air platforms operating in conjunction with U.S. ground forces that monitor an area to detect hostile forces and establish Positive Identification (PID) before any U.S. troops come into contact," specifically in densely populated urban areas.[47] More broadly, research efforts that leverage autonomy and AI to improve situational awareness, battlespace visualization, and decision-making are all relevant for precision capabilities.

Circumstances change quickly in military operations; targeting information that was accurate mere minutes ago can become obsolete in a split second. Currently, Automatic Target Recognition (ATR) systems that detect, identify, and track high-valued targets from designated sensor data provide limited and static mission support. DARPA's advanced "Automatic Target Recognition (ATR) Technology" program tackles these challenges through (1) the development of online adaptive algorithms that improve sensor performance, (2) algorithm training technology allowing for the rapid incorporation of new targets, and (3) technologies reducing required data rates, processing times, and the overall hardware and software demands of ATR systems.[48]

Endurance

Autonomous and AI-enabled weapons and systems can help ensure U.S. forces are well-supplied and protected from enemy attacks, as well as enhance the functionality and longevity of military equipment. U.S. military research related to technologies that support force protection, logistics, and sustainment can enhance survivability and endurance. These efforts therefore contribute directly to U.S. military readiness and effectiveness.

Lightening the Physical and Cognitive Workloads

Cumbersome equipment and supplies can reduce warfighters' physical endurance and stamina.[49] Advances in human augmentation—i.e., a mode of human-machine teaming that focuses on improving human performance by using mechanical, wearable, and implantable capabilities—could help lighten the warfighters' physical load through "smart" gear and devices, reducing exhaustion and increasing situational awareness.[50] DARPA's applied research on "Biomedical Technology," for example, aims to "develop new neural architectures and data processing algorithms to interface the nervous system with multiple devices, enabling control of robotic prosthetic-limb technology," in order to improve warfighter performance.[51]

AI could also help reduce the cognitive burden on the warfighter.[52] The Air Force, for instance, is investing in applied research related to human-analyst augmentation to "advance machine intelligence, information operations, operator-aiding technologies for advanced and multi-domain integrated ISR capabilities," including a focus on "human-centric analyst technology to develop cognitive systems engineering solutions for airman data overload, work integration, and mission performance."[53] In addition, using personnel data, AI could potentially predict when individuals may become too stressed or suffer psychological or physical injuries, notifying commanders and allowing them to make appropriate adjustments.[54] Army applied "Human Factors Engineering Systems Development" program is researching "sources of stress, potential stress moderators, and intervention methods...to address current and future warrior performance issues," in part through exploiting adaptive learning methods and strategies.[55]

Force Protection

There is a broad range of autonomy and AI applications for force protection that can help reduce risk to military personnel and improve overall effectiveness. AI employed in automated weapon systems, for instance, can provide protection from incoming aircraft, missiles, rockets, artillery, and mortar shells. Robotic autonomous systems and AI can also be employed for dangerous and hazardous missions, such as explosive ordnance disposal, route clearance, and chemical, biological, radiological, and nuclear reconnaissance—thereby reducing troop exposure to these hazards.[56]

Advances in human-machine teaming are also relevant to force protection. DARPA's applied research on "Advanced Land Systems Technology" seeks to "leverage advances in artificial intelligence to enable integrated manned-unmanned operations and decrease warfighter exposure through the use of autonomous agents." The broader aim of the project is to "break the relative symmetry of land combat to give U.S. forces a decided advantage in the current and future ground battlefield."[57]

Logistics

Logistics are the foundation of endurance, and an essential aspect of increasing survivability and minimizing risk to military personnel. AI applications to streamline back-office processes, personnel management, logistics, and equipment maintenance could improve the longevity and functionality of military equipment, increase efficiency, save costs, and ensure on-schedule operations. Such efforts are already underway across the services.

The Air Force, for example, has tested the F-35's Autonomic Logistics Information System that uses real-time sensor data to feed a predictive algorithm and identify when to inspect the aircraft or replace certain parts. The Army is working with IBM's Watson to tailor the maintenance schedules for the Stryker fleet based on data collected from vehicle sensors.[58]

In terms of S&T research, Army's "Autonomous Ground Resupply" project, for instance, seeks to improve the ground supply distribution system across multiple levels of strategic and tactical sustainment operations.[59] Army's "Rotarywing MEP Integration" research aims to "mature and apply tactical behavior algorithms and safe-flight technologies to enable unmanned and optionally manned aircraft to maintain safe, responsive, flexible, and tactical formation flight with manned helicopters for unmanned wingman applications in re-supply, reconnaissance, surveillance and attack missions."[60]

Challenges and Risks

The basic technologies that facilitate coordination, improve precision, and augment endurance already exist. But advances in AI can usher in a new paradigm for human-machine collaboration, as well as collaboration between machines and other intelligent agents and systems. DARPA's applied research on "Artificial Intelligence and Human Machine Symbiosis," for instance, is already working toward a future where machines can function "not only as tools that facilitate human action but as trusted partners to human operators."[61] Trust between humans and intelligent agents and systems is pivotal for effective coordination and as such, critical for military effectiveness. There are, however, outstanding questions about human attitudes toward technology that could stymie the safe deployment of human-machine teams, especially in operational environments.

Some research shows, for example, that while algorithms generally outperform humans in forecasting and prediction tasks, people nonetheless trust and prefer humans' forecasts to those made by algorithms.[62] Moreover, evidence from a series of studies conducted under the Department of Defense Autonomy Research Pilot Initiative, which explored human interactions with an autonomous squad member (a robotic mule that accompanies a dismounted soldier squad within a simulated military environment), showed that participants lost trust in the robotic mule when it made errors and had lower confidence in its reliability even as its subsequent performance improved.[63] Resolving this "trust gap" and ensuring that human team members fully understand what the system can and cannot do in a given environment may be necessary before the U.S. military can deploy some of the AI technologies it is currently researching.

At the same time, there are serious concerns about the implications of "automation bias," i.e., the tendency of humans to trust machines too much, especially in complex and high-risk situations, when they lack confidence in their own decisions or when dealing with sophisticated technologies.[64] Evidence from studies in aviation, for instance, suggests that as it becomes more difficult for human operators to disentangle the factors that influenced the machine's decision, they come to accept these solutions without question.[65] Indeed, investigations into the fratricides caused by the semi-autonomous Patriot surface-to-air system in 2003 showed that they were caused in part due to "unwarranted and uncritical trust in automation."[66]

While human-machine collaboration is a foundational aspect of the U.S. military's vision of future warfare, progress toward using intelligent agents and systems as trusted partners to human operators will require breakthroughs not only in AI and robotics that extend the capabilities of machines, but also in cognitive science, neuroscience, psychology, communications, and social sciences to better understand what is required to build and maintain trust in human-machine teams. Without a thorough understanding of trust in human-machine teams, the U.S. military is likely to see slower progress toward fielding AI as an enabler on future battlefields, which in turn could impair the U.S. ability to achieve its broader strategic goals.

The integration of AI into military systems also carries great promise for improving precision capabilities and augmenting endurance and military readiness. Yet increasing reliance on AI also introduces risks and safety challenges stemming from the complexity, opaqueness, and unpredictability of these technologies. These and other challenges have implications for precision and endurance.

Precision

Precision capabilities are the cornerstone of U.S. military power as the unparalleled accuracy of precision-guided munitions and strikes not only increases effectiveness but also limits collateral damage. As advances in autonomy and AI enhance these capabilities through improved ISR, better situational awareness, and decision-support, reliance on precision strikes will likely increase. But when these strikes fail to eliminate their target on the first try and individuals move to another structure, they expand the potential for civilian casualties and collateral damage. In Mosul, for example, where Islamic State militants used the city's infrastructure for fighting positions, repeated precision strikes created destruction similar to that caused by dumb bombs and indiscriminate artillery salvos.[67] While AI may enhance precision capabilities, a broader question remains about the cumulative effects of precision warfare, especially in densely populated urban environments.[68]

Moreover, as military operations unfold, they radically alter the environment—buildings are destroyed, streets become impassable, hostile actors gain and lose ground, and civilians flee to safer areas. All of this information must be added to existing models for them to update their learning and ultimately create a new model in a rapid and iterative fashion. Ensuring the reliability of these systems requires new data input verification, automatic data validation, and model and parameter section validation—all of which may be impossible with systems deployed in theater.[69] Yet without such updates, the ability of these systems to provide accurate, real-time information in support of decision-making, greater situational awareness, and precise use of force significantly declines.

