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Robotics and Autonomous Systems

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ROBOTICS AND AUTONOMOUS SYSTEMS 2017

ABSTRACT: The Robotics and Autonomous Systems (RAS) Industry has seen ever-increasing relevance and importance in its applications both within the Department of Defense (DOD) and throughout society. Enhancing human productivity in activities ranging from self-driving automobiles to unmanned aircraft that can deliver weapons without requiring human control or consent, the development and advancement of these technologies have the potential to alter daily life as we know it. These emerging capabilities provide ample opportunity for the DOD to influence and leverage these capabilities to support national security strategies. This paper will examine the industry, current and future RAS applications as they relate to increased human productivity, and the implications these advancements have on our way of life. It will then provide recommendations on what the DOD can do to better position itself to capitalize on RAS growth and prevent missteps.

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Human Engineering Robotics Lab, Pittsburgh, PA
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> "*We stand on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before. We do not yet know just how it will unfold, but one thing is clear: the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society.*" [1]

> *"…an entirely new war-fighting regime in which unmanned and autonomous systems play central roles for the United States, its allies and partners, and its adversaries. U.S. defense leaders should begin to prepare now for this not so distant future – for war in the Robotic Age."*[2]

INTRODUCTION

A vital aspect of maintaining the United States' (U.S.) technological superiority in the area of national security is leveraging and optimizing the most advanced systems available to the Department of Defense (DOD). In order to do so, the DOD has relied upon industry to produce technological dominance, affordability, and capacity.[3] Further, continued technological improvement has been a bedrock economic principle for growing the U.S. economy and improving its citizens' standard of living.[4] In the past decade, the trend in many of these systems has been to further distance the operator from the battlespace either physically, cognitively, or both, through the collective capabilities of robotics and autonomous systems (RAS). Similarly, many civilian industries have witnessed the introduction of robotics, including systems with some degree of autonomous capability, into some aspect of their operations.

RAS are becoming indispensable for human productivity in two specific aspects. First, the ability to teleoperate in "real-time" to accomplish tasks which are dull, dirty or dangerous; and second, to accomplish tasks with greater speed or precision than humans are capable. The impact of these two aspects of robotics on human productivity is most easily seen through their influence on time – either "expanding" our productive potential by allowing humans to shed simple tasks to concentrate on others, such as with self-driving vehicles; or through time "compression" whereby the system can operate and make autonomous decisions exponentially quicker than humans are capable.

Nevertheless, increasing reliance on these capabilities does not come without a cost. As this paper will demonstrate, the complexities of these machines are mirrored by the difficult issues that arise in their use. Robots are beginning to replace human workers around the world with impacts being felt in labor markets. Additionally, issues have surfaced regarding our ability to trust in these systems or, more specifically, the software that controls them. It is one thing to have a human-piloted jet release weapons against the enemy; it's another to allow an armed drone to decide whom to attack without human involvement. This uneasiness is only amplified with the near-constant threat of cyber intrusions into "impenetrable" computer systems such as the Office of Personnel Management,[5] Yahoo, and JP Morgan Chase.[6] Finally, there appears to be little consensus on the direction within the RAS enterprise to include standardized terminology, legal norms and regulatory frameworks, or outcomes desired by the U.S. military and civilian communities.

This paper delivers an analysis of the RAS industry, provide examples of how these systems increase human productivity through the ability to teleoperate or gain a “time advantage,” present several issues for consideration, and deliver recommendations on how the U.S. Government in general, and the DOD specifically, can best leverage these systems. This paper also offers several definitions to provide a common frame of reference and enable a broader community to contribute to the discussion on the current and future use of RAS.

Definitions

For the purposes of this paper:

A ***robot*** is a “powered machine capable of executing a set of actions by direct human control, computer control, or a combination of both. It comprises a platform system, software, and a power source,”[7] capable of sensing, deciding, and acting. Robots have military (such as unmanned aerial, maritime, and ground platforms), industrial (such as heavy manufacturing platforms), commercial (such as medical, service, and agricultural platforms), and personal (entertainment, cleaning, education and security platforms) applications.

*“**Artificial Intelligence*** (AI) is conventionally, if loosely, defined as intelligence exhibited by machines. Operationally, it can be defined as those areas of [research and development] R&D practiced by computer scientists who identify with one or more of the following academic sub-disciplines: Computer Vision, Natural Language Processing (NLP), Robotics (including Human-Robot Interactions), Search and Planning, Multi-agent Systems, Social Media Analysis (including Crowdsourcing), and Knowledge Representation and Reasoning (KRR). The field of Machine Learning (ML) is a foundational basis for AI.”[8]

Autonomy can be defined as the ability of a machine to carry out a task for which it was not originally trained or programmed.[9] Autonomy is based in large part on artificial intelligence. Multiple frameworks exist to classify levels of autonomy; however, there is no single, accepted U.S. Government framework to classify autonomy levels. Figure 1 represents a basis for discussing the levels of increasing autonomy in robotics and computer systems.

Automation exists on the spectrum of autonomy and refers to the level of human input required by a system to execute a given task in a given environment.[10] The primary distinction (for the purposes of this paper) between automation and autonomy is that autonomy enables a machine to carry out a task for which it was not pre-programmed, whereas automation enables a machine to carry out a task (regardless of complexity) for which it was pre-programmed.

DoD Four Levels of Autonomy

Level	Name	Description
1	Human Operated	**A human operator makes all decisions**. The system has no autonomous control of its environment although it may have information-only responses to sensed data.
2	Human Delegated	**The vehicle can perform many functions independently of human control when delegated to do so**. This level encompasses automatic controls, engine controls, and other low-level automation that must be activated or deactivated by human input and must act in mutual exclusion of human operation.
3	Human Supervised	**The system can perform a wide variety of activities when given top-level permissions or direction by a human.** Both the human and the system can initiate behaviors based on sensed data, but the system can do so only if within the scope of its currently directed tasks.
4	Fully Autonomous	**The system receives goals from humans and translates them into tasks to be performed without human interaction**. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs.

DoD Unmanned Systems Integrated Roadmap FY2011-2036

Figure 1. DOD Four Levels of Autonomy[11]

INDUSTRY DYNAMICS

RAS do not constitute an industry unto themselves. Rather, there is a range of military, industrial, commercial, and personal robotics firms that compete both in robotics-specific markets and within traditional markets, such as aerospace or manufacturing. Similarly, no independent autonomy or artificial intelligence industry exists. Many firms investing in artificial intelligence research and development do so to support their core business and improve their competitiveness within their specific market. There is neither a North American Industry Classification System (NAICS) code for robotics and autonomy[12], nor are robotics and autonomy a defined sector in the Standard & Poor's (S&P) classification system.[13]

To understand the U.S. and global RAS industry, it is helpful to analyze where firms compete directly with one another and where they are participants in specialized portfolios or markets. For example, manufacturers of unmanned aerial vehicles do not directly compete with manufacturers of robotic surgical equipment. Unmanned aerial vehicles manufacturers do compete with one another and with manufacturers of manned aircraft. Accordingly, RAS stakeholders can apply frameworks, such as the Porter's Five Forces Model, to analyze the overall industry and firms within it. The Porter's Five Forces Model considers the bargaining power of suppliers, the bargaining power of buyers, the threat of new entrants, the threat of substitutes, and the extent of rivalry within the industry.[14]

Taking a holistic look at the global robotics market also provides useful insights from a different perspective into the trajectory of major RAS firms. For example, in 2011 industrial robots accounted for 84% of the market value for global robots, dominated by four major industrial robotics firms: ABB Robotics (Swedish-Swiss conglomerate, 5.3% market share); Yaskawa Electric Corporation (Japan, 4.4%); FANUC Ltd (Japan, 4.2%); and Kuka Industrial Robots (Germany, 3.2%). Since then, the field has expanded dramatically and is on the verge of exponential growth due to a confluence of factors. One industry analyst projects the market for mobile civilian and military robotics will exceed $14B by 2019.[15] Five of the more important factors are:

- The DOD has employed thousands of unmanned aerial, maritime, and ground vehicles in operations over the past 15 years, creating a strong demand signal. Recognizing that use and technology's trajectory, former Secretary of Defense Ashton Carter initiated efforts in 2016 to leverage advances in technology, such as human-machine collaboration and assisted human operations, in search of a Third Offset Strategy which, when developed, would initiate a new era of strategic advantage.[16]

