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Robotics and Autonomous Systems

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ROBOTICS AND AUTONOMOUS SYSTEMS 2016

ABSTRACT: The Robotics and Autonomous Systems (RAS) Enterprise has played a major role in the Department of Defense over the past two decades with the operational employment of unmanned aircraft systems. It has significant potential to continue to shape the role of unmanned systems in the future. Advances in cyber, electronic warfare, robotics, unmanned systems, and other technologies will influence the nexus of capabilities for DoD's Third Offset Strategy. In pursuit of this strategy, DoD needs to plan for the integration of the warfighter and the technological advances in autonomy over the next several decades. This report outlines the major issues affecting the defense sector of the RAS Enterprise and DoD's ability to acquire and employ RAS. It then makes recommendations to enable DoD to better capitalize on the technology, strengthen its relationship with the industry and ultimately improve the nation's warfighting capability.

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INTRODUCTION

The Third Offset, first articulated by Secretary of Defense Chuck Hagel and later refined by Secretary Ashton Carter, is an effort of continuous innovation toward maintaining a competitive advantage over our adversaries, during a period of growing parity in military capability. It relies upon the nuclear deterrence created under the New Look Strategy while maximizing the capabilities developed under the Long-Range Research & Development Planning (LRRDP) Program. While technology-focused, it is human-centric; intended to augment, rather than usurp, the human's ability to conduct operations.

Developments within industries related to Robotics and Autonomous Systems (RAS) represent the most visible and accountable aspects of the Third Offset, and highlight awareness of the paradigm shift in technological innovation in the United States. In the twentieth century the government drove innovation and moved industries to achieve its ends. With the dawn of the twenty-first century, industry determines areas for development, and the government seeks to leverage its products. If the U.S. is to realize the promise of the Third Offset, we must enhance understanding of the emerging RAS Enterprise to develop agile processes for leveraging advances in the private sector and academia. The overall RAS Enterprise consists of a nascent, loosely defined RAS industry along with government labs, government sponsored research institutions, government engineering companies and academia.

There are three challenges specific to RAS. The first is capturing the breadth of innovation across the RAS Enterprise. Myriad programs exist sponsored by private companies, universities, state governments, and national laboratories; however, there appears to be no mechanism to catalogue efforts across the Enterprise. DoD established the Defense Innovation Unit-Experimental (DIUx) in Silicon Valley to engage private sector companies that do not have habitual relationships with DoD. The initiative holds promise, but only if it can be expanded and leveraged to enable broader access. Additionally, talent management is a concern within academia and industry in their support to DoD. Companies and innovation groups are collaborating with community colleges to provide Science, Technology, Engineering, and Mathematics (STEM) education. This is necessary to develop local employee pools as well as labor pools consisting of US citizens to allow them to work on DoD projects.

The second challenge is fostering cultural change to enable greater acceptance of emerging robotics and autonomous capabilities within the U.S. This will stimulate the RAS Enterprise to continue working on technologies necessary for national security. Furthermore, academia and RAS companies face challenges as they work within the Defense Acquisition System to meet DoD's growing appetite for innovation. Despite efforts to refine the process, it continues to act as both a barrier to entry for new companies that may want to support the DoD, and as an impetus for established companies to divest themselves of defense-related products.

The third challenge relates to autonomy and establishing a clear role for it in support of military capabilities. DoD already established a policy against the fielding of fully autonomous offensive systems. Deputy Secretary of Defense Work defended this as a reflection of our society and a statement of confidence the government places in its warfighters.[1] However, as computing speed and the ability of systems to perceive their environments increase, a time may come when failing to embrace the full capabilities of autonomy may be seen as unethical.