DOD AI ethics principles establish that human beings are ultimately responsible for the development, use, and outcomes of AI systems. Progress toward operational AI will therefore require a stronger emphasis on robustness and resilience. In addition, traceability may be particularly important for assurance with online ML systems that continue to learn on dynamic inputs in real time.[70]

Endurance

Challenges in applying AI to augment endurance capabilities include effective distribution of tasks in human-machine teams and scaling AI for logistics.

Different concepts for human-machine teaming and manned-unmanned collaboration are being developed across DOD to reduce risk to military personnel and minimize the cognitive burden on warfighters. But human operators already inundated with combat responsibilities may become overwhelmed if they are also responsible for overseeing several unmanned air or ground vehicles. Consequently, this may decrease their situational awareness, increase stress, and expose them to unnecessary harm.[71] Indeed, research on autonomous vehicle technology for Army convoy operations shows that in a mix of manned and unmanned trucks, the soldiers who remain in the convoy would perform more tasks involving sensing and decision-making, resulting in a higher cognitive burden.[72] If human-machine teaming merely redistributes the burden down the chain of command rather than reduce it, the overall effectiveness of human-machine collaboration can be called into question.

From a technical standpoint, AI applications for logistics present a "low-hanging fruit" for DOD.[73] Nonetheless, issues such as data access, quality, ownership and control, intellectual property protections, and data-related policies and standards could pose a barrier to fielding such technologies as they advance through the research cycle or in adapting commercial applications.

A recent RAND report on the DOD AI posture finds that the Department "faces multiple challenges in data, including the lack of data. When data do exist, impediments to their use include lack traceability, understandability, access, and interoperability of data collected by different systems."[74] Moreover, the Joint Artificial Intelligence Center's experience thus far demonstrates the barriers to scaling successful AI projects throughout the military bureaucracy. Scaling requires an agile technical culture, data literacy, integrated and modular information architecture, and remodeling of legacy systems for better AI integration. This is a huge endeavor that also needs to be undertaken with safety, ethics, and reliability in mind.[75]

Taken together, autonomous and AI-enabled systems that improve coordination, precision, and endurance capabilities can help U.S. forces be better prepared for future warfare. In the near term, the U.S. military can build up its endurance capabilities, readiness, and effectiveness by developing and maturing AI applications for lightening warfighters' cognitive and physical load, force protection, sustainment, and logistics. Such tools and systems are increasingly available; the critical challenge is scaling these technologies across DOD. Moreover, as human-machine collaboration evolves, the effectiveness of human-machine teams will depend in part on how physical and cognitive tasks are shared and divided—e.g., whether teaming reduces burden or merely redistributes it. Finally, while operational AI remains on the horizon, employing AI-enabled precision capabilities will require early investments in system robustness, resilience, and traceability.

Interoperability

America's network of alliances and partnerships is a force multiplier in the strategic competition against China and Russia. With AI as the focal point of this strategic competition, U.S. national security leaders and experts have urged closer collaboration with allies to shape the trajectory of AI in line with liberal democratic values. As countries integrate AI into their systems, the United States and its allies will need to coordinate closely on their respective and shared AI-enabled capabilities and ensure that hardware and digital systems are interoperable and secure.[76]

Coordination is the cornerstone of interoperability; AI applications for command and control can help U.S. and allied forces develop a common operating picture. The gap in military capabilities between the United States and its allies, both within and outside of NATO, also heightens the importance of comparable endurance capabilities in sustaining interoperability, cohesion, and effectiveness.

Coordination

Broadly speaking, deepening coordination and interoperability with allies and partners requires the alignment of operational concepts, modular force elements, communications, information sharing, and equipment.[77] In tightly integrated multinational operations, coordination is facilitated by interoperable command centers with standardized communications, data networks, ISR systems, and force elements. In missions where the battlespace is partitioned between the allies, coordination can be maintained through ad hoc techniques and procedures relying heavily on liaison officers.[78] When coalition forces operate in the same battlespace, convergence on a common operating picture is essential.

A common operating picture allows coalition partners to share plans, orders, locations, graphics, and reports, as well as identify gaps in sensor coverage. Advances in autonomous and AI-enabled systems can help increase situational awareness, enable rapid deconfliction, minimize response times, and contribute to more effective mission command by forming a common operational picture. These developments then strengthen interoperability between the United States and its allies.[79]

Several research efforts related to autonomy and AI can contribute to interoperability. DARPA's advanced "Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE)" research focuses on "innovative networking and information sharing approaches that enable U.S. and coalition forces to coordinate tactical operations effectively, efficiently, and securely by eliminating today's prohibitive security cost and complexity barriers."[80]Army basic research on "Intelligent and Survivable Command and Control, Communication, Computing, and Intelligence (C4I)" addresses the areas of "information assurance, signal processing for wireless battlefield communications, information extraction from multi-modal data human-agent naturalistic communication, and intelligent systems for C4I."[81] These C4I technologies, as the project states, "must accommodate heterogeneous security infrastructures, multi-service and multi-national interoperability, and information exchange/security mechanisms between multiple levels of security."[82]

Endurance

Comparable endurance capabilities are critical for working effectively with allies and partners, and for sustaining interoperability and cohesion in coalitions like NATO. Given the dual-use nature of AI technology, NATO allies—including those with less advanced military-industrial capacities—may be able to adapt certain commercial off-the-shelf applications at a reduced price point.[83] Most of these applications are in logistics, linking them to endurance.

While European allies have predominantly focused on economic and societal applications of AI, a number of notable efforts point to potential convergences relevant to endurance.[84] The UK Ministry of Defense's Autonomy Programme identifies defense resupply and logistics challenges through the Defense and Security Accelerator as one of its key activities.[85] In 2019, MoD also allocated £66 million (about $83 million) in funding to accelerate robotic projects for the British Army, including autonomous logistics vehicles supporting the distribution of supplies in conflict zones.[86]

France's military AI strategy views "logistics, support, and operational readiness" as one of the priority areas for the Ministry of Defense.[87] The German Army identifies AI for personnel and material management, including predictive maintenance as one the key areas for action on AI development.[88] Several European countries with funding help from the European Defense Fund are also collaborating on the development of an unmanned land vehicle, equipped with cyber defense solutions and an integrated network of sensors, to improve situational awareness, maneuver efficiency, and transportation support for troops.[89]

The fact that AI innovation occurs predominantly in the private sector and outside of the conventional defense industrial space offers opportunities for smaller countries. Based on its fact-finding mission to Singapore, NATO's Science and Technology Committee observed that "small and medium-sized Allies with smart scientists and engineers can play an outsized role in AI development and adoption," which could both increase interoperability and contribute to allied burden sharing.[90]

Challenges and Risks

Advances in AI pose new problems and amplify existing challenges for coordination in multinational coalitions and disparities in endurance capabilities that can undermine interoperability. America's alliances and partnerships are an "asymmetric strategic advantage that no competitor or rival can match."[91] But as the National Security Commission on Artificial Intelligence warns, U.S. allies are "concerned about being able to operate effectively together as the United States fields greater numbers of autonomous systems."[92]

Coordination

Serious barriers to AI-enabled coordination exist between different nations. Most basically, there are security risks inherent to common or interoperable information systems and databases vulnerable to disruption, manipulation, and data theft. Another challenge stems from the tension between AI-enabled speed and the nature of coalition decision-making processes. Machine speed in information processing and decision-support provides undeniable operational advantages. But the compressed timelines enabled by machine speed are antithetical to decision-making in alliances, which typically unfolds through protracted negotiations and political compromise.[93]

The proliferation of autonomous and AI-enabled weapons and systems on the battlefield also increases the operational tempo. Sustaining such tempo can place a significant physical and cognitive burden on military personnel, amplifying attrition rates on people and equipment. Yet if U.S. allies do not possess similar technologies and therefore cannot operate at the same speed, interoperability could suffer. Technological disparities could require breaking up the mission and the battlespace according to coalition member capabilities. Such devolution may diminish effectiveness and increase costs and risks.[94]

Questions surrounding trust in AI systems could also undermine coordination in multinational coalitions. Research shows significant cross-national variation in trust in AI technologies, including between the United States and its NATO allies. One 2018 survey found that trust in AI was at 21 percent of respondents in Germany and Canada, 23 in Great Britain and France, and 25 in the United States, compared to 40 percent in Italy and 43 in Turkey.[95] It is therefore possible that commanders from some states may be more reluctant to rely on AI-enabled systems during multinational operations.[96] This, in turn, could undermine coordination, interoperability, and overall effectiveness.