- Semiconductors, which provide the processing power and connectivity underlying robotics and autonomy, have decreased in size and increased in computing power so it is now possible to make more capable robots that are small and increasingly affordable. Multiple firms have embarked on producing seven-nanometer chips – the next advance in decreased size and increased processing power in microchips – which could enable more extensive use of artificial intelligence and autonomy.[17]

- Standardizing programming languages, hardware interfaces, and safety is creating common requirements against which industry can produce. Programming languages for robots have moved toward standardization, with Robot Operating System, an open-source and market standard, increasingly using only about ten languages out of thousands.[18] Multiple firms with which this industry study met noted the common use of end effector interfaces for robotic systems, which provides a standard to which other firms can invest and compete, confident their systems can be integrated. In 2015, the International Organization for Standardization created a technical committee to develop robotics safety standards but which exclude toys and military applications.[19]

- Demographics, specifically rapidly aging populations in Asia and Europe, are driving more companies to utilize robots to replace unavailable labor or perform precision tasks humans cannot do. Demographics are also creating a demand for robots that can care for the elderly, such as home care robots. On the other end of the spectrum, young entrants to the workforce increasingly have grown up playing highly immersive video games. These experiences have made young employees comfortable with interfacing with robotic systems and high-tech capabilities, creating a pull for robotics by the workforce.

- The transition to online shopping and financial transactions is happening even faster than expected, made possible by robotics, automation, improved broadband, and cyber security.[20]

The aforementioned factors will potentially increase the number of new RAS firms, increasing rivalry within the sector. However, increased competition and acceptance of RAS will be inhibited by multiple frictions. First, although many RAS technologies are cutting edge, they must operate in an environment designed to accommodate human beings. During one site visit, a company described separating tasks within their organization to optimize the capabilities of humans and machines, as robot technology could not perform tasks involving the fine motor skills at the same speed as a human employee.[21] Second, companies that can reap extraordinary efficiencies from robotics and automation, such as Amazon and Google, are purchasing robotics firms (and their associated intellectual property rights/patents) to control, and then limit the spread of, patented technologies giving their companies a competitive advantage. For example, following its 2012 purchase of Kiva Robotics, which gave Amazon command of the entire automated warehouse industry, Amazon ended the sale of Kiva's products to warehouse operators and retailers that had come to rely on them. According to an industry analysis, “It's taken four years, but a handful of startups are finally ready to replace Kiva and equip the world's warehouses with new robotics.” [22]

Trust and culture are related barriers addressing the degree to which RAS will be accepted. For example, it will take time to develop trust in robots to believe that they will perform as expected, delaying adoption; accepting an autonomous vehicle without a steering wheel may be difficult for many who have fond memories of the freedom a vehicle gave them as teenagers. Next, adoption of RAS technologies may be avoided due to the large capital expenditure often required. During a visit to a small manufacturing company, the representatives we met with indicated their size would not allow them to automate processes as the business case did not support replacing employees.[23] This may slow widespread adoption of certain technology as nearly 90 percent of companies have fewer than 20 employees, according to the Small Business and Entrepreneurship Council.[24] Lastly, the regulatory environment may delay certain technologies from widespread use, as state and federal laws limit their use.

A final and important industry consideration for RAS is how the traditional interactions between the government, academia, and the defense industrial base may be changing. The technologies associated with previous military-technical revolutions – such as stealth, guided weapons, and modern battlefield networks – were developed through government investment in basic research and development, leading to production by major defense firms, and later spinning off into commercial products. Unlike these prior military-technical advances, the commercial sector is leading many of the developments that could trigger similar break-out capabilities for RAS.[25] Reflecting this trend, despite the rising promise of AI and autonomy conveyed during this industry study’s site visits, public investments in AI have remained relatively flat as illustrated in Figure 2.

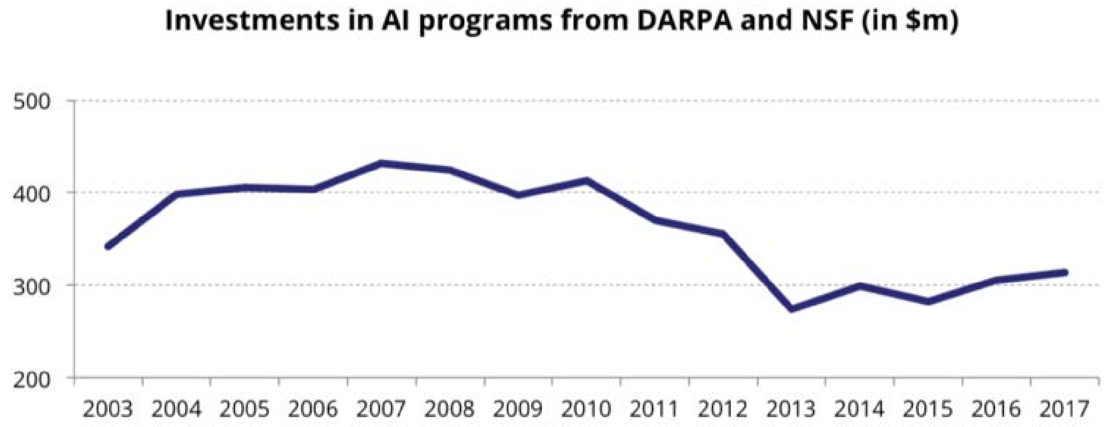

Figure 2. Investments in AI programs from DARPA and National Science Foundation[26]

The largest technology firms are investing in their own basic research, which focuses on funding in-house research labs, rather than crowding out public funding from universities. Facebook created its own AI research lab in 2013 with a leading AI expert; Google has had its own machine learning lab since 2016 and is building additional labs.[27] The results of these commercial research efforts are only likely to surface when these companies can identify a business case they can monetize, potentially leaving government behind in some areas. Nevertheless, key differences remain between commercial and military uses for AI and autonomy research, as highlighted by the Defense Science Board,

> Most commercial applications of autonomous systems are designed for operation in largely benign environments, performing well-understood, safe, and repetitive tasks, such as routing packages in a fulfillment center warehouse. Design for commercial systems rarely considers the possibility of high-regret outcomes in complex, unpredictable, and contested environments. In military operations, these can include an adversary whose goal is to neutralize the use and effectiveness of such systems, either through deception, direct force, or increased potential for collateral damage or fratricide.[28]

These emerging government-academia-industry dynamics are neither good nor bad, but highlight issues that affect government policy, regulation, and interaction with industry. Specifically, industry's leading role for many of these emerging areas changes the extent to which the government can shape industry's focus, the incentives to which industry will respond, the speed with which these emerging technologies are likely to spread within the U.S. and internationally, and the extent to which the government can control their spread (if appropriate or desired). Additionally, in the U.S. some companies may deliberately avoid providing the U.S. military access to their technologies, either due to reputational or financial risks,[29] which requires careful consideration and relationship management.

ROBOTICS AND AUTONOMOUS SYSTEMS VALUE PROPOSITION

The RAS sector has expanded rapidly as it introduces a technological advantage to a wide spectrum of industries, enabling increases in efficiency and the opening of new market segments.

RAS technologies provide the means to become more productive by removing humans from performing dull, dirty, and dangerous activities; performing tasks humans are incapable of performing; and freeing humans from routine work to perform more cognitively-advanced tasks.[30] One useful construct to illustrate the value proposition of RAS describes the impact these technologies have on productivity through the manipulation of the time available to human beings to perform routine tasks.

In addition to manipulating time, RAS' value depends on how it is substituted for humans.[31] RAS could substitute one robot for one human, such as using Explosive Ordnance Disposal (EOD) robots replacing service members one-for-one. Similarly, UAS could be made to surpass human physiological thresholds limiting the performance of manned aircraft. It could also substitute many robots for one human, such as multiple robotic crop sprayers replacing a manned crop duster. Another substitution example could be one robot for many humans, such as an industrial robot in a factory replacing numerous humans. Finally, robots could substitute for humans such as using swarm technology to overwhelm an air defense system. Swarming refers to the concept of robotic systems autonomously coordinating with one another, as well as with humans, to perform military missions.[32] The proposition is swarms could more cost-effectively, rapidly, and with lower risk to human carry out military missions presented by adversary's capabilities. Each of these substation examples has a different implication for organizational changes, resources needed to implement them, and improvements in productivity and efficiency.