***Methodology*:** The Eisenhower School Robotics and Autonomous Systems Industry Study Seminar for Academic year 2015-2016 assesses that DoD must make necessary investments now in its support of the RAS Enterprise to ensure it establishes the pipeline for innovation it is needs in its vision of the Third Offset. This paper summarizes the Seminar's observations of the industry based on visits to small, medium, and large companies that develop robots and autonomous systems for commercial and DoD applications, government and private sector sponsored innovation centers, and universities. Group members also met with non-government organizations representing views on policies related to autonomy. Additionally, we visited similar organizations in Japan to gain perspective on another nation's perceptions, goals, and challenges. The challenges raised regarding RAS capabilities, which address human, ethical, economic, and technological perspectives, form the basis of our recommendations.

This paper consists of two parts. Part I provides our definition of the RAS Enterprise, summarizes the challenges it poses to both the government and the private sector, and provides recommendations for action. Part II consists of select essays on various aspects of RAS written by individual seminar members.

PART I - THE ROBOTICS AND AUTONOMOUS SYSTEM ENTERPRISE

Industry Definition.

While a general understanding of Robotics and Autonomous Systems (RAS) as an industry may exist, the Federal Government does not formally recognize it as a distinct industry under the North American Industry Classification System (NAICS). Most elements of RAS are established subsets of multiple NAICS categories, including Aircraft Engine and Parts Manufacturing (33641), Ship Building/Repair (336621), Boat Building (336611), and Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing (334511). Similarly, domestic and international companies participating in RAS activities vary, ranging from major defense contractors to medical service providers. There are also significant efforts in academia in the areas of research and education. The amorphous nature of RAS may coalesce into a distinct industry in the future, but for now it approximates an enterprise, with multiple actors pursuing roughly aligned objectives absent a clear structure.

In addition to defining the RAS Enterprise, it is critical to develop a common understanding of autonomy. The Defense Science Board describes autonomy as "…a capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, self-governing."[2] It ranges from a system executing discrete tasks designated by a human controller to the system having full discretion to make decisions, perform actions, and determine whether to notify the human of decisions and actions taken.[3] Table 1 below illustrates the Maybury classifications of autonomy and corresponding levels of automation. Central to developing a teaming arrangement between humans and autonomous systems is deciding what level of autonomy is appropriate and possible.

Maybury Classifications	Sheridan & Verplank Level	Automation Description
No Autonomy	**1**	Computer offers no assistance: human does the whole job up to the point of turning it over to the computer to implement.
Partial Autonomy	**2**	Computer helps by determining the options.
	3	Computer helps determine options and suggests one, which the human need not follow.
Supervisory Autonomy	**4**	Computer selects action and the human may or may not do it.
	5	Computer selects action and implements it if the human approves.
	6	Computer selects action, informs the human in plenty of time to stop it.
Full Autonomy	**7**	Computer does the whole job, tells the human what it did.
	8	Computer does the whole job, tells the human what it did only if the human explicitly asks.
	9	Computer does the whole job, tells the human what it did if it decides he should be told.
	10	The computer decides whether or not to do the whole job. If it decides to do the job, it can determine whether or not to tell the human about it.

Table 1. Maybury Classifications and Levels of Automation[4]

Benefits of Autonomy: The potential benefits of increased autonomy for society and national economic security are innumerable. Society is already reaping the benefits of autonomous functions – think smart phones and navigation systems that automatically identify options for the user. An example of a future societal benefit is the further development of autonomous surgical robots. The wide-spread adoption of this capability could extend the "service life" of surgeons, whose dexterity typically degrades with age, while also providing more precise and less invasive procedures for patients, thus reducing risk and recovery time.[5] Extrapolating further, autonomy represents a significant enabler, even a paradigm-shift, in other capabilities (e.g. driverless vehicles and associated roadways), and achieving and integrating higher levels of autonomy could trigger an economic renaissance similar to the dot-com era.