Given the contested debate surrounding autonomous weapon systems, public outcry in some countries could set political leaders against the use of AI-enabled weapons and systems. These dynamics reiterate the importance of collaborating with allies on issues of AI safety and security. Fortunately, there is an appetite for such engagement. A cross-national CSET survey of official representatives from allied countries shows that the majority agreed on "the need for international coordination and management of AI military applications, specifically autonomous weapons systems and unmanned vehicles for submarine detection."[97]

Endurance

U.S. allies and partners have significantly different military and technological capabilities that create divergences in their respective abilities to withstand hostile actions and tough environments. If allied or partner forces experience attrition in military equipment without adequate logistical support and cannot resupply, their casualty rates will likely increase as their morale and motivation to stay in the fight decline. Endurance capabilities are therefore an important aspect of maintaining effective collaboration with allies and partners, and sustaining interoperability and cohesion in coalitions like NATO. As the United States and other wealthy and large NATO members integrate AI capabilities into their military systems, this capabilities gap and the threat to NATO interoperability are likely to grow.

Overall, autonomous and AI-enabled systems can strengthen interoperability between the United States and its allies by streamlining coordination and supporting endurance capabilities. There are, however, significant challenges to ensuring hardware and digital systems are interoperable and secure, balancing speed and coalition decision-making and operations, reconciling different attitudes toward military AI, and narrowing the gap in endurance capabilities.

Strategic Assessment Key Takeaways

The above analysis of how advances in autonomous and AI-enabled weapons and systems could influence U.S. military capabilities and strategic interests supports issues raised in the budgetary assessment report and draws attention to additional challenges and opportunities.

First, human-machine collaboration—a key theme in the budgetary assessment—is at the core of autonomy and AI applications that facilitate coordination and increase endurance. In some circumstances, effective human-machine collaboration can also moderate the risks posed by machine speed and complexity. Yet gaps in our understanding of trust in human-machine teams can erode these advantages, and as a result, undermine deterrence, military effectiveness, and interoperability.

Second, AI applications that enhance endurance can contribute to military effectiveness and readiness as well as enable interoperability with allies. While operational AI is a long-term objective, many technologies that support force protection, logistics, and sustainment are increasingly attainable. Ensuring that U.S. allies also benefit from these technologies can help mitigate discrepancies in allies' endurance capabilities which would otherwise undermine interoperability, cohesion, and effectiveness.

Third, optimal use of autonomy and AI for enhancing U.S. military capabilities and achieving desired strategic effects for deterrence, military effectiveness, and interoperability requires significant improvements in AI system robustness, resilience, trustworthiness, and security.

South China Sea Vignette

The preceding discussion of the strategic effects of U.S. military investments in autonomy and AI is not merely an academic exercise; it helps us understand the potential real-world implications of capability gains—and risks—due to incorporation of these technologies. This vignette highlights a few potential benefits and risks from employing autonomous and AI-enabled weapons and systems to advance U.S. strategic interests in the South China Sea.

The South China Sea is a vital arena in the strategic competition between the United States and China. U.S. interests in the South China Sea include maintaining security and treaty commitments to Japan, the Philippines, and South Korea; preventing China from becoming a regional hegemon in East Asia; strengthening the U.S.-led security architecture in the Western Pacific; and defending freedom of navigation and the principle of peaceful resolution of disputes.

The U.S. military has no local shore bases from which to project power in Southeast Asia, and its dependence on more distant bases in Japan, South Korea, and Guam presents operational limitations. The reach and persistence enabled by greater autonomy in unmanned systems allows the United States to reassure its allies in the region, ensure freedom of navigation, and collect intelligence. But enhanced Chinese maritime situational awareness, coupled with robust A2/AD capabilities, could limit the U.S. ability to meet these objectives and operate in the South China Sea.

China already employs a range of radars, sensors, and unmanned maritime vehicles for surveillance, mapping, monitoring, mine placement, and mine countermeasures with options for decoy, deception, and targeting. Since 2018, there has also been a push in research and development efforts to expand autonomy in UUVs, build up their speed, endurance, reach, and persistence, and leverage AI for decision-support to assist submarine commanders. Moreover, China invested in radar and signals intelligence capabilities on the Spratly and Paracel islands, which facilitate situational awareness in air and sea in the South China Sea and connect to China's existing SIGINT collection network.[98]

As China invests in technologies allowing greater reach, persistent surveillance capabilities, and situational awareness, a parallel effort seeks to deny freedom of movement to its potential adversaries. China's military modernization plan has prioritized the development of A2/AD capabilities that span the air, maritime, space, electromagnetic, and information domains to conduct long-range attacks against adversary forces in the Western Pacific Ocean. While China's A2/AD capabilities are most robust within the first island chain, Chinese bases in the South China Sea would add to the regional network, keeping adversary forces away from China's mainland and Taiwan.[99]

Taken together, these developments could constrain the U.S. ability to conduct a range of missions in the South China Sea. Most basically, the reach and persistence enabled by the proliferation of underwater sensors and the deployment of increasingly autonomous vehicles increase the likelihood of the PLA Navy detecting, locating, tracking, and even engaging U.S. or allied underwater vehicles. Deploying U.S. UUV systems for ISR under these conditions will also become a formidable task. Not only will these systems be required to navigate past mines and evade underwater sensors and weapons, they may not be able to transmit collected information in real time without being detected and countered.[100]

Notably, the U.S. Navy's AWS Surveillance applied research program is geared toward tackling this challenge. The program invests in technologies that "support the conduct of covert, wide-area surveillance ranging from one day to six months," which can "provide clandestine indications and warnings in far forward and contested operating areas," using "non-observable platforms and/or deployed automated sensors employing passive sonar, or other non-detectable methods."[101]

Employing USVs could be another way to overcome some of the challenges to potential U.S. operations in the South China Sea. Indeed, U.S. Navy applied research on Unmanned and Autonomous Systems speaks directly to this need to "augment expensive manned systems with less expensive unmanned, fully autonomous systems that can operate in all domains."[102]

USVs are highly suitable for mine warfare missions and could reduce the risk minefields pose to personnel and more expensive assets. USVs could also be used to diminish the effectiveness of Chinese A2/AD systems, by deceiving sensors and jamming or targeting them to impair overall network performance.[103] Moreover, USVs could be highly effective for military deception, leading the adversary to misallocate resources and attack USVs instead of valuable manned assets. Notably, estimates of USV applications already in or near market suggest they are capable of some of these missions or could serve in such roles in the short to medium term.

The potential for escalation from employing autonomous and AI-enabled weapons and systems in contested environments such as the South China Sea remains a matter of debate. Some observers posit that autonomous systems could make crises involving unmanned patrols over disputed territory "more likely but less dangerous."[104] Countries are less likely to use force over the loss of an unmanned system compared to the loss of servicemembers or civilians.

On the other hand, non-negligible risks accompany the speed, unpredictability, and opaqueness of autonomous systems, potentially leading to inadvertent escalation. For instance, reliance on increasingly autonomous systems for military deception or even more innocuous missions could fuel misperceptions and miscalculations that may trigger an escalation, especially in a highly militarized region like the South China Sea. It is possible that the military deception is successful and a human operator fails to detect a USV being used as a deceptive target. Nonetheless, the human operator can still assess context and decide not to engage out of caution—seeking perhaps not to expose their own position, avoid escalation, or remain within the larger strategy.

In contrast, an autonomous system designed to detect and engage certain targets will proceed apace. Autonomous and AI-enabled systems are not well equipped to understand context and make judgments that a human operator, while fallible, could navigate. Additional concerns remain around AI-enabled preemptive engagements leading to escalation, as well as scenarios where both sides employ autonomous systems that can interact in unpredictable and possibly dangerous ways.

Engagements unfold rapidly and the decision to fire can take seconds. Machine speed is perpetually at odds with meaningful human control. Maintaining human control over the decision to use lethal force in denied environments is particularly challenging considering that autonomous systems don't yet have the capability for reliable underwater communication.

This brief overview illustrates a number of themes raised in this report:

- In the short term, the key national security risks posed by AI stem from using increasingly autonomous systems in roles and situations that can lead to inadvertent escalation.

- Autonomous and AI-enabled weapons and systems can help enhance U.S. military capabilities and advance America's strategic goals. But their deployment in operational settings requires them to operate as intended, explain their decision-making process in a manner comprehensible to humans, and remain resilient to adversarial attacks and manipulation.[105] Consistent investment in resilient, robust, trustworthy, and secure AI is therefore vital.