This section offers a thorough discussion of this value proposition, first describing how RAS technologies enable removing humans from dull, dirty, and dangerous jobs; then discussing the DOD's use of innovation and RAS technologies; and finally explaining the time construct.

"The Three D's" - Dull, Dirty, and Dangerous

Employee demands, government regulations, and employer efforts to enhance productivity have resulted in improvements to working conditions by progressively removing humans from jobs considered dull, dirty, and dangerous. RAS technologies, including advanced robotics and artificial intelligence more able to perform human-centric activities, offer the ability to further disrupt the workplace, freeing employees from performing these activities. The DOD Unmanned Systems Integrated Roadmap, for example, explains the rationale for using these systems by illustrating how machines offer capabilities unmatched by humans: "Unmanned systems provide persistence, versatility, survivability, and reduced risk to human life, and in many cases are the preferred alternatives especially for missions that are characterized as dull, dirty, or dangerous."[33] According to the DOD:

- "Dull missions are ideal for unmanned systems because they involve long-duration undertakings with mundane tasks that are ill suited for manned systems. Good examples are surveillance missions that involve prolonged observation…
- Dirty missions have the potential to unnecessarily expose personnel to hazardous conditions. A primary example is chemical, biological, and nuclear detection missions...
- Dangerous missions involve high risk. With advances in capabilities in performance and automation, unmanned systems will reduce the risk exposure to personnel by increasingly fulfilling capabilities that are inherently dangerous."[34]

DOD's Third Offset Strategy and Technology Diffusion

The DOD has a long history of using innovation to create a strategic military advantage to support the country's national security. In 2016, former Secretary of Defense Carter initiated an effort to determine how emerging commercial RAS technologies and changes to military doctrine could produce new human-machine team constructs providing a new era of strategic advantage. The core tenets the DOD has focused its efforts in search of this Third Offset Strategy include: deep-learning systems, human-machine collaboration, human-machine combat teaming, assisted human operations, and network-enabled, cyber-hardened weapons.[35]

Central to the DOD's ability to effectively integrate RAS into the military's operating construct is the ability to ensure it can maintain sustained capability overmatch against potential adversaries. As such, the diffusion of RAS technology internationally is an important consideration – both the extent to which it diffuses to partners and allies, and the extent to which it diffuses to adversaries, thus blunting U.S. advancements. Given the prominent role of commercial firms developing military RAS, the simple demonstration of a technology is usually sufficient to prompt diffusion of some commercial innovations,[36] which is not always the case with new military technologies.

It is likely at the lower technological end of RAS, the characteristics of commercial diffusion – namely, industry advances and demonstrations – will lead nations to more easily, though not seamlessly, acquire and integrate them into their militaries. As RAS platforms become more sophisticated and military-oriented, successfully integrating RAS will require militaries to adjust their organizational constructs, change doctrine, and divert resources from more traditional capabilities. Similarly, high-end RAS diffusion requires a supply-chain for components, battle-networks, and industry to spin-out cutting edge research into military platforms,[37] a significant barrier to entry.

Although it might become easier to acquire specific technologies and use them for military purposes, that is a far cry from full integration into a national military. Such integration requires an adaptive military willing to shift its core competencies, something that is often beyond the most capable militaries. In addition, the advanced Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) capabilities needed to fully utilize these technologies might remain accessible mainly to the wealthiest states, such as the U.S., China, and Japan, but even in that case the diffusion of commercial technologies could ease these challenges.[38]

In addition to commercial diffusion and a military's willingness to undertake organizational changes and invest resources to effectively integrate RAS dynamics, several other factors are likely to directly influence the pace and extent of RAS diffusion. These factors include trust and ethical concerns; a nation's security concerns and risk preferences; real or perceived manpower or cost savings; emulating other nations' use of RAS; standardization of RAS systems; a nation's desire to build an domestic RAS industry; as well as other factors.

Real-Time Telepresence

In the early years of the Global War on Terrorism following the attacks on the U.S. in 2001, the use of EOD robots increased dramatically to combat the adversary's use of Improvised Explosive Devices (IEDs) against Allied forces. EOD robots assumed the dangerous work of disarming potentially lethal devices, removing humans from the immediate area of the bomb as they teleoperated the robots from a distance in real-time. Multiple companies have since invested in further development of this technology with some of the more well-known including SRI International and their Taurus Dexterous Robot[39], Endeavor Robotics (a spin-off of iRobot) and their widely used PackBot, and RE^2, a robotic end-effector manufacturer.[40]

Telepresence is also proving to be useful in the maritime domain. Textron, Incorporated developed a small USV, the Common Unmanned Surface Vehicle (CUSV), to conduct a variety of missions including mine countermeasures; intelligence, surveillance, and reconnaissance; and harbor security. With more than 2,000 operational hours since 2009, successful participation in several exercises with the Navy, and two additional CUSVs on order for delivery in 2018[41], these platforms should integrate fairly easily into the Navy's fleet.[42]

Additionally, telepresence is removing humans from urban danger. The Dallas Police Department's use of an EOD robot with C4 explosive attached to it to kill an armed suspect introduces novel applications for the technology. Endeavor Robotics is also interested in expanding the use of its EOD robots into law enforcement with a non-lethal Taser which would target humans in high threat environments.[43] The delivery technology is here. Robots protecting humans in real-time through telepresence in dangerous environments is a proven capability both on the battlefield and the urban landscape.

Real-time teleoperation is being utilized to save lives and money in other capacities as well. The robotics surgical equipment industry manufactures computer-controlled mechanisms to support the treatment of illness and injuries.[44] Over the past five years, doctors and hospitals began to transition from open surgeries, which require larger incisions, toward more minimally invasive surgeries — including the use of robotic equipment — which are credited with enhancing precision and reducing pain, recovery time, and the risk of infection, among other benefits.[45] Notably, managing infections costs hospitals $10 billion per year and, as a result, robotic surgery is considered a lucrative option for many hospitals.[46]

Time Expansion

Through what this paper labels the "expansion of time," RAS allow for increased productivity and efficiency by operating with a certain degree of autonomy, decreasing human workload or freeing the operator to perform other actions. By allowing the operator to accomplish multiple functions simultaneously, these autonomous systems are becoming more prolific throughout industrial and military applications.

In the maritime domain, for example, RAS conduct a number of missions on and below the surface. An unmanned surface vehicle (USV), currently in testing through 2018 and developed under a Defense Advanced Research Projects Agency (DARPA) contract, has the ability track submarines and carry different payloads to support other missions like mine sweeping operations.[47] This Anti-Submarine Warfare Continuous Train Unmanned Vessel, known as Sea Hunter, is designed to operate with a high degree of autonomy; although a human would remain in control of the vessel, manual navigation is not required.[48] One advantage of unmanned platforms is the significant difference in operational cost over traditional manned platforms. The Sea Hunter is estimated to cost $15,000 – $20,000 per sailing day compared with $700,000 for a destroyer.[49] Under the surface, Riptide Autonomous Systems developed a micro unmanned undersea vehicle (UUV) to serve as a flexible platform capable of fulfilling a number of potential missions, allowing the purchaser to determine how best to employ this capability. For example, with a range of 1,500 miles, this platform would be ideal for underwater ISR collection. Figure 3 provides an overview of DOD unmanned maritime systems by mission.