The value of autonomy today is in the way it complements human inductive abilities with fast and accurate deductive skills, making Human-Machine Teams (HMT) that are more effective than human operators alone. In the future, autonomous systems will supplant human operators in an increasing number of functions as those systems begin to match human induction capabilities. This will make autonomy more valuable as it will free up human capital and allow constrained resources to go further.[6] DoD has already invested heavily in autonomy,[7] and plans to invest more on HMT specifically to allow limited human capital to be as effective as possible. Defense News reports that DoD plans to spend $3.6B in FY2017 on developing Third Offset technologies, which include autonomy and HMT. They also plan to spend an additional $3B across the Future Years Defense Program on "human-machine collaboration and teaming."[8]

As a National Defense University speaker noted, the goal is to control time -- the operational tempo within a conflict. The speaker espoused that autonomy can and will significantly accelerate decision making and enhance human-machine teaming with unmanned vehicles and robots, for ourselves as well as for our allies and adversaries. This teaming will be essential because the required speed of decision making will progress beyond human capability. These comments correlate directly to Secretary Work's vision for the Third Offset strategy. He states that autonomy, human-machine collaboration, and machine-assisted operations are part of the “basic building blocks”.[9] The impact of achieving this vision is a paradigm shift from an Observe, Orient, Decide, Act (OODA) loop to a Decide, Observe, Orient, Act (DOOA) decision cycle. With autonomous systems that can correctly reason intent, these systems can hypothesize and formulate decisions and associated triggers beforehand, then decide whether to act. While these systems can be pre- programmed, learning systems can improve the methodologies. This allows exponentially faster actions once either the human or the system identifies the trigger(s) based on observations and orientations. Achieving this level of decision-making pace with sufficient trust is no small task. Autonomous systems will have to progress to the point of being able to discern Commander’s Intent through a combination of situational awareness and reasoning based on a combination of deduction, induction, and abduction.

Current Conditions

Despite its amorphous nature, there is a market within the U.S. for robotics and autonomous systems for both defense and non-defense products. We characterized this market as monopolistically competitive, with multiple firms offering similar products. There are a large number of small firms where competition is fierce to establish products with first mover, competitive advantages. As expected, the number of larger firms is lower, because they have established successful products and secured market share. The markets are more concentrated at the high-end for larger, more sophisticated systems such as DoD’s unmanned aerial systems (e.g. General Atomics MQ-9 Reaper, Textron’s RQ-7 Shadow, Northrop Grumman’s RQ-4 Global Hawk and MQ-4C Triton). For these concentrated areas of the market, the threat of substitution is low once DoD commits to production of particular systems. There are numerous threats to new entries, to include the specialized technical workforce required along with the needed knowledge and insights into working with the DoD customer. On the commercial level, there are a number of potential customers for RAS products.

Several drivers influence the RAS market. Drivers include miniaturization, quest for artificial intelligence, commercial search for competitive advantages, and the desire to spare people from having to perform work that is dull, dirty, or dangerous. Robotics in manufacturing enable miniaturization of components with a precision and consistency that human hands cannot match. Conversely, miniaturization enables greater capability in smaller packages for robotics. The value of artificial intelligence and autonomy in general is touched on above. Concerning competitive advantage, robotic systems offer companies a means of potentially reducing manpower costs while at the same time improving product quality and consistency thereby giving them a leg up on any competitors who use manual, human labor for assembly type tasks. Last but not least, altruistically, improvements in robotics promise to alleviate mankind from work that is dull, dirty, or dangerous. A concept embraced by DoD for Explosive Ordinance Disposal (EOD) and Airborne Intelligence, Surveillance, and Reconnaissance (ISR) and one that almost anyone could get behind.

For the markets of unmanned aerial systems, ground systems, and underwater systems, DoD represents a monopsony for defense-related applications. DoD faces the choice of either accepting commercial technology or pay to have it developed and integrated into defense applications. Conditions in individual markets are as follows.