Conclusion

The United States faces a period of great uncertainty. The COVID-19 pandemic is taking a major toll on the U.S. and global economy, and the crisis will likely trigger a reprioritization of national security spending.[106] Yet given the escalating tensions with China, and with Russia and other competitors also pursuing advances in military AI, securing America's global leadership in artificial intelligence is more important than ever.

The U.S. military is investing in a broad range of research and development efforts applying autonomy and AI to unmanned systems, information processing, decision support, targeting functions, and other areas. These investments are often explicitly geared toward enhancing military capabilities such as speed, precision, coordination, reach, persistence, lethality, and endurance. On a strategic level, these technological advances and capability enhancements are ultimately meant to strengthen deterrence, ensure military effectiveness in future conflicts, and facilitate interoperability with U.S. allies.

As the U.S. defense community implements its vision for AI, the most effective approach is to focus on the near-term. Human-machine collaboration is a prominent theme across the different U.S. military research programs related to autonomy and AI. By directing more attention to understanding the role of trust in human-machine teams, the U.S. military could accelerate the development and fielding of intelligent agents and systems as trusted partners to human operators across different missions and environments. There are also great opportunities in leveraging existing and relatively safe AI technologies for logistics and sustainment to streamline personnel management and enhance the functionality and longevity of military equipment. Moreover, when it comes to working with allies, collaboration on AI for logistics and sustainment is both technologically attainable and politically feasible.

The emphasis on near-term effects also mitigates risks: the risk from not delivering on ambitious expectations due to technical limitations of AI and from over-eager adoption and use of AI-enabled systems the limitations of which warfighters don't fully comprehend.

In the longer term, our assessment shows that failing to advance reliable, trustworthy, and resilient AI systems could undermine U.S. strategic interests. Emphasizing safety and security across all stages of the AI system lifecycle, working with allies on common standards, and minimizing the risk of inadvertent escalation by maintaining an open channel of communication with countries like China and Russia can help mitigate the potential adverse effects of military AI. Ultimately, today’s investments will set the course for the future of AI in national security. By prioritizing reliable and secure AI systems, the United States will be able to ensure long-term military, technological, and strategic advantages.

Acknowledgments

In the process of research and writing, the authors benefited from the insights and feedback of many colleagues and experts. Thanks to Jason Matheny, Igor Mikolic-Torreira, Dewey Murdick, Helen Toner, Lynne Weil, Melissa Flagg, and Andrew Imbrie for their valuable comments. We are grateful to Danielle Tarraf of RAND and Martijn Rasser of the Center for a New American Security for reviewing the report and providing thorough and thoughtful comments that significantly strengthened our work. Many thanks also to Philippe Loustaunau for data support, Gina Acevedo and Tarun Krishnakumar for research support, Farhana Hossain for help with data visualization, and Matt Mahoney and Alexandra Vreeman for editorial support.

Document Identifier: doi: 10.51593/20190044

Appendix: Definitions

This appendix compiles existing definitions of artificial intelligence, autonomy, autonomous weapons, and weapon systems across the Department of Defense that were encountered throughout the project.

Artificial Intelligence

Department of Defense Artificial Intelligence Strategy 2018

"AI refers to the ability of machines to perform tasks that normally require human intelligence—for example, recognizing patterns, learning from experience, drawing conclusions, making predictions, or taking action—whether digitally or as the smart software behind autonomous physical systems."[107]

Defense Science Board

The DSB conducted a study on autonomy in which they explain "the primary intellectual foundation for autonomy stems from artificial intelligence (AI), the capability of computer systems to perform tasks that normally require human intelligence (e.g., perception, conversation, decision making)."[108]

Defense Innovation Board

The DIB published recommendations for AI principles in which the group defined AI as "a variety of information processing techniques and technologies used to perform a goal-oriented task and the means to reason in the pursuit of that task."[109]

DARPA

John Launchbury, former Director of DARPA's Information Innovation Office, defined AI as "a programmed ability to process information." He highlights three consecutive waves of AI: handcrafted knowledge (expert systems in the 1980s), statistical learning (machine learning and neural network models), and contextual adaptation (next evolution of AI). These three waves demonstrate AI progress along four dimensions: perception, learning, abstraction, and reasoning.[110]

FY2019 National Defense Authorization Act

1) Any artificial system that performs tasks under varying and unpredictable circumstances without significant human oversight, or that can learn from experience and improve performance when exposed to data sets.

2) An artificial system developed in computer software, physical hardware, or other context that solves tasks requiring human-like perception, cognition, planning, learning, communication, or physical action.

3) An artificial system designed to think or act like a human, including cognitive architectures and neural networks.

4) A set of techniques, including machine learning, that is designed to approximate a cognitive task.

5) An artificial system designed to act rationally, including and intelligent software agent or embodied robot that achieves goals using perception, planning, reasoning, learning, communicating, decision making, and acting.[111]

National Security Commission for Artificial Intelligence

NSCAI uses the FY2019 NDAA definition of AI and further defines AI in its interim report as "the ability of a computer system to solve problems and to perform tasks that would otherwise require human intelligence."[112]

Autonomy

DOD Community of Interest on Autonomy

"At the most basic level, autonomy draws on three broad, multidisciplinary technical fields: perception, cognition, and action."[113]

National Defense Industrial Association

At the NDIA 19th Annual Science & Engineering Technology Conference, the Air Force Autonomy Colonel Lead defined autonomy as "the computational capability for intelligent behavior that can perform complex missions in challenging environments with greatly reduced need for human intervention, while promoting effective man-machine interaction."[114]

DARPA

"Autonomy refers to a system's ability to accomplish goals independently, or with minimal supervision from human operators in environments that are complex and unpredictable."[115]

Defense Innovation Board

The DIB did not explicitly define autonomy in its recent AI principles publication, but the group recognizes that AI is not equivalent to autonomy.[116]

Defense Science Board

The DSB offers two definitions of autonomy in two separate reports. The first report, *Task Force Report on the Role of Autonomy in DoD Systems*, published July 2012, states that autonomy is a capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, "self-governing."[117]

The second report, *Study on Autonomy*, published June 2016, asserts that autonomy "results from delegation of a decision to an authorized entity to take action within specific boundaries" and distinguishes between systems that are automated and autonomous. For a system to be autonomous, DSB states that it needs "to have the capability to independently compose and select among different courses of action to accomplish goals based on its knowledge and understanding of the world, itself, and the situation.[118]

Stockholm International Peace Research Institute

In November 2017 SIPRI published the report *Mapping the Development of Autonomy in Weapons Systems,* where it defines autonomy as "the ability of a machine to execute a task, or tasks, without human input, using interactions of computer programming with the environment." SIPRI went further to describe an autonomous system as "by extension, usually understood as a system—whether hardware or software—that, once activated, can perform some tasks or functions on its own."[119]

Weapon System

DoD Dictionary of Military and Associated Terms on Weapon system

"A combination of one of more weapons with all related equipment, materials, services, personnel, and means of delivery and deployment (if applicable) required for self-sufficiency (JP 3-0)."[120]

Autonomous Weapons

DEPARTMENT OF DEFENSE DIRECTIVE 3000.09

Lethal Autonomous Weapon Systems do not have a singularly accepted and explicit definition mainly because of the range of ways in which autonomous platforms are generally defined. Following are the definitions given by the 3000.09 Directive of the DOD:[121]

- ***Autonomous weapons systems***: "A weapon system(s) that, once activated, can select and engage targets without further intervention by a human operator. This includes human-supervised autonomous weapon systems that are designed to allow human operators to override operation of the weapon system, but can select and engage targets without further human input after activation."

- ***Human-supervised autonomous weapon system:*** "An autonomous weapon system that is designed to provide human operators with the ability to intervene and terminate engagements, including in the event of a weapon system failure, before unacceptable levels of damage occur."[122]

- ***Semi-autonomous system:*** "A weapon system that, once activated, is intended to only engage specific targets or specific target groups that have been selected by the human operator." The document specifies fire-and-forget homing munitions such as guided air-to-air missiles as examples.

"Semi-autonomous weapon systems that employ autonomy for engagement-related functions including, but not limited to, acquiring, tracking, and identifying potential targets; cueing potential targets to human operators; prioritizing selected targets; timing of when to fire; or providing terminal guidance to home in on selected targets, provided that human control is retained over the decision to select individual targets and specific target groups for engagement.

"'Fire and forget' or lock-on-after-launch homing munitions that rely on TTPs to maximize the probability that the only targets within the seeker's acquisition basket when the seeker activates are those individual targets or specific target groups that have been selected by a human operator."