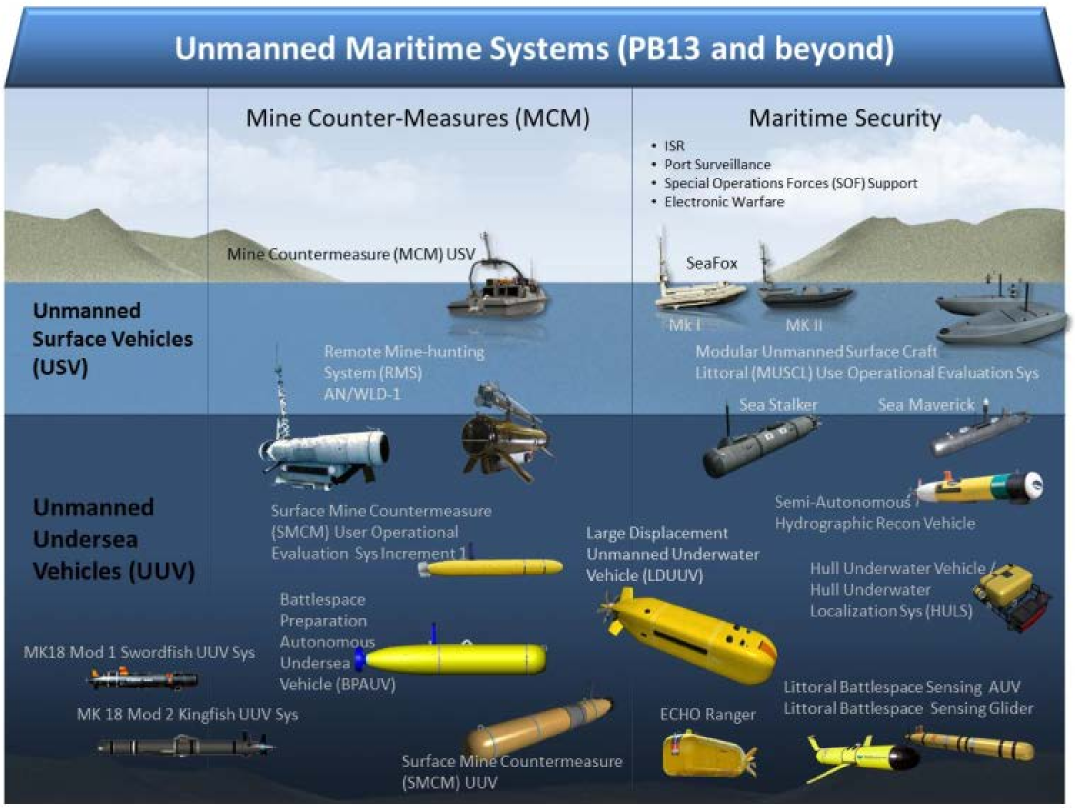

Figure 3. DOD Unmanned Maritime Systems[50]

Despite the obvious utility of unmanned maritime systems, the autonomous vehicles making the quickest technological advancements are found on land and in the air. With its successful history, Google might be assumed to be the leader in Autonomous Vehicle (AV) technology. However, a recent report by Navigant Research, a company analyzing emerging technology markets, named Ford as the leading company among 18 competitors developing AV technology.[51] This was based on several criteria including vision, strategy, partners, sales, product capability, reliability, and staying power.[52] Navigant looks not only at the technology development, but also the ability of companies to translate this technology into a product that can be sold to the masses.[53]

Ford has invested and acquired a number of companies who are experts in their field to bring the self-driving technology to the auto giant.[54] Velodyne, SAIPS, Nirenberg Neuroscience, and Civil Maps are all companies with technology Ford is leveraging in developing their AV fleet.[55] Ford CEO Mark Fields is banking on their reputation as a solid car making company to sell their AVs. Since consumers trust the Ford brand, they will believe the AVs will be as safe as they expect any Ford vehicle would be.[56]

Unlike other car companies who have a stair-step approach to introducing AV technology to the market, Ford has decided to go directly to fully autonomous vehicles operating in regular driving conditions[57] as part of a ride-hail service by 2021, although at this point it is unclear who Ford will partner with for this service.[58] After more than a decade conducting research and development, Ford's AV will operate without a steering wheel and pedals to accelerate or brake, expanding travelers' time by allowing them to focus on other activities.[59] In 2016, Ford had the largest test fleet on the road of any car manufacturer.[60] They were also the first to demonstrate their AV's ability to operate in snow and at night, conditions which are much more challenging than operating during the day.[61]

Finally, Unmanned Aerial Systems (UAS) are populating the skies with more frequency. Military UAS automate takeoff and landing and allow persistence of onboard sensors over targets for up to 36 hours. Operated remotely, they require neither multiple aircrews to man the aircraft for long-endurance flights nor several piloted aircraft to cover the same time window. In the future, fully autonomous UAS will eliminate the need for an aircrew altogether, freeing human resources to focus on other tasks and duties. Figure 4 provides an overview of DOD unmanned aerial systems. Additionally, UAS with full autonomous systems will overcome deficiencies in human manual and cognitive skills that result from a lack of proper training and practice.[62] Autonomous passenger drones currently being tested in Dubai, United Arab Emirates will be capable of safe operation in reduced weather conditions - a common cause of cancelled or delayed flights with human-piloted aircraft.[63]

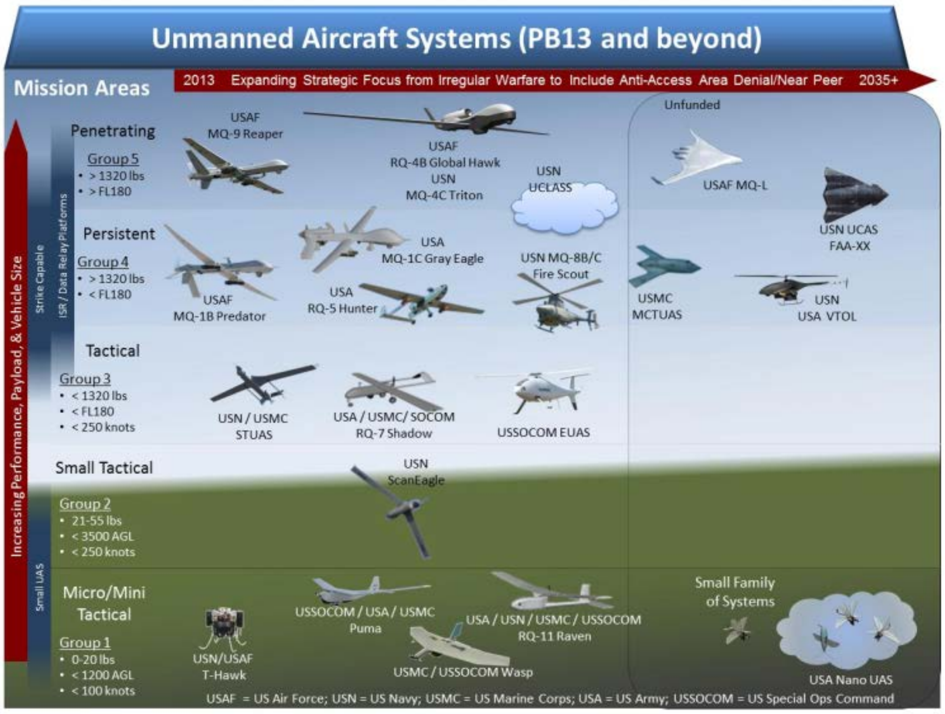

Figure 4. DOD Unmanned Aircraft Systems[64]

Time Compression

RAS are also capable of providing humans with time "compression" by performing functions faster than human cognition. Leveraging this capability, an operator who bestows a certain level of autonomy to a system will enjoy lightning-quick decision making and exponentially greater computations by the system than he or she could make.

More data has been created in the past two years than in the entire previous history of the human race, [65] creating a bottleneck when it comes to human decision making. If AI were used to replace the human it would be able to decrease time within the decision-making loop. Israel's Iron Dome system provides an excellent example of this speed increase. When being attacked by weapons from Gaza, Israel has only moments to react and defend its population centers. Iron Dome has demonstrated it can go through the detection, identification, launch and destruction kill chain against incoming fire in less than 30 seconds.[66] Similar to Israel, speed is indeed an issue for the DOD.

The U.S. Army has incorporated Counter-Rocket, Artillery, and Mortar (C-RAM) defensive technology into its expeditionary Brigade Combat Teams (BCT)[67] to close a capability gap that exists at the BCT level where they are not able to protect themselves against incoming fire in a timely manner. Looking toward the future, Robert Work, the former Deputy Secretary of Defense, stated "China and Russia are developing battle networks that are as good as our own. They can see as far as ours can see; they can throw guided munitions as far as we can…What we want to do is just make sure that we would be able to win as quickly as we have been able to do in the past."[68] Achieving this capability requires weapons systems to provide a competitive advantage through time compression

Both in combat and the marketplace, the benefits of RAS are undeniable and alluring. In South Korea, Patriot missile batteries scan the skies to automatically observe, classify and alert American forces to the launch of North Korean missiles with the goal of creating a weapons intercept solution in seconds and destroying them once the operator approves. Meanwhile, less than 50 miles away, automated assembly lines in LG's state-of-the-art panel display plant in Paju, South Korea manufacture industry-leading organic light-emitting diode (OLED) displays with far higher tolerances than humans could deliver.