Unmanned Aerial Systems (UAS): In the RAS Enterprise, UAS is the most mature market with applications including but not limited to, agriculture, search and rescue, and humanitarian purposes. The burgeoning global UAS market was valued in excess of $10B in 2015 (i.e., defense, civil, and commercial – combined), and is expected to grow to $14.9B by 2020.[10] DoD has been the largest stakeholder to date, with its inventory of UASs increasing 40-fold from 2002 to 2010, and its annual UAS procurement costs increasing from $284M to $3.3B respectively.[11] In 2015, DoD spent over $6B when operations, maintenance, and RDT&E were also included (see Appendix.) The UAS industry is also growing in diversity, with international manufacturers becoming increasingly prevalent. However, North America still remains the dominant producer and consumer, as reflected by its sixty-five percent global market share as of 2015.[12]

Although the UAS industry is growing rapidly, particularly in the low-cost and recreational markets, a relatively small number of well-funded and well-established aerospace manufacturers continue to dominate the defense-related market (see Appendix.) The diversity of the UAS market creates an interesting continuum of competition. For example, whereas the broader low-cost market, typically associated with smaller UASs, represents an imperfect competition situation, the high-end market is clearly an oligopoly. It has distinct industry leaders, many which have long-standing relationships with DoD.

***Unmanned Maritime Systems (UMS)*:** According to the Association for Unmanned Vehicle System International (AUVSI) there were roughly 560 active products in the unmanned maritime systems or UMS marketplace in 2013.[13] The U.S. and United Kingdom have over half of the world's active UMS and the other company locations include Australia, Canada, France Germany, Japan, Italy, Norway and the Russian Federation.[14] To date most of the vehicles in development, production or employment are for underwater use, but the demand for surface vehicles is growing.[15] UMS are generally smaller vehicles with an average length for unmanned underwater vehicles (UUV) and unmanned surface vehicles (USV) of 12 and 21 feet, respectively. There are at least 225 companies from 34 countries registered with AUVSI as part of the UMS market.[16] The majority, over 50 percent, are located in the U.S.[17] The companies range from small firms, where the UMS is its primary market, to large defense conglomerates where the UMS is but one of their markets. DoD's Unmanned Systems Roadmap shows an annual investment between RDT&E, production and operations and maintenance of approximately $400M.[18] As the overall international defense and security market for UMVs is approximately $912M, DoD's demand represents a substantial portion of the current market.[19] The UMS marketplace is an emerging market with a monopolistic competitive structure with many companies, products and buyers. The market is growing, and over time commercial interests will dominate, particularly in the shipping and oil industries; defense demand is expected to grow more modestly.

***Unmanned Ground Systems (UGS)*:** A large portion of the defense-relevant UGS market consists of unmanned ground vehicles (UGV) dominated by North America, with the market at $6.44B. Europe and the Asia-Pacific are expected to drive significant growth of the global UGV market. Estimates from multiple agencies suggest that by 2020, the market will grow to around $18.65B. The UGV market's overall growth in Europe and Asia-Pacific can be primarily be attributed to Intelligence, Surveillance, and Reconnaissance (ISR) and combat in the defense sector. However, the same technology, to include specific equipment, can be leveraged for mining, agriculture and other areas within the commercial sector[20]. Multiple buyers will continue to affect the market. In the U.S. alone, DoD, the Department of Homeland Security, state and local police, and hazard response organizations are all elements in the market to buy UGVs to include Vehicle Borne IED specific UGVs.

CHALLENGES FACING THE RAS ENTERPRISE

Unlike the First and Second Offsets, the RAS capabilities relevant to developing the Third Offset are not exclusive to the government domain. Autonomy and robotics are already proliferating throughout the private sector. Challenges remain for developing and integrating RAS capabilities into the public domain, to include the interplay between the Federal Government and private sector as well as managing the RAS talent pool within both the public and private sectors. The RAS Industry Study's research, interviews, and site visits with the organizations and activities listed on page 3 identified the following challenges.