Endnotes

[1] U.S. Department of Defense, *Summary of the 2018 Department of Defense Artificial Intelligence Strategy: Harnessing AI to Advance Our Security and Prosperity* (Washington, DC: Department of Defense, 2018), https://media.defense.gov/2019/Feb/12/2002088963/-1/-1/1/SUMMARY-OF-DOD-AI-STRATEGY.PDF.

[2] Some of the recommendations in this report were also articulated in a report published jointly by the Bipartisan Policy Center and CSET. See Bipartisan Policy Center and the Center for Security and Emerging Technology, *Artificial Intelligence and National Security*, (Washington, DC: BPC, CSET, June 2020), https://bipartisanpolicy.org/wp-content/uploads/2020/07/BPC-Artificial-Intelligence-and-National-Security_Brief-Final-1.pdf.

[3] Congressional Research Service, *Defining Readiness: Background and Issues for Congress* (Washington, DC: CRS, June 2017), https://fas.org/sgp/crs/natsec/R44867.pdf.

[4] United States Department of Defense, *Summary of the 2018 National Defense Strategy of the United States of America* (Washington, DC: Department of Defense, 2018), https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

[5] Office of the Under Secretary of Defense (Comptroller), *Defense Budget Overview: United States Department of Defense Fiscal Year 2021 Budget Request* (Washington, DC: Department of Defense, February 2020), 1–8, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/fy2021_Budget_Request_Overview_Book.pdf; The FY 2020 U.S. defense budget allocated $3.7 billion to unmanned and autonomous systems that will enhance "freedom of maneuver and lethality in contested environments through development of offensive-armed Unmanned Surface Vessel, Unmanned Undersea Vehicle, and Autonomous Logistics Platforms," and $927 million for AI and machine learning projects through the Joint Artificial Intelligence Center (JAIC) and Advanced Image Recognition (Project Maven).

[6] U.S. Department of Defense, *Summary of the 2018 Department of Defense Artificial Intelligence Strategy.*

[7] Mark T. Esper and Katharina McFarland, "Remarks by Secretary Esper at National Security Commission on Artificial Intelligence Public Conference," *U.S. Department of Defense Transcript*, November 5, 2019, https://www.defense.gov/Newsroom/Transcripts/Transcript/Article/2011960/remarks-by-secretary-esper-at-national-security-commission-on-artificial-intell/.

[8] According to Paul Scharre, "Autonomous systems pose both an opportunity and a challenge for warfighters. Militaries who harness their advantages will be able to field forces with greater range, persistence, mass, coordination, and speed on the battlefield." See Andrew P. Williams and Paul D. Scharre, eds. *Autonomous Systems: Issues for Defence Policymakers* (Norfolk, VA: NATO, 2015), 3, https://www.act.nato.int/images/stories/media/capdev/capdev_02.pdf; The SIPRI study on autonomy in weapon systems posits that "at the operational level, military planners believe that autonomy enables weapon systems to achieve greater speed, accuracy, persistence, reach and coordination on the battlefield." See Vincent Boulanin and Maaike Verbruggen, "Mapping the Development of Autonomy in Weapon Systems" (Stockholm International Peace Research Institute, November 2017), viii,

https://www.sipri.org/sites/default/files/2017-11/siprireport_mapping_the_development_of_autonomy_in_weapon_systems_1117_1.pdf; Zachary Davis' analysis of AI applications at the operational and strategic levels of war highlights factors such as speed, range, lethality, precision, and coordination. See Zachary S. Davis, "Artificial Intelligence on the Battlefield: An Initial Survey of Potential Implications for Deterrence, Stability, and Strategic Surprise" (Lawrence Livermore National Laboratory, 2019), https://cgsr.llnl.gov/content/assets/docs/CGSR-AI_BattlefieldWEB.pdf; Mass is another quality or capability which is most often referenced to swarms, See Paul Scharre, "Robotics on the Battlefield Part II: The Coming Swarm" (Center for a New American Security, October 2014), 5, https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf?mtime=20160906082059.

[9] United States Department of Defense, *Summary of the 2018 National Defense Strategy of the United States of America*, 6.

[10] Note that this conceptualization of endurance is different from those that focus on the ability of AI to perform long-duration tasks that exceed human endurance, which to us is more akin to persistence. For the latter conceptualization, see Congressional Research Service, *Artificial Intelligence and National Security* (Washington, DC: CRS updated November 2019), 27–28, https://fas.org/sgp/crs/natsec/R45178.pdf.

[11] Department of Defense, *Summary of the 2018 National Defense Strategy*.

[12] Modernizing Soldier lethality is one of the Army's six modernization priorities, meant to "increase the capability of individual Soldier weapons, provide Soldiers with enhanced night vision, and increase their ability to quickly understand and react to emerging situations – increasing their lethality, precision, and survivability." U.S. Army, *Army Modernization Strategy: Investing in the Future* (Washington, DC: Department of Defense, 2019), https://caccapl.blob.core.usgovcloudapi.net/web/repository/Army-Modernization-Strategy.pdf.

[13] For instance, as Olivia Garland argues, "although lethality is deeply tied to the capacity to cause death, this does not mean tactical lethality is about killing more." Olivia Garland, "Lethality: An Inquiry," *The Strategy Bridge*, November 1, 2018, https://thestrategybridge.org/the-bridge/2018/11/1/lethality-an-inquiry; Edward Carpenter and Jessica Libertini suggest quantifying lethality as "the average of the destruction inflicted on the enemy force and the survival of the friendly force and any civilians in the engagement area." Edward H. Carpenter and Jessica M. Libertini, "Quantifying Lethality on the Back of a Napkin," *The Strategy Bridge*, July 9, 2019, https://thestrategybridge.org/the-bridge/2019/7/9/quantifying-lethality-on-the-back-of-a-napkin; Also see W.A. Rivera and Arnel P. David, "Towards a More Comprehensive Understanding of Lethality," *Small Wars Journal*, February 29, 2020, https://smallwarsjournal.com/jrnl/art/towards-more-comprehensive-understanding-lethality.

[14] Scott Padgett, "The Virtual Sixth Sense—Transforming soldier lethality through artificial intelligence and augmented reality," *Small Wars Journal*, May 2019, https://smallwarsjournal.com/jrnl/art/virtual-sixth-sense-transforming-soldier-lethality-through-artificial-intelligence.

[15] This conceptualization of endurance combines insights from the protection and sustainment warfighting functions. Department of the Army, *Protection* (Washington, DC: ADP 3–37, July 31, 2019). https://fas.org/irp/doddir/army/adp3_37.pdf; Department of the Army, *Sustainment* (Washington, DC: ADP 4–0, July 31, 2019), https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN18450_ADP%204-0%20FINAL%20WEB.pdf.

[16] U.S. Army, *Robotic and Autonomous Systems Strategy* (Fort Eustis, VA: U.S. Army Training and Doctrine Command, March 2017), https://www.tradoc.army.mil/Portals/14/Documents/RAS_Strategy.pdf.

[17] S.M. Amadae, Shahar Avin, John Borrie, Vincent Boulanin, Justin Bronk, Martin Hagström, Michael C. Horowitz, Anja Kaspersen, Chris King, Jean-Marc Rickli, Frank Sauer, Dimitri Scheftelowitsch, Page O. Stoutland, and Petr Topychkanov, "The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk" (SIPRI, May 2019), https://www.sipri.org/sites/default/files/2019-05/sipri1905-ai-strategic-stability-nuclear-risk.pdf.

[18] The distinction between enterprise and operational AI is derived from the 2019 RAND report on DOD's AI posture. See Danielle C. Tarraf, William Shelton, Edward Parker, Brien Alkire, Diana Gehlhaus Carew, Justin Grana, Alexis Levedahl, Jasmin Leveille, Jared Mondschein, James Ryseff, Ali Wyne, Dan Elinoff, Edward Geist, Benjamin N. Harris, Eric Hui, Cedric Kenney, Sydne Newberry, Chandler Sachs, Peter Schirmer, Daniel Schlang, Victoria M. Smith, Abbie Tingstad, Padmaja Vedula, and Kristin Warren, *The Department of Defense Posture for Artificial Intelligence: Assessment and Recommendations* (Santa Monica, CA: RAND, 2019), xii, http://www.rand.org/pubs/research_reports/RR4229.html.

[19] Michael J. Mazarr, "Understanding Deterrence" (RAND Corporation, 2018), https://www.rand.org/content/dam/rand/pubs/perspectives/PE200/PE295/RAND_PE295.pdf.