Automation and advanced data analytics have begun transforming other civilian occupations as well. In the financial sector, for example, robots using proprietary algorithms to rapidly trade stocks have infiltrated a field formerly dominated by human traders communicating on an exchange floor.[69] The ability for computers to analyze large amounts of data quickly and make corresponding decisions has enabled high-frequency trading, increasing the overall stock market volume such that 50 percent of transactions are now done in this manner.[70] As RAS technologies continue to advance, other fields relying heavily on data analysis are also opportune for disruption in a similar fashion.

In addition to compressing time in the financial sector, autonomy and AI are currently enabling and enhancing the government's and military's ability to analyze growing datasets. Such autonomy will enable humans to process datasets larger than they are currently capable of analyzing, identify patterns and trends, and improving the quality and speed of analysis over time. One example of this potential is full-motion video data from remotely-piloted aircraft. A senior U.S. Air Force officer described the military's current use of remotely-piloted aircraft, stating that despite the airframes being unmanned, they are manpower-intensive to operate, maintain, and analyze the collected data. The military remains in the industrial age of robotics; the information age will enable machines to autonomously identify and track objects and rapidly highlight trends or connections between data points, freeing humans to focus on higher-level analysis.[71]

The promise of time compression also applies to cyber defense. The Defense Science Board recently proposed the development and deployment of a "comprehensive network of sensors"[72] feeding autonomous systems that "will in real-time develop options to thwart the attack in the timeframe required to protect the target."[73] As adversaries increasingly incorporate autonomy into their cyber-attacks, the concept of "counter autonomy" will become equally important.[74]

While the capabilities of autonomous systems cannot be easily refuted, in many cases the prospect of pairing the cognitive time compression and workload expansion of a RAS with the intellect and intuition of a human may be the pinnacle of efficiency. Human-machine collaboration is one of the five pillars of the Third Offset Strategy. In essence, human-machine collaboration "teams up human insight with the tactical acuity of computers by allowing machines to help humans make better, faster decisions. Pairing the two will combine the ability of humans to think on the fly with the quick problem-solving methods of artificial intelligence."[75]

While it is evident human-machine collaboration is closely associated with the human-machine combat teaming and assisted human operations elements of the Third Offset Strategy, the deep-learning systems element also play a significant role. With deep-learning systems, where machines would also be used for big-data analytics to assist the human operator in sifting through greater volumes of information to find that which is useful and "for indications and warnings in cyber defense, electronic warfare attacks and large-density missile raids when human reactions just aren't fast enough,"[76] it becomes clear that the Third Offset Strategy is built around exploiting the strategic and tactical advantages of human-machine collaboration. In fact, with regard to deep-learning, it is considered the "cutting edge of the cutting edge."[77] Early artificial intelligence basically concentrated on "mimicking human decision making processes and carrying out tasks in ever more human ways."[78] Machine learning was the next advancement in which "the development of neural networks has been key to teaching computer to think and understand the world in the way we do, while retaining the innate advantages they hold over us such as speed, accuracy and lack of bias."[79] In the hierarchy of artificial intelligence and autonomy applications, deep-learning then takes machine learning to the next level by using multi-layered neural networks to teach the machine.[80]

U.S. Air Force Colonel John Boyd's observe, orient, decide, act (OODA) loop describes a process in which an individual "gets inside" his or her opponent's decision cycle and gains the tactical advantage by observing and reacting to unfolding events more rapidly than the opponent.[81] In the digital age of high-tech weaponry, military leaders whose weapons systems can make fully informed decisions faster will prevail in battle. The future development of full autonomy and AI systems capable of operating independently and analyzing data faster than humans will provide the U.S. with a significant advantage over its adversary. The Chairman of the Joint Chiefs of Staff, General Joseph F. Dunford, stated, "information operations, space and cyber capabilities and ballistic missile technology have accelerated the speed of war, making conflict today faster and more complex than at any point in history." In addition, "the speed of war has changed, and the nature of these changes makes the global security environment even more unpredictable, dangerous and unforgiving. Decision space has collapsed and so our processes must adapt to keep pace with the speed of war."[82]

ISSUES FOR CONSIDERATION

Increasing reliance on RAS does not come without costs. The complexities and capabilities of the technology raise difficult issues for consideration in the areas of cybersecurity, trust, and the role of government.

Cybersecurity

A vital aspect of maintaining U.S. technological superiority is ensuring the cybersecurity of DOD networks and systems. There has been increasing concern in recent years that the cybersecurity of DOD weapon systems is not getting the attention it deserves. As weapon systems have become increasingly sophisticated and technologically advanced, the intricacies associated with advanced technology have introduced complexity making it difficult to discern vulnerabilities caused by underlying functionality, interconnections, associated subsystems, and weaknesses in hardware and software. Increasing autonomy on these systems compounds the potential vulnerabilities by embedding significantly more complicated software and data sets as well as a wider variety of sensors. Delegating decisions to autonomous systems based upon complex algorithms, and eventually machine learning, presents perhaps the ultimate complication to security. In this case, seeding bad data within the system or to its sensors could actually mislead the artificial intelligence learning process. Another insidious possibility is the mashup of cloud computing and robotics in the form of cloud robotics[83], where the hardware is akin to a "thin client" computer terminal that depends upon cloud-based computing and storage. In this case, compromise of the cloud would offer an adversary fleet-wide control of all of the robots assigned to that particular cloud computing cell.

In February 2016, the Director of National Intelligence identified cybersecurity as the top strategic threat to the U.S., stating that "Many actors remain undeterred from conducting reconnaissance, espionage, and even attacks in cyberspace because of the relatively low costs of entry, the perceived payoff, and the lack of significant consequences."[84] DOD's Director for Operational Test and Evaluation noted in his most recent annual report to Congress that DOD programs and networks recently have demonstrated effective defenses against attacks during test events, but "despite this progress, critical missions remain at risk when subjected to cyber-attacks emulating an advanced nation-state adversary."[85]

Over the past five years, the DOD and Congress have provided guidance intended to strengthen the cybersecurity of weapon systems—including autonomous and semi-autonomous weapon systems—by establishing information technology standards, roles and responsibilities, and oversight mechanisms. Figure 5 includes key guidance and requirements for cybersecurity of DOD autonomous weapon systems. However, the guidance to date may not be as comprehensive as necessary, and there are indications that policy is not being implemented as intended. DOD cybersecurity and IT officials responsible for implementing these policies cited numerous concerns about the sufficiency of current guidance to defend against or mitigate the impacts of a cyber attack on DOD weapon systems.[86] These concerns relate to the prioritization of cybersecurity as a department-wide goal; distinguishing between IT systems and platform IT systems; planning for, testing, and monitoring cybersecurity; and coordination across the DOD and the military services. These concerns were underscored by comments from others in the RAS community.

Date Issued	Title	Purpose
November 2012	Directive 3000.09: *Autonomy in Weapon Systems*	Minimize the probability and consequences of failures in autonomous and semi-autonomous weapon systems by, among other things, addressing cybersecurity
March 2014 (update)	Instruction 8500.01: *Cybersecurity*	Implement a multi-tiered cybersecurity risk management process
April 2015 (update)	DOD Cyber Strategy	Guide the development of the DOD's cyber forces and strengthen its cyber defense and cyber deterrence posture
April 2015	Memorandum: *Better Buying Power 3.0*	Integrate cybersecurity in planning, designing, developing, testing, manufacturing, and sustaining activities of military systems
November 2015	2016 National Defense Authorization Act, Sec. 1647	Evaluate the cyber vulnerabilities of each major weapon system of the DOD by not later than December 31, 2019
May 2016 (update)	Instruction 8510.01: *Risk Management Framework for DoD Information Technology*	Establish an integrated enterprise-wide decision structure for cybersecurity risk management
January 2017 (update)	Instruction 5000.02: *Operation of the Defense Acquisition System*	Assign, reinforce, and prescribe procedures for acquisition responsibilities related to cybersecurity

Figure 5. Key Guidance and Requirements for Cybersecurity of DOD Autonomous Weapon Systems[87]

There is evidence cybersecurity has yet to be embraced as a department-wide goal shared by all weapon system stakeholders. One official noted cybersecurity guidance is only read by the information technology community and that until others in the operational community make cybersecurity a higher priority, there will continue to be cybersecurity vulnerabilities. This point was underscored numerous times when talking with DOD users and industry providers of technology. For example, when asked about cybersecurity risks of Navy unmanned systems, an official commented it was the responsibility of the cyber group to assess system vulnerabilities. Similarly, a representative of a robotics company in Boston referred a question on cybersecurity to the technical staff, whom he cited as the ones responsible for knowing how to follow DOD's cybersecurity guidance.