***Interplay Between Government and Industry*:** The public and private sector face numerous challenges associated with innovation and adopting new capabilities. Not exclusive to RAS, the effects of these challenges vary across the spectrum of the private sector, from the large defense contractors down to small businesses and innovation centers. The foci for this section are the RAS-Enterprise-articulated challenges in the areas of leveraging innovation, navigating the Federal Acquisition System, and addressing the professed stigma of developing RAS military (lethal) systems.

Better Buying Power (BBP) 3.0's vision is "achieving dominant capabilities through technical excellence and innovation" and relevant goals to the RAS Enterprise include incentivizing innovation and productivity within both government and industry.[21] This indicates DoD's strong desire to leverage innovative technologies. Discussions with the private sector, from large defense contractors to small start-up companies, indicated a strong desire to work with DoD to develop and/or demonstrate innovative capabilities. Challenges to effect the BBP 3.0 goals within the RAS Enterprise stem from inadequate communications.

Both large and small companies indicated a lack of understanding of DoD's strategy and requirements related to RAS capabilities. One example of this is DoD Directive 3000.09 on autonomy in weapon systems, which states that "autonomous and semi-autonomous weapon systems shall be designed to allow commanders and operators to exercise appropriate levels of human judgment over the use of force."[22] This should be a seminal document to inform DoD intent, but the International Committee for Robot Arms Control (ICRAC) reported the release as, "[DoD] quietly released Directive 3000.09."[23] ICRAC views this directive as a means for leadership to deflect discussions and disavow support for lethal autonomous systems.[24] This illustrates that DoD is not doing enough to effectively and clearly transmit its intent.

The converse of this challenge is limiting innovation. Both large and particularly small companies expressed frustration in being able to communicate their innovative ideas, research, and products that they believe are germane for DoD. The specific challenge for DoD is capturing the breadth of innovation across the RAS Enterprise. Contrary to previous offset technologies, a significant amount of RAS research and development is occurring in the private sector, both nationally and internationally. Thus, DoD may have current and future blind spots in this field. As former Secretary of Defense Rumsfeld stated, "There are known unknowns. … But there are also unknown unknowns. There are things we don't know we don't know."[25] Figure 1 below illustrates some of the major pockets of innovation within the U.S. and illuminates the potential magnitude of this two-way communication challenge.