[20] Vincent Boulainin (editor), "The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk" (Stockholm International Peace Research Institute, May 2019), 82, https://www.sipri.org/sites/default/files/2019-05/sipri1905-ai-strategic-stability-nuclear-risk.pdf.

[21] United States Department of the Air Force, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Air Force, Justification Book Volume 1 of 3, Research, Development, Test & Evaluation, Air Force, Vol–I* (Washington, DC: Department of Defense, 2019), vol 1–11, https://www.saffm.hq.af.mil/Portals/84/documents/FY20/RDTE/FY20_PB_RDTE_Vol-I.PDF?ver=2019-03-18-153506-463.

[22] United States Department of the Navy, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Navy, Justification Book Volume 1 of 5, Research, Development, Test & Evaluation, Navy Budget Activities 1, 2, and 3* (Washington, DC: Department of Defense, 2019), vol 1–128, https://www.secnav.navy.mil/fmc/fmb/Documents/20pres/RDTEN_BA1-3_BOOK.pdf.

[23] Michael C. Horowitz, "When speed kills: Lethal autonomous weapon systems, deterrence and stability," *Journal of Strategic Studies* 42, no. 6 (August 2019): 764–788.

[24] Boulanin and Verbruggen, "Mapping the Development of Autonomy in Unmanned Systems," 24, 26.

[25] Rebecca Hersman and Bernadette Stadler, "Situational Awareness and Strategic Stability" (Center for Strategic and International Studies, July 2019); Horowitz, "When speed kills."

[26] Jonathan Gates, "Is the SSBN Deterrent Vulnerable to Autonomous Drones?," *RUSI* 161, no. 6 (December 2016): 28–35, https://www.tandfonline.com/doi/abs/10.1080/03071847.2016.1265834; Sylvia Mishra, "Could unmanned underwater vehicles undermine nuclear deterrence?," *Australian Strategic Policy Institute,* May 8, 2019, https://www.aspistrategist.org.au/could-unmanned-underwater-vehicles-undermine-nuclear-deterrence/.

[27] Bradley Martin, Danielle C. Tarraf, Thomas C. Whitmore, Jacob DeWeese, Cedric Kenney, Jon Schmid, and Paul DeLuca, *Advancing Autonomous Systems: An Analysis of Current and Future Technology for Unmanned Maritime Vehicles* (Santa Monica, CA: RAND, 2019), 20, https://www.rand.org/content/dam/rand/pubs/research_reports/RR2700/RR2751/RAND_RR2751.pdf.

[28] Michael C. Horowitz, Paul Scharre, and Alexander Velez-Green, "A Stable Nuclear Future? The Impact of Autonomous Systems and Artificial Intelligence," Arxiv, December 2019, https://arxiv.org/pdf/1912.05291.pdf.

[29] United States Department of the Navy, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Navy, Justification Book Volume 1 of 5,* vol 1–259.

[30] Paul Scharre and Michael Horowitz, "An Introduction to Autonomy in Weapon Systems" (Center for a New American Security, February 2015), https://s3.amazonaws.com/files.cnas.org/documents/Ethical-Autonomy-Working-Paper_021015_v02.pdf?mtime=20160906082257.

[31] Wong, Yuna Huh, John M. Yurchak, Robert W. Button, Aaron Frank, Burgess Laird, Osonde A. Osoba, Randall Steeb, Benjamin N. Harris, and Sebastian Joon Bae, *Deterrence in the Age of Thinking Machines* (Santa Monica, CA: RAND, 2020), 52, https://www.rand.org/pubs/research_reports/RR2797.html.

[32] Berkeley J. Dietvorst, Joseph P. Simmons, and Cade Massey, "Algorithm Aversion: People Erroneously Avoid Algorithms After Seeing Them Err," *Journal of Experimental Psychology: General* 144, no. 1 (2015): 114–126; Julia Macdonald and Jacquelyn Schneider, "Battlefield Responses to New Technologies: Views from the Ground on Unmanned Aircraft," *Security Studies* 28, no. 2 (February, 2019): 216–249.; John K. Hawley, "Patriot Wars: Automation and the Patriot Air and Missile Defense System" (Center for a New American Security, January 25, 2017), https://www.cnas.org/publications/reports/patriot-wars.

[33] Keir Lieber and Daryl Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," *International Security* 41, no. 4 (April 25, 2017): 9–49.; Li Xiang, "Artificial intelligence and its impact on weaponization and arms control," in *The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk: East Asian Perspectives* (Sweden: Stockholm International Peace Research Institute, October 2019).

[34] Andrew Imbrie, Ryan Fedasiuk, Catherine Aiken, Tarun Chhabra, and Husanjot Chahal, "Agile Alliances: How the United States and its Allies can Deliver a Democratic Way of AI" (Center for Security and Emerging Technology, February 2020), https://cset.georgetown.edu/wp-content/uploads/CSET-Agile-Alliances.pdf.

[35] U.S. Joint Operations, *Joint Operations Doctrine* (Washington, DC: Joint Operations, 2017), I–2, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_0ch1.pdf?ver=2018-11-27-160457-910.

[36] Department of Defense, *Summary of the 2018 Department of Defense Artificial Intelligence Strategy*, 15–16.

[37] Larry Lewis, "Redefining Human Control: Lessons From the Battlefield for Autonomous Weapons" (Center for Naval Analyses, March 2018), 7, https://www.cna.org/CNA_files/PDF/DOP-2018-U-017258-Final.pdf.
[38] Johan Schubert, Joel Brynielsson, Mattias Nilsson, and Peter Svenmarck, "Artificial Intelligence for Decision Support in Command and Control Systems" (Stockholm: Swedish Defense Research Agency, 2018), https://www.foi.se/download/18.41db20b3168815026e010/1548412090368/Artificial-intelligence-decision_FOI-S--5904--SE.pdf.
[39] Theresa Hitchens, "Air Force Expands 5G As It Transforms to Multi-Domain Ops: Donovan," *Breaking Defense*, September 4, 2019, https://breakingdefense.com/2019/09/air-force-expands-5g-as-it-transforms-to-multi-domain-ops-donovan/.
[40] Mick Ryan, "Human-Machine Teaming for Future Ground Forces" (Washington, DC: Center for Strategic and Budgetary Assessments, 2018), 11, https://csbaonline.org/uploads/documents/Human_Machine_Teaming_FinalFormat.pdf.
[41] United States Department of the Navy, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Navy, Justification Book Volume 1 of 5,*vol. 1–31.
[42] United States Department of the Air Force, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Air Force, Justification Book Volume 1 of 3,* vol. 1–67.
[43] Lewis, "Redefining Human Control," iii.
[44] Convention on Certain Conventional Weapons, *Humanitarian Benefits of Emerging Technologies in the Area of Lethal Autonomous Weapon Systems* (Geneva: CCW, March 2018), https://unog.ch/80256EDD006B8954/(httpAssets)/7C177AE5BC10B588C125825F004B06BE/$file/CCW_GGE.1_2018_WP.4.pdf.
[45] Quote from Section 1 of Executive Order 13732, United States Policy on Pre- and Post-Strike Measures To Address Civilian Casualties in U.S. Operations Involving the Use of Force, of July 1, 2016. See Department of Defense, *Annual Report on Civilian Causalities in Connection with United States Military Operations* (Department of Defense, 2018), 3, https://media.defense.gov/2019/May/02/2002126767/-1/-1/1/ANNUAL-REPORT-CIVILIAN-CASUALTIES-IN-CONNECTION-WITH-US-MILITARY-OPERATIONS.PDF.
[46] Davis, "Artificial Intelligence on the Battlefield," 6–7.
[47] United States Department of Defense, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Defense Advanced Research Projects Agency, Defense-Wide Justification Book Volume 1 of 5, Research, Development, Test & Evaluation, Defense-Wide* (Washington, DC: Department of Defense, 2019), vol 1–102, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2020/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol1_DARPA_MasterJustificationBook_PB_2020.pdf.
[48] United States Department of Defense, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Defense Advanced Research Projects Agency, Defense-Wide Justification Book Volume 1 of 5,* vol. 1–236.