There also are indicators current policy is not sufficient in planning for, testing, and monitoring cybersecurity. For example, one official noted cybersecurity requirements should be included in all weapon system contracts, and that such requirements should include updates and maintenance beyond software patches. Another official observed program management staff rarely includes sufficient cybersecurity expertise to ensure the appropriate controls are built in from the start. However, one official noted where previously cybersecurity was considered to be an obstacle and treated as an "add-on" in most programs of record, there appears to be culture change where programs are starting to think about integrated cybersecurity from the program start. Finally, because commercial applications are largely driving industry investments in autonomy, security is taking a backseat to capability. Cybersecurity is what economists might call a positive externality, quite similar to inoculations. Society shares in both the cybersecurity risks and the benefits resulting from individual decisions.

Trust

In his novel *I Robot* scientist Isaac Asimov offered three laws for robots that have become what some would argue is the unofficial international law on robotics:

(1) A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
(2) A robot must obey the orders given it by human beings except where such orders would conflict with the first law.
(3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.[88]

Taking these laws at face value it is clear that trust is at the core of the relationship between robots and humans.[89]

In the last four months, this industry study observed technology demonstrations requiring various interactions between humans and machines, from human-robot assembly lines to unmanned boats teleoperated by a human. In all of these interactions, the human places a certain amount of trust in the robotic system. For example, in the human-robot assembly line, the robot has a preprogrammed routine the human can learn and a failsafe the human can use if anything goes wrong. Trust looked different, though, in nearly every human-robot interaction we encountered and is even more critical when humans interact with systems with autonomous functions. There is an inverse relationship between autonomy and trust, with increased levels of autonomy resulting in lower trust in the system. This poses a significant challenge for developers, buyers, and operators of robotic systems. Gaining trust in RAS will continue to be a challenge for the industry and a hindrance to the expanded use of these systems in industry, national security, and daily life.

For example, humanitarian workers are using small, commercially-available UAVs to assist in surveying natural disasters, identifying areas of conflict, and assisting in the location of victims in crisis. There is the potential for larger military-grade UAVs with longer flight times and battery life to be used during a humanitarian response. However, while there are many in the international NGO community who see the possibilities for drones in humanitarian action, there are quite a few who remain skeptical. A survey sponsored by the European Commission found that 60 percent of humanitarian workers surveyed believed that drones can have a positive impact in disaster response operations. The opinions shifted significantly on the use of drones in conflict zones. Here, humanitarian workers were sharply split: while 40 percent stated that drones should never be used by humanitarian organizations in conflict settings, 41 percent said they would consider using drones even during armed conflicts. [90] This shows the continued conflict over trusting autonomous systems in a variety of fields but at the same time recognizes the potential for humanitarian workers to use these systems to help make their response time to crises quicker especially in natural disasters where in the past they may not have had the ability to respond for sometimes days.

In 2017, the Campaign to Stop Killer Robots issued a statement opposing the introduction of RAS capable of self-selecting targets and engaging them with lethal effect.[91] The organization expressed two fundamental concerns with such lethally autonomous weapons. First, the ability to wage war becomes even easier when humans are not sent to fight, and second, it is immoral for machines to kill humans. However, as technology has increased, incidents of warfare have decreased.[92] In the 1950s, there were 250 deaths per million people caused by war, today there are fewer than 10 per million.[93] So it seems that advancing technology has not increased the impetus for humans to kill other humans.

Nonetheless, the advancement of AI in weapon systems needs to address trust and accountability. Until now, a human has always been "in the loop" with regard to command and control of a weapon system. From the lance's thrust to the bowstring or trigger's pull and now the pressing of a key, a human has had a direct connection to a weapon's deployment. Humans are trained and trusted to attack the correct targets and are held accountable for their actions in accordance with the law. As the U.S. continues to develop the software and AI necessary to produce lethal autonomous weapons, such command and control becomes even more critical. If a lethal autonomous weapon is employed by the military and violates international humanitarian law through the targeting and killing of non-combatants, the DOD will be held responsible and must be able to understand why the action occurred. However, the current state of technology limits our ability to understand the decision process of AI, which therefore hinders the DOD's ability to deploy such weapons.[94]

Role of Government

As the importance of RAS applications continues to increase across the global commercial sector, the role of the U.S. Government in harnessing potential RAS overmatch capabilities is becoming more critical for a Third Offset Strategy. Several factors serve to complicate the effectiveness of the government's role, but two stand out as examples of impediments to success.

The first major factor is a lack of a comprehensive long-term engagement strategy with industry and academia, who are leading the government in terms of R&D expenditures and innovation to acquire new cutting-edge technologies. The exponential advancements within industry and academia for RAS have outstripped the government's, and specifically DOD's, ability to keep pace and has created a paradigm shift from the days when the government developed the technologies it needed in-house and could push their commercialization to the private sector. Today, the government finds itself having to pull the most advanced RAS technologies from industry and academia in order to meet mission needs.

Former Secretary of Defense, Ashton Carter, believes the "speed of innovation is what sets the Third Offset apart from previous strategies" and the "priority of Third Offset planners is to promote a culture of innovation and forge stronger partnerships with private industry in order to expand the network of talented people and ideas."[95] Yet, there are many types of innovation and the term is thrown around somewhat carelessly in both the private and public sector. Innovation expert, Clayton M. Christensen, describes two types of innovation, sustaining and disruptive, and argues there is a "strategically important distinction between sustaining technologies and those that are disruptive."[96] Sustaining technologies "foster improved performance" and disruptive technologies "bring to market a very different value proposition" to the customer that replaces other technologies and makes them irrelevant in the long term.[97] Throughout most of the 21st Century the DOD drove several disruptive innovations in the private sector – everything from computers, to the microwave, and the internet. However, the DOD is falling behind the private sector in many aspects with 21st Century technology advancements due to a rapidly changing environment and outdated processes.

DOD's strategy has been more aligned with sustaining innovation – making only incremental changes, such as better radars and electronic warfare systems, lower radar cross section aircraft, and longer range weapons. Sustaining innovation is certainly necessary, but the performance improvement slope over time is less than disruptive innovation. As depicted in Figure 6 below, Christensen's concept for "disruptive technologies causes problems because it does not initially satisfy the demands of even the high end of the market."[98] "Because of that, large companies," much like the DOD, "choose to overlook disruptive technologies until they become more attractive profit-wise," or less risky for DOD.[99] "Disruptive technologies, however, eventually surpass sustaining technologies in satisfying market demand with lower costs. When this happens, large companies who did not invest in the disruptive technology sooner are left behind."[100] Yet, technological advancements alone are not the whole story. Disruptive innovation also relies upon changes in doctrine and organizational changes. Technology, doctrine, and organizational changes, all play a significant role in creating innovative solutions to complex problems. Hence, the need for the DOD to think more outside the box and not just focus solely on technology, but combine advancements in RAS technologies with novel approaches to doctrine and organizations.

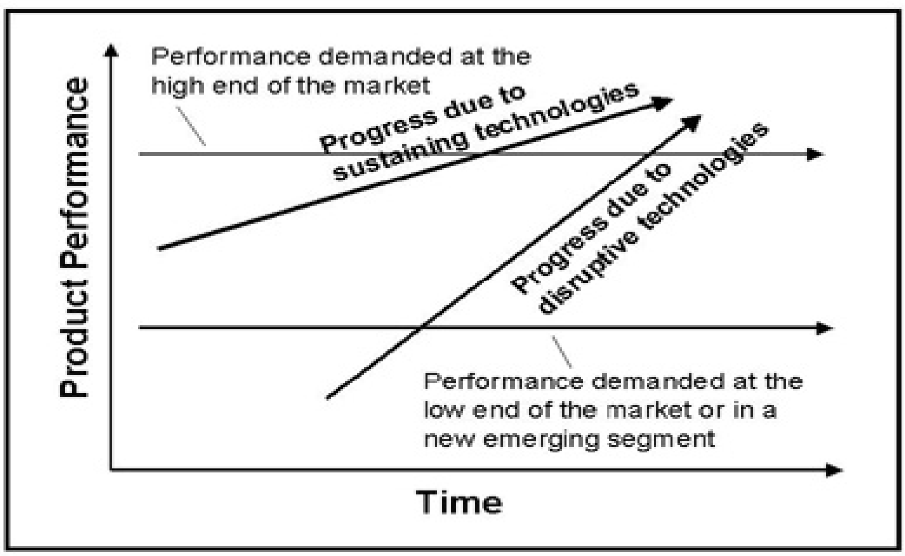

Figure 6. Disruptive vs. Sustaining Technologies[101]