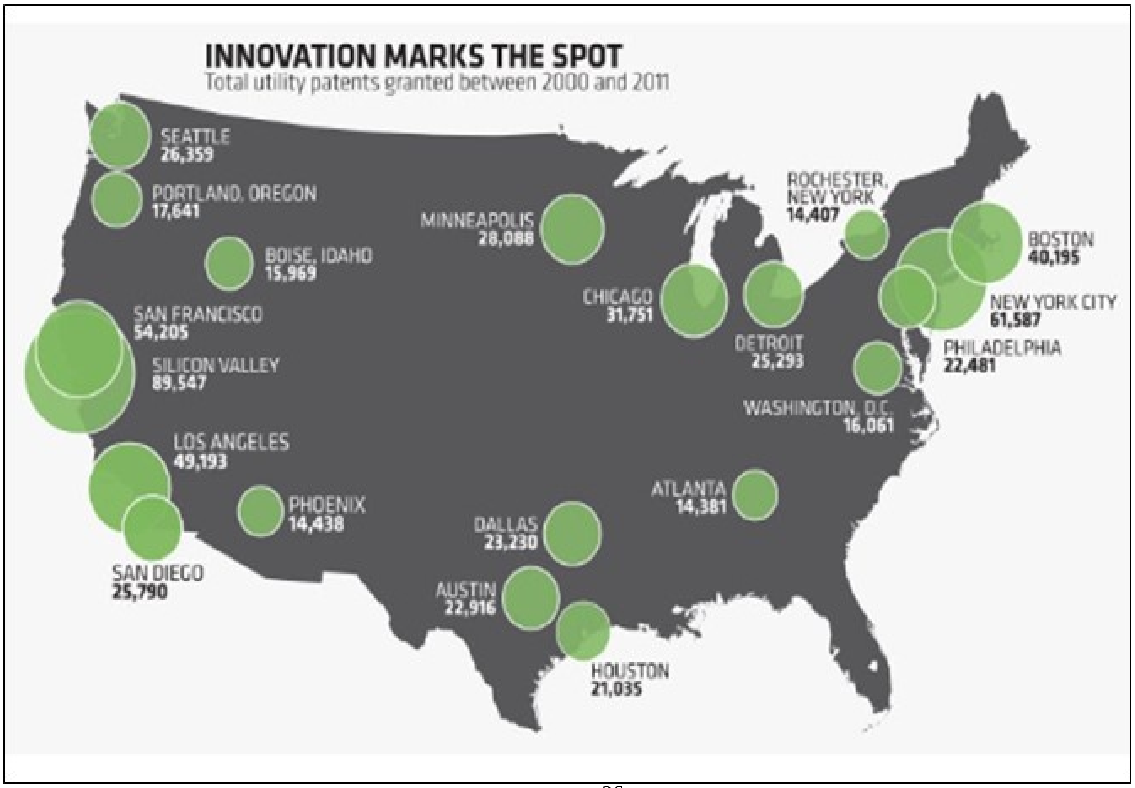

Figure 1. Map of U.S. Major Innovation Cities[26]

Another challenge area for the RAS Enterprise is navigating the Defense Acquisition System. These challenges range from frustration to a barrier to entry. For example, both large and small companies expressed concerns about untimely contract payments. For the larger companies, this issue adds extra labor and overhead to collect payment – costs ultimately borne by the customer (DoD). The impacts on smaller companies can be much more severe, potentially causing their dissolution if they do not have the capital to continue operations. The acquisition bureaucracy itself can be a barrier to entry into the defense market for start-up companies like those within the innovation centers at Innovation Works and MassChallenge. Groups within these centers were very interested in demonstrating their innovative products to the DoD community but were obviously frustrated in their efforts to find venues or points of contact. The acquisition bureaucracy and comparatively smaller market share could also push companies out of the defense market. Earlier this year iRobot, "a leader in delivering robotic technology-based solutions," divested its defense-related business in order to focus on commercial applications, which it views as much more lucrative.[27]

iRobot is an example of a company unwilling to participate in the defense industry for monetary reasons, but both DoD and the RAS Enterprise are also encountering more nebulous reasons for personnel and companies being unwilling to work with the military. Perhaps the reasons are akin to the negative perceptions associated with the term "drone" – people and companies perceive working with the military as disreputable. Though our research could not find definitive analytics to support these statements, both U.S. and Japanese companies and agencies articulated issues and examples of personnel having angst and companies being unwilling to work on military-related projects. Japan, in particular, is a microcosm of this extreme. Conversations with both Japanese industry and defense agencies clearly revealed a cultural bias against working on defense projects. Like Japan, the impacts for DoD could be a reduced industrial base, and the impacts for industry are recruitment and retention issues.

Trust: One challenge facing industry and the DOD is trust between humans and machines. Current machines, or robots, operate under relatively basic algorithms, using "if, then" statements that even non-computer programmers conceptually understand rather easily. However, current advances in artificial intelligence (AI) learning algorithms allow computers to make decisions that humans do not understand. The game of "Go" dates more than 2,500 years and has more possible moves than atoms in the universe, yet AI company Google DeepMind developed algorithms that beat 18-time world champion Lee Se-dol 4 games to 1.[28] Many believed that developing computers capable of winning "Go" was impossible due to the presumed level of intuition the game requires, but Google DeepMind thought they could create winning algorithms within 10 years after starting the project.[29] Instead, it took them only 18 months.[30] The problem with these algorithms is that computers do not currently provide explanations to the decisions they make. Because of this lack of feedback, humans find will remain skeptical towards incorporating advanced AI into our daily lives, and even more so into wartime lethality decision making. Moving forward, computers using highly advanced deductive or inductive reasoning must provide decision-making explanations to AI programmers, enabling them to better understand what's going on the inside of brain of the computer, much like a psychologist attempts to understand the behavior of a human brain. Those programmer then need to be able to change a computers AI behavior. Until we can learn what a computer is thinking, and then modify the way it learns, senses, decides and acts, military leaders will be apprehensive in delegating complete autonomous control to lethal weapon systems due to a lack of trust.