[49] U.S. Army Center for Army Lessons Learned, "The Modern Warrior's Combat Load," Task Force Devil, April-May 2003, 89, http://thedonovan.com/archives/modernwarriorload/ModernWarriorsCombatLoadReport.pdf; Ellen Haring, "Marine's requirements for infantry officers are unrealistic, Army colonel says," *Marine Corps Times*, October 15, 2016, https://www.marinecorpstimes.com/opinion/2016/10/15/marines-requirements-for-infantry-officers-are-unrealistic-army-colonel-says/.
[50] Andrew Feickert, Jennifer K. Elsea, Lawrence Kapp, and Laurie A. Harris, *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress*, CRS Report No. R45392 (Washington, DC: CRS, 2018), https://crsreports.congress.gov/product/pdf/R/R45392; Ryan, "Human-Machine Teaming."
[51] United States Department of Defense, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Defense Advanced Research Projects Agency, Defense-Wide Justification Book Volume 1 of 5,* vol. 1–53.
[52] Padgett, "The Virtual Sixth Sense."
[53] United States Department of the Air Force, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Air Force, Justification Book Volume 1 of 3*, vo. 1–63.
[54] Michael Horowitz, Paul Scharre, Gregory C. Allen, Kara Frederick, Anthony Cho, and Edoardo Saravalle, "Artificial Intelligence and National Security" (Center for a New American Security, July 2018), 10, https://www.cnas.org/publications/reports/artificial-intelligence-and-international-security.
[55] United States Department of the Army, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Army, Justification Book of Research, Development, Test & Evaluation, Army RDT&E – Volume I, Budget Activity 2* (Washington, DC: Department of Defense, 2019), 501, https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2020/Base%20Budget/rdte/02%20RDTE%20-%20Vol%201%20-%20Budget%20Activity%202.pdf.
[56] Feickert, et al., *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI),* 9.
[57] United States Department of Defense, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Defense Advanced Research Projects Agency, Defense-Wide Justification Book Volume 1 of 5,* vol 1–100.
[58] Congressional Research Service, *Artificial Intelligence and National Security*; Sydney J. Freedberg Jr., "AI Logistics Let Combat Units Move Faster: Uptake's DIUX Contract," *Breaking Defense*, June 27, 2018, https://breakingdefense.com/2018/06/ai-logistics-can-speed-up-army-tanks-uptakes-diux-contract/.
[59] United States Department of the Army, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Army, Justification Book of Research, Development, Test & Evaluation, Army RDT&E – Volume I, Budget Activity 3* (Washington, DC: Department of Defense, 2019), 276–329, https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2020/Base%20Budget/rdte/03%20RDTE%20-%20Vol%201%20-%20Budget%20Activity%202.pdf.
[60] United States Department of the Army, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Army, Justification Book of Research, Development, Test & Evaluation, Army RDT&E – Volume I, Budget Activity 3*, 90.
[61] United States Department of Defense, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Defense Advanced Research Projects Agency, Defense-Wide Justification Book Volume 1 of 5*, vol 1–82.

[62] Berkeley J. Dietvorst, Joseph P. Simmons, and Cade Massey, "Algorithm Aversion: People Erroneously Avoid Algorithms After Seeing Them Err," *Journal of Experimental Psychology: General* 144, no. 1 (2015): 114–126; Michael C. Horowitz, Paul Scharre, and Alexander Velez-Green, "A Stable Nuclear Future? The Impact of Autonomous Systems and Artificial Intelligence," Arxiv, December 2019, https://arxiv.org/pdf/1912.05291.pdf.
[63] Julia L. Wright, Jessie Y.C. Chen, Shan G. Lakhmani, "Agent Transparency and Reliability in Human–Robot Interaction: The Influence on User Confidence and Perceived Reliability," *IEEE Transactions on Human-Machine Systems* 50, no. 3 (June 2020): 254–263, doi: 10.1109/THMS.2019.2925717.
[64] For a review of these factors, see Kate Goddard, Abdul Roudsari, and Jeremy C. Wyatt, "Automation bias: a systematic review of frequency, effect mediators, and mitigators," *Journal of the American Medical Informatics Association,* vol 19, no. 1(2012): 121–127, doi:10.1136/amiajnl-2011-000089; Ryan, "Human-Machine Teaming."
[65] M.L. Cummings, "Automation Bias in Intelligent Time Critical Decision Support Systems" (American Institute of Aeronautics and Astronautics, July 2012), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=073721BD8AA0FA360C632E4265F27507?doi=10.1.1.91.2634&rep=rep1&type=pdf; Kimberly F. Jackson, Zahar Prasov, Emily C. Vincent, and Eric M. Jones, "A Heuristic Based Framework for Improving Design of Unmanned Systems by Quantifying and Assessing Operator Trust" (Human Factors and Ergonomics Society, 2018), https://journals.sagepub.com/doi/pdf/10.1177/1541931213601390.
[66] Paul Scharre, *Army of None* (New York: W. W. Norton & Company, 2018), 324; Hawley, "Patriot Wars."
[67] Maj. Amos C. Fox, "Precision Fires Hindered By Urban Jungle," *Association of the United States Army*, April 16, 2018, https://www.ausa.org/articles/precision-fires-hindered-urban-jungle.
[68] Margarita Konaev, *The Future of Urban Warfare in the Age of Megacities*, Focus stratégique, No. 88, (Paris: Ifri, 2019), https://www.ifri.org/sites/default/files/atoms/files/konaev_urban_warfare_megacities_2019.pdf.
[69] Defense Innovation Board, *AI Principles: Recommendations on the Ethical Use of Artificial Intelligence by the Department of Defense, Supporting Document* (Washington, DC: October 2019), 36–37, https://media.defense.gov/2019/Oct/31/2002204459/-1/-1/0/DIB_AI_PRINCIPLES_SUPPORTING_DOCUMENT.PDF.
[70] Defense Innovation Board, *AI Principles, Supporting Document,* 36–37.
[71] Ryan, "Human-Machine Teaming."
[72] Shawn McKay et al., *Automating Army Convoys: Technical and Tactical Risks and Opportunities* (Santa Monica, CA: RAND, 2020), https://www.rand.org/pubs/research_reports/RR2406.html.
[73] Tarraf et al., *The Department of Defense Posture for Artificial Intelligence.*
[74] Tarraf et al., *The Department of Defense Posture for Artificial Intelligence*, xiii.
[75] Karan Sachdeva, "3 Principles to move from AI Pilots to AI @ Scale," *IBM Big Data & Analytics Hub Blog*, August 14, 2019, https://www.ibmbigdatahub.com/blog/3-principles-move-ai-pilots-ai-scale; Michael Horowitz and Casey Mahoney, "Artificial Intelligence and the Military: Technology is only half the battle," *War On The Rocks*, December 25, 2018, https://warontherocks.com/2018/12/artificial-intelligence-and-the-military-technology-is-only-half-the-battle/;

Lt. Gen. John N.T. "Jack" Shanahan, Media Briefing on A.I.-Related Initiatives within the Department of Defense, August 30, 2019, https://www.defense.gov/Newsroom/Transcripts/Transcript/Article/1949362/lt-gen-jack-shanahan-media-briefing-on-ai-related-initiatives-within-the-depart/.

[76] Martin Dufour, "Will artificial intelligence challenge NATO interoperability?," *NATO Defense College Policy Brief*, No. 6, December 2018, http://www.ndc.nato.int/news/news.php?icode=1239.

[77] Interoperability is generally defined as the "ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together." Myron Hura et al., *Interoperability: A Continuing Challenge in Coalition Air Operations* (Santa Monica, CA: RAND, 2000), 7–8, https://www.rand.org/pubs/monograph_reports/MR1235.html.

[78] Hura et al., *Interoperability*.

[79] David K. Spencer, Stephen Duncan, and Adam Taliaferro, "Operationalizing artificial intelligence for multi-domain operations: a first look," *Proc. SPIE 11006, Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications*, 1100602 (May 10, 2019), https://doi.org/10.1117/12.2524227; Alun Preece et al., "Explainable AI for Intelligence Augmentation in Multi-Domain Operations," Presented at AAAI FSS-19: Artificial Intelligence in Government and Public Sector, November 7, 2019, Arlington, VA, https://arxiv.org/pdf/1910.07563.pdf.

[80] United States Department of Defense, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Defense Advanced Research Projects Agency, Defense-Wide Justification Book Volume 1 of 5,* vol 1–195.

[81] United States Department of the Army, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Army, Justification Book of Research, Development, Test & Evaluation, Army RDT&E – Volume 1, Budget Activity 1* (Washington, DC: Department of Defense, 2019), 68, https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2020/Base%20Budget/rdte/01%20RDTE%20-%20Vol%201%20-%20Budget%20Activity%201.pdf

[82] United States Department of the Army, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Army, Justification Book of Research, Development, Test & Evaluation, Army RDT&E – Volume 1, Budget Activity 1*, 68.