Former Defense Secretary Ash Carter sought to address the DOD's challenge of providing disruptive innovative technologies by establishing the Defense Innovation Initiative (DII) and the Strategic Capabilities Office (SCO) and establishing outposts in Silicon Valley, Austin, and Boston under the new Defense Innovation Unit-Experimental, or DIUx.[102] In addition, former Under Secretary of Defense for Acquisition, Technology, and Logistics, Frank Kendall, established his “Better Buying Power” initiative to provide approaches to streamline acquisition and spur DOD innovation – with Better Buying Power 3.0 setting a goal of achieving “dominant capabilities through technical excellence and innovation.”[103] With over $18.0 billion budgeted toward the Third Offset Strategy from 2017 to 2021, the DOD is investing heavily in its vision for the future.[104] As mentioned previously, public and private RAS technologies will underpin much of this strategy and apply the technologies across multiple weapon systems. The question is if there is a comprehensive, long-term cohesive strategy in advancing and procuring new RAS technologies for the DOD – the evidence suggests there is not.

For example, according to a DIUx official, their business model is notable in that it has achieved significant acquisition efficiencies when matching the needs of priority, short-term DOD programs with readily available commercial technological solutions. By focusing on a 24-month time horizon, this official noted DIUx has been able to successfully identify and pair DOD customers with commercial vendors and venture capital companies to create short-term win-win outcomes. However, DIUx is not positioned to enable a longer range engagement strategy for technologies having a slower maturation period. And while DIUx maintains a database of DOD programs and commercial companies, the information it maintains on emerging technologies is only as current as the companies’ willingness to share it.

Numerous DOD labs and research institutes including the Air Force Research Laboratory, Naval Research Laboratory, DARPA, SRI, and the Lawrence Livermore National Laboratory, invest millions in RAS-related technologies. Yet, there appears to be no collaboration between all the organizations to exchange information and lessons learned. One author even called the DOD’s strategy “a high-tech version of the casting call for the tryouts for America’s Got Talent; even the producers have no idea who will show up or how they will perform.”[105] The DOD has not clearly identified its needs to private industry and conversely, private industry seems to be unwilling to invest in risky technologies to “push” to the DOD if they do not have commercial viability.

The second major factor complicating the government’s role in improving the acquisition of RAS technologies is closely coupled with a long-term engagement strategy and centers around the importance of balancing investments in technologies and workforce. Government should lead by investing in RAS portfolios in which it has the subject matter expertise, while looking to industry for commercial synergies and leveraging industry’s discoveries. In many aspects, commercial industry outspends the government on RAS R&D and leads innovation. Government should leverage industry’s investments on RAS and examine how it can better partner with industry, academia, and technology hubs. The question is not about whether government should be a leader or fast follower in innovation, but perhaps how the DOD can capitalize on both strategies.

The DOD can capitalize on the work small start-up companies are doing to develop technologies with military applications through targeted investments. Specifically, agencies and business incubators in Pittsburgh, Boston, and Silicon Valley with a focus on RAS start-up companies which all face similar challenges of energizing entrepreneurship. DOD should assist these companies to transition from basic research to commercialization. This investment should be the beginning of a larger, long-term effort to have the DOD actively involved in the commercial development of small-scale state-of-the-art technologies that support the Third Offset Strategy.

Recognizing the DOD may not be the lead, U.S. Government stakeholders should determine where it would be in our national interest to drive the establishment of international norms and standards and where it is in our interest to block them. There are no agreed upon international frameworks or laws for RAS in war. The U.S. should selectively promote international norms for the evolving use of RAS in war by creating formal and informal norms of accepted behavior, stigmatizing certain systems, and using end-use agreements to control how exported systems are used. The U.S. also has an opportunity to ensure U.S. RAS industry competitiveness by defining worldwide industry standards for robotics and automation and motivating international firms to work toward those standards.

From a workforce perspective, the increasing use of RAS should be seen as an opportunity to improve the existing workforce, rather than simply replace them through automation. Not only is it advisable for job seekers to stay ahead of the innovation curve, it is possible for them to be part of the innovation solution. The TechHire initiative proposed by President Obama in his 2016 economic report to Congress would benefit younger workers by providing more technology training opportunities.[106] Federal, state, and local governments could also incentivize businesses to retrain workers who may lose jobs due to automation.

Impact on Employment

Predictions about the impact RAS will have on future employment vary widely. PriceWaterhouseCoopers asserted 38 percent of jobs in the U.S. are highly subject to automation within the next 15 years,[107] while over half of respondents in a Pew Research canvas of experts predicted technology would displace jobs by 2025, but not more than those it creates.[108] Despite the contrasting viewpoints, one area of mutual agreement emerges – technology will continue to advance and the workplace of the future involves increased interactions and teaming between man and machine.

At first, today's revolution in the workplace appears to be a furtherance of previous reforms driven by advancement in electronics and computer technology, which have had positive economic impacts and have driven increases in overall employment. However, closer examination reveals today's RAS innovations possess capabilities enabling them to challenge human capabilities far beyond the routine activities they were able to replace previously. In an article for WIRED, Kevin Kelly explained this is driven by what he refers to as the "second wave of automation, one that is centered on artificial cognition, cheap sensors, machine learning, and distributed smarts."[109] He further asserted these developments will enable robots to replace warehouse workers, farm workers picking fruits and vegetables, janitors, and long-haul truck drivers[110] (a feat proven possible in October 2016, when an autonomous truck completed a 120-mile journey delivering beer from Fort Collins to Colorado Springs, Colorado[111]), occupations having activities which were previously difficult to replicate with machines and representing a significant number of jobs. Kelly argues the impact could be felt deeper, with the work done by white collar employees also becoming susceptible to automation, as artificial intelligence will be able to perform the "rote tasks of any information-intensive job."[112]

As described previously, removing humans from performing dull, dirty and dangerous activities and increasing productivity through the manipulation of the time required to perform tasks were central themes associated with our analysis of the RAS sector's value proposition from a human capital perspective.[113] One agency using industrial robots indicated automating certain functions was necessary to meet customer demands for speed of service and due to difficulty locating a sufficient volume of human capital to meet business requirements.[114] These trends are mirrored in the DOD, the largest employer in the U.S. Government. The Packbot, for example, allowed EOD technicians to combat improvised explosive devises from a distance, enhancing service member safety.[115] Unmanned systems proved useful in the air domain as well with small UAS being employed for increased battlefield awareness[116] and larger UAS allowing pilots to operate from well outside the area of operations, enhancing safety while still meeting mission requirements.[117]

In 2015, Secretary Carter announced 'Force of the Future,' an effort to prepare the department for future human capital needs.[118] This occurred a few months before introducing the effort to develop the Third Offset Strategy, perhaps foreshadowing the role RAS platforms would have on the defense workforce. And yet, the current wave of technological innovation in the RAS sector is too new to understand the full impact on total employment in the United States. However, two implications emerge from a deep analysis of the industry: (1) robotics and automation will affect employees across the occupational spectrum, but (2) the degree of the impact will vary significantly based upon the occupation. To hedge against the negative consequences associated with this technological revolution, governments must initiate proactive measures now. Taking action to increase interest in Science, Technology, Engineering, and Mathematics (STEM) and provide access to training programs in vocational fields will ensure the workforce has the skills employers require; augmenting current government programs can provide assistance to retrain employees for new, in-demand occupations.