Talent Management: The challenge of talent management within the RAS Enterprise is multi-pronged. Businesses must manage developing a pool of qualified people capable of working in a diverse group of STEM-related fields. They must ensure cognitive diversity to assure innovative thought. They must safeguard against, or prepare for, talent-scavenging by other firms looking to acquire skills rapidly vice growing them in-house. And if that were not enough, they must also account for talent shortfalls within DoD, facing end-users who potentially lack the skills necessary to fully engage in the product arena.

The complex technical nature of RAS demands individuals with diverse experiences and skillsets. Whether people are operators, programmers, designers, or engineers of RAS technologies, diverse experiences allow them to solve problems through collaboration and innovation. Strong educational backgrounds in STEM foster the ability to understand, design, operate, and constantly improve RAS. Cultural diversity is equally important as it fosters a comprehensive understanding of the global economy and the interdependence of nations to foster peace, security, and prosperity. Corporate executives worldwide recognize the importance of diversity in the workforce. Forbes Insights reported that senior executives believed "diversity is crucial to encouraging different perspectives and ideas that foster innovation."[31]

While most organizations value diversity from racial, socio-economic, and gender perspectives, one cannot ignore the importance of cognitive diversity, especially with respect to the RAS Enterprise. Cognitive diversity is "the extent to which the group reflects differences in knowledge, including beliefs, ideas, viewpoints, opinions, assumptions, preferences and perspectives."[32] An important subcomponent of cognitive diversity is cognitive style diversity, which relates to the differences in how people process information.[33] Cognitive style diversity is a key contributor to members of a team ascertaining different factors from the same piece of information. It can directly influence how those individuals react to data, and any underlying assumptions that they may make on how the group should move forward. In keeping with this assessment, Human Resources organizations "encourage greater cognitive diversity" when businesses conduct recruitment activities, particularly at senior levels because they recognize the importance of having the "right mix of personalities, skills and styles".[34] Technological disciplines that enable the innovation and progress within RAS rely heavily on cognitive diversity. Education is a foundational element in achieving a high level of cognitive diversity.

Even if a firm is doing everything right as far as growing its talent pool and ensuring cognitive diversity, it may still fall victim to "talent-scavenging" and find itself short on talent. A pertinent talent-scavenge example occurred in February 2015 when Uber recruited 40 personnel from Carnegie Mellon University's National Robotic Engineering Center (NREC). A self-funded division of Carnegie Mellon, NREC works on applications for DoD and private companies. With no resident robotic expertise, Uber entered the autonomous vehicle market through recruitment of NREC talent to include the center's director and several top project managers. Reportedly, Uber offered individual bonuses of hundreds of thousands of dollars and doubled salaries to attract key personnel.[35] This type of mass exodus creates a problem not only for academic institutions, but also for DoD. Currently, Uber owns the critical robotic expertise that was previously accessible to DoD. Future research conducted by these specialists belongs to Uber. Access will cost the government significantly more, or may be denied altogether.