[83] Stephan De Spiegeleire, Matthijs Maas, and Tim Sweijs, "Artificial Intelligence and the Future of Defence" (*The Hague* Centre for Strategic Studies, 2017), 106, https://hcss.nl/report/artificial-intelligence-and-future-defense.

[84] For more on European military approaches to AI, see Ulrike Esther Franke, "Not smart enough: The poverty of European military thinking on artificial intelligence," *European Council on Foreign Relations*, December 19, 2019, https://www.ecfr.eu/publications/summary/not_smart_enough_poverty_european_military_thinking_artificial_intelligence; Ulrike Franke & Paola Sartori, "Machine politics: Europe and the AI revolution," *European Council on Foreign Relations*, July 11, 2019, https://www.ecfr.eu/publications/summary/machine_politics_europe_and_the_ai_revolution.

[85] UK Government, *Autonomy Programme* (Defence Science and Technology Laboratory, January 2018), https://www.gov.uk/guidance/autonomy-programme.

[86] "UK Commits £66m Funding to Boost Military Robotics Projects," *Army Technology,* March 6, 2019, https://www.army-technology.com/news/uk-funding-military-robotic-projects/.

[87] Ministère des Armées, *Artificial Intelligence in Support of Defence, Report of the AI Task Force, September 2019* (Paris: Ministère des Armées, 2019), 14.
[88] German Army Concepts and Capabilities Development Centre, *Artificial Intelligence in Land Forces* (Cologne: Federal Ministry of Defense, 2019), https://www.bundeswehr.de/resource/blob/156026/3f03afe6a20c35d07b0ff56aa8d04878/download-positionspapier-englische-version-data.pdf.
[89] Kelsey D. Atherton, "Estonian war robots could have big implications for future NATO plans," *C4ISRNET*, August 3, 2018, https://www.c4isrnet.com/unmanned/2018/08/03/estonian-war-robots-could-have-big-implications-for-future-nato-plans/.
[90] NATO, *Artificial Intelligence: Implications for NATO's Armed Forces* (Slovenia: Science and Technology Committee, October 2019), https://www.nato-pa.int/download-file?filename=sites/default/files/2019-10/REPORT%20149%20STCTTS%2019%20E%20rev.%201%20fin-%20ARTIFICIAL%20INTELLIGENCE.pdf.
[91] Department of Defense, *Summary of the 2018 National Defense Strategy*, 8.
[92] National Security Commission on Artificial Intelligence, *Interim Report* (Washington, DC: November 2019), 45–46. https://www.nscai.gov/reports
[93] Erik Lin-Greenberg, "Allies and Artificial Intelligence: Obstacles to Operations and Decision-Making," *Texas National Security Review* 3, no. 2 (Spring 2020), https://tnsr.org/2020/03/allies-and-artificial-intelligence-obstacles-to-operations-and-decision-making/.
[94] Hura et al., *Interoperability*.
[95] "Entrepreneurialism: The Emergence of Social Entrepreneurialism to Compete with Business Entrepreneurialism," Ipsos Global Affairs, November 2018, 40, https://www.ipsos.com/sites/default/files/ct/news/documents/2018-10/entrepreneurialism-2018-global-report.pdf. Respondents were asked whether they "agree," are "neutral", or "disagree" with the statement: "I trust artificial intelligence."
[96] Lin-Greenberg, "Allies and Artificial Intelligence."
[97] Imbrie, et al. "Agile Alliances," 23–24
[98] Gregory B. Poling, "The Conventional Wisdom on China's Island Bases is Dangerously Wrong," *War on the Rocks*, January 10, 2020, https://warontherocks.com/2020/01/the-conventional-wisdom-on-chinas-island-bases-is-dangerously-wrong/; "A Constructive Year for Chinese Base Building," *CSIS Asia Maritime Transparency Initiative*, December 14, 2017, https://amti.csis.org/constructive-year-chinese-building/; Alexander Neill and Meia Nouwens, "China's Radar Installations in the Spratly Islands—What Do They Tell Us About its Ambitions for the South China Sea?" *International Institute for Strategic Studies*, February 19, 2018, https://www.iiss.org/blogs/analysis/2018/02/china-radar.
[99] The term first island chain refers to a string of islands, including Japan and the Philippines, that encloses China's near-seas region. The term second island chain, which reaches out to Guam, refers to a line that can be drawn that encloses both China's near-seas region and the Philippine Sea between the Philippines and Guam.
[100]Martin et al, *Advancing Autonomous Systems.*
[101] United States Department of the Navy, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Navy, Justification Book Volume 1 of 5,* vol 1–202.
[102] United States Department of the Navy, *Fiscal Year (FY) 2020 Budget Estimates, March 2019, Navy, Justification Book Volume 1 of 5*, vol. 1–244

[103] Scott Savitz, Irv Blickstein, Peter Buryk, Robert W. Button, Paul DeLuca, James Dryden, Jason Mastbaum, Jan Osburg, Phillip Padilla, Amy Potter, Carter C. Price, Lloyd Thrall, Susan K. Woodward, Roland J. Yardley, and John M. Yurchak, *U.S. Navy Employment Options for Unmanned Surface Vehicles (USVs)* (RAND Corporation, 2013), https://www.rand.org/content/dam/rand/pubs/research_reports/RR300/RR384/RAND_RR384.pdf.
[104] Nathan Leys, "Autonomous Weapon Systems and International Crises," *Strategic Studies Quarterly* 12, no. 1 (Spring 2018): 62. https://www.jstor.org/stable/pdf/26333877.pdf?refreqid=excelsior%3A7e0c8aff2a7a8f44399b542606c61698.
[105] Jessica Cussins Newman, "Toward AI Security Global Aspirations for a More Resilient Future" (Center for Long-Term Cybersecurity, February 2019), https://cltc.berkeley.edu/wp-content/uploads/2019/02/CLTC_Cussins_Toward_AI_Security.pdf.
[106] Daniel Egel, Howard J. Shatz, Krishna, B. Kumar, and Ted Harshberger, "Defense Budget Implications of the COVID-19 Pandemic," *Real Clear Defense*, April 7, 2020, https://www.realcleardefense.com/articles/2020/04/07/defense_budget_implications_of_the_covid-19_pandemic_115178.html.
[107] Department of Defense, *Summary of the 2018 Department of Defense Artificial Intelligence Strategy*, 5.
[108] Defense Science Board, "Summer Study on Autonomy," 4.
[109] Defense Innovation Board, *AI Principles*, 5.
[110] John Launchbury, A DARPA Perspective on Artificial Intelligence, DARPA, https://www.darpa.mil/attachments/AIFull.pdf.
[111] John S. McCain National Defense Authorization Act for Fiscal Year 2019, H.R. 5515, 115th Congress, (2018).
[112] National Security Commission on Artificial Intelligence, *Interim Report*, 7.
[113] Office of Technical Intelligence, *Technical Assessment: Autonomy,* Department of Defense (Washington, DC: February 2015), 1, https://defenseinnovationmarketplace.dtic.mil/wp-content/uploads/2018/02/OTI_TechnicalAssessment-AutonomyPublicRelease_vF.pdf.
[114] Kris Kearns, *DOD Autonomy Roadmap*, Department of Defense (Austin, TX: March 21, 2018), 4,https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2018/science/Kearns.pdf.
[115] Sandeep Neema, "Assured Autonomy," DARPA, https://www.darpa.mil/program/assured-autonomy.
[116] Defense Innovation Board, *AI Principles*, 5.
[117] Defense Science Board, "The Roles of Autonomy in DOD Systems" (Washington, DC: July 2012), 1, https://fas.org/irp/agency/dod/dsb/autonomy.pdf.
[118] Defense Science Board, "Summer Study on Autonomy," 4.
[119] Boulanin and Vergruggen, "Mapping the Development of Autonomy in Weapon Systems," 5.
[120] Department of Defense, *DOD Dictionary of Military and Associated Terms*, last updated January 2020, 230, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/dictionary.pdf.
[121] Undersecretary for Defense (Policy), *Autonomy in Weapon Systems*, DOD 3000.09, November 21, 2012, https://www.hsdl.org/?view&did=726163.

[122] DODD 3000.09 specifically indicates that it does not cover "autonomous or semi-autonomous cyberspace systems for cyberspace operations; unarmed, unmanned platforms; unguided munitions; munitions manually guided by the operator (e.g., laser- or wire-guided munitions); mines; [or] unexploded explosive ordnance."