POLICY RECOMMENDATIONS

1. **Cybersecurity –** The DOD must work to understand and minimize the cybersecurity risks associated with robotics and autonomous systems and deliberately balance residual risks with expected capabilities when considering long-term investments and operational employment. **The DOD should update existing guidance related to the cybersecurity of autonomous and semi-autonomous weapon systems to ensure it is sufficient and implemented appropriately to adequately and appropriately plan for, research, test, and monitor cybersecurity throughout the program lifecycle.**

2. **Trust –** Gaining trust in RAS will continue to be a challenge for industry and a hindrance to the expanded use of these systems in national security. Thus, the advancement of autonomy and AI in weapon systems needs to address the issues of trust and accountability. The current state of technology limits our ability to understand the decision process of AI. **Before deploying fully autonomous systems in the field, the DOD must ensure it has the technological capability to understand how the system will behave in different scenarios and to determine the degree of risk the U.S. will accept when using such systems.**

3. **Government Strategy and Investment – The DOD must develop a more comprehensive, long-term strategy to integrate RAS into the military and to engage**

with industry and academia. It must do this to better leverage commercial R&D in autonomy and AI – in part, by using seed investments – while focusing government labs on critical technologies addressing national security priorities. Initial efforts should focus on establishing processes and systems enabling the transfer of technology to government that the private sector has developed in the areas of data analytics, cyber defenses, human-machine interfaces, and efficiency-related technologies prevalent in the commercial sector. **The DOD should increase the workforce's knowledge and skills in advanced technology through targeted recruitment and hiring of highly qualified civilian and uniformed employees, incentivizing the commercial sector to assist the government in transitioning technology for government applications, and connecting the government and private sector workforces to create synergy in innovative work. The U.S. should also define industry standards to ensure U.S. RAS industry competitiveness and motivate firms to work toward those standards.**

CONCLUSION

RAS offer significant opportunities to increase human productivity and improve efficiency. Through this study we examined a cross-section of military and industrial RAS applications to gain an understanding of the relevant topics with which those engaged in this sector have to contend. In doing so, we have gained an appreciation of the benefits of robotics and autonomy. By expanding and compressing time, RAS enable humans to gain advantages both in combat and business. Additionally, they decrease workloads on operators by automating tasks deemed dull, dirty, or dangerous.

However, these advantages come at some cost. Without a coherent strategy, the U.S. government is largely implicit in allowing the civilian industry to drive RAS innovation. While the DOD has offered a Third Offset Strategy concept to inspire research into a capability that will provide a long-term comparative advantage, it is relying on industry to determine the next leap forward. Additionally, the impacts of increased use of RAS are being felt throughout the labor force although not necessarily acknowledged. Finally, the subject of trust in these proliferating technologies remains a point of concern that should be addressed deliberately.

As the modern world approaches an inflection point in technological advancement, leadership is needed to steer the discussion in ways benefitting society writ large. The U.S. Government needs to be part of that conversation if it wants to ensure its interests are protected. Otherwise, our international competitors and industry partners will be allowed carte blanche to drive our strategy. At least, until the robots do it for us.

APPENDIX A

ADDITIONAL RECOMMENDATIONS

Cybersecurity

- DOD should update existing guidance related to the cybersecurity of autonomous and semi-autonomous weapon systems to ensure it is sufficient and implemented appropriately to:
    - Establish cybersecurity as a department wide goal shared by all weapon system stakeholders;
    - Address the unique requirements of platform information technology systems;
    - Help ensure sufficient resources are dedicated to implementing DOD's cybersecurity guidance and that identified issues are addressed;
    - Adequately and appropriately plan for, test, and monitor cybersecurity throughout the program lifecycle;
    - Ensure sufficient coordination between the services, and between DOD and the services, to invest in research to advance lethal autonomous weapons software reliability and cybersecurity;
    - Include auditability and algorithmic transparency principles in its autonomy R&D efforts and include them in requirements for new acquisitions; and
    - Explicitly require cybersecurity criteria as a part of every Analysis of Alternatives.
- DOD should work with DHS and the Office of Management and Budget to select and implement regulatory incentives for industry to more explicitly include cybersecurity in its R&D associated with robotics and autonomous systems.
- Autonomous vehicle manufacturers and software developers should implement National Highway Transportation Safety Administration guidance on cybersecurity measures.[119]

Trust

- Government and industry should increase the use of human-machine teaming with the goal of demonstrating the safety and effectiveness of this important technological relationship.
- DOD should revise after action reporting and case study development of deployed human-robot teams to ensure that we continue to track and identify any breakdowns of trust or anthropomorphizing behavior which could lead to disaster.
- DOD should collect qualitative data at a variety of points in the T&E process which will allow us to see the evolution of trust and understanding of the system by the human team member.

Role of Government

- U.S. Government should take a *laissez-faire* approach to diffusion of most RAS, but explore potential levers it can exercise over military-exclusive implementations.
- U.S. Government cultivate trusting relationships with U.S. industry that is leading RAS development, particularly those with military applications.
- DOD communicate the five fundamental aspects outlined by Former Deputy Defense Secretary Robert Work, of achieving a Third Offset to industry and DOD agencies; prioritize investments.
- DOD set up "meet and greets" between private industry and the Services to demonstrate what capabilities exist and where technology is headed; the Warfighter can in turn tell industry what may or may not work or what it needs.
- U.S. should create a master database of robotics and autonomous systems technologies and organizations to establish a baseline of situational awareness for decision makers both domestically and internationally.

- Federal, State, and Local Governments should update existing laws to clearly address accidents caused by autonomous vehicles by balancing responsibility between manufacturers and users.
- Federal Aviation Administration (FAA) and other related authorities should streamline their processes in developing proper laws and regulations for passenger drones operations.
- FAA should involve the industry in shaping the regulations to keep up with rapidly developing innovations in drone technology.
- FAA should grant fast testing approvals for companies that are manufacturing passenger drones because the technology is advancing in a fast base and delaying the approvals makes the current technology obsolete.
- U.S. should support reshoring of manufacturing by USG use of human-cyber interaction to generate best practices and streamline government regulations.
- U.S. should prioritize development aid on helping governments build simple online governance to facilitate business, including intellectual property protection.
- The U.S. should continue to work with allies and partners to ensure International Humanitarian Law, also known as the Law of Armed Conflict, is in line with the quicker timelines associated with LAWs.
- The U.S. should take the lead in the development of International Norms and Standards for autonomous systems.
- The U.S. should lead global development of robotics standards and share best practices with U.S. States.

<u>Workforce</u>

- Federal, state, and local governments should incentivize businesses to retrain workers who may lose jobs due to automation.
- U.S. should develop a workforce to meet the skills robotics and autonomous systems employers need by:
    - Developing the STEM pipeline through grants to K-12 STEM programs;
    - Developing vocational skills through tuition free public education programs; and
    - Retraining displaced workers.
- DOD should enable flexible skills for military personnel by drawing on initiatives like Navy Sailor 2025 and DOD Force of the Future, which will drive flexible training and technology development.

<u>Defense Acquisition System</u>

- Leverage the private sector in cheaper commercial systems, data analytics, cyber defenses, human-machine interfaces, and efficiency-related technologies that are prevalent in the commercial sector.
- Establish more small contracts with start-up companies investing in RAS, with incentives to accelerate products and/or technologies. Smaller companies can benefit and even accelerate with small amounts of funding – less than 100k in some cases.
- Encourage large defense contractors, such as Lockheed Martin and Boeing, via incentives, to develop relationships with smaller RAS companies that can contribute to the larger acquisition programs.
- Allow more risk via additional experimentation, potentially incentivize “successful” failures.
- Clearly articulate human-machine collaboration requirements in contractual language.

DOD Research, Development, Test, & Evaluation

- Unify the efforts across all agencies, laboratories, and research institutes; exchange lessons learned, share progress and capabilities, continually communicate with DOD senior leaders that have knowledge across all RAS developments (to include private and public) on program status.
- Continue to pursue research and development in autonomy and artificial intelligence; enhance research for artificial intelligence applications for large data analysis.
- Focus UAS research on speed, range, and endurance for small platforms with priority on propulsion systems and beyond-line-of-sight and all-weather operations.
- Incorporate initiatives on perception (advanced sensors), AI, and robotics research and development on advanced platforms for complex environments.[120]
- Ensure that we are capturing a quality of T&E data to perform the proper analysis.
- Include a variety of human participants in T&E that reflect the full range of skill and familiarity levels.

Miscellaneous

- U.S. Government and military should sink extensive resources into conceptualizing new doctrine and organizational constructs to exploit today's and tomorrow's likely capabilities.
- DOD should deploy smaller, faster, cheaper RAS technologies.
- DOD should reconsider small UAV as a part of the airpower doctrine to enable the use of autonomous technology for military operations.
- DOD should debate and refine policies related to, or affected by, lethal autonomous weapons.
- The U.S. should smartly consider counter-RAS systems that could address a range of current and emerging use cases for RAS.

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