Beyond managing their in-house talent, firms must also account for the need to compensate for DoD capabilities. Former Chairman of the Joint Chiefs of Staff Admiral Mullen predicted, "we will find out that, yes we [the military] are less than 1% [of the population] and we are living in fewer and fewer places and we don't know the American people and the American people don't know us."[36] This statement has implications for RAS beyond the growing civilian-military divide. In terms of military recruiting by state, the highest-rate contributors were Georgia, Florida, Idaho, Virginia and South Carolina. The District of Columbia was last. California had the highest number of enlistments in 2013 - a total of 18,987 - but the state supplies a relatively low percentage of its 18- to 24-year olds, the age group that fills the military rolls every year.[37] With respect to the talent and innovative thought found in areas such as Silicon Valley, it is this specific age group and talent base that DoD must prioritize. This may suggest that the recruits needed for optimally leveraging RAS technologies are being acquired by other institutions or dis-incentivized to join the military service. Businesses face the talent management challenge of helping a customer that "doesn't know what they don't know."

OUTLOOK – FUTURE HEALTH OF THE ENTERPRISE

From a defense industrial perspective, the outlook for the RAS Enterprise is mixed. While the RAS Enterprise is able to support national security resource requirements in the short term, impediments exist preventing the industry from achieving its full potential for defense applications. Long-term the outlook worsens as competitors challenge U.S. This is due in part to both political and social considerations. All is not lost however as the RAS Enterprise is still in a competitive position and with the right incentives can maintain a preeminent position in the global market place. Additionally, opportunity to regrow the relationship between DoD and other members of the Enterprise is strongest in the autonomy sector that perhaps any other. Each operating domain provides unique challenges for every service providing almost endless opportunities for innovation.

Currently the RAS Enterprise is able to support national security requirements as evidenced by leading edge programs such as General Atomics' MQ-9 Reaper and Northrop Grumman's RQ-4 Global Hawk and MQ-4C Triton. For larger RAS applications however, the levels of competition drop off which insinuates increased costs due to lack of competition. DoD has in recent years favored fewer large contracts over more numerous small contracts.[38] While this is beneficial for companies that win such a contract, it is harmful for the industry as a whole and puts more pressure on small and medium sized firms. Couple this with reduced availability of research funding[39] and one has a recipe for constricting competition to a reduced subset of potential companies. Fewer companies in the game lead to reduced surge and mobilization potential when needed by DoD.

Impediments negatively impacting the short-term (1-5 year) outlook for the RAS Enterprise include reduced competition, fewer providers in the DoD market, eroding technological advantages, and slow changes in laws and regulations impacting related industry. Reduced competition, bolstered by lack of a true open source architecture for RAS applications in DoD coupled with reduced availability of government funded research has led to increasing costs. Tight funding availability has forced some companies such as iRobot to divest their defense sectors to focus on commercial only.[40] Beyond a shrinking pool of companies participating in the RAS defense sector, the technical advantage of commercial RAS is suffering due to archaic regulatory and legal environments. Outdated restrictive regulations from the FAA and export controls are impeding growth in UAS sectors according to the firms visited. Although the FAA is working towards correcting its regulations as directed by Congress in 2012, progress has been slow.[41] Other legal changes allowing for further employment of autonomous systems in society are slowly coming about. The National Highway Traffic Safety Administration recently approved the classification of Google's self-driving car as a driver[42], a significant step in clearing the way to allow driver-less cars to legally drive by themselves without a human "safety-net". Contrasting this progress, testing of driverless convoys across the European Union (EU) have already been conducted[43], arguably a step ahead of individual passenger cars. Access to talent is also a potential area of concern. While matriculation rates are generally up for engineering degrees, 47 percent of Master's degrees and nearly 55 percent of Doctoral degrees awarded in the U.S. were earned by nonresident aliens,[44] most of whom would be unable to work on DoD programs due to citizenship requirements.

Looking ahead, the long-term (2020-2035) outlook for the RAS Enterprise will see the rise of peer competitors who may surpass U.S. RAS industrial capability. Globalization has had a profound impact on the rate of diffusion of technology. Following the Global Trends 2030 prediction, as power diffuses so will technology.[45] Technology promulgation and global competition will give rise to peer competitors capable of challenging U.S. preeminence in RAS technologies. A focus of top levels of the Japanese government is advancing robotic manufacturing as a means to reinvigorate Japan's economy as a global force.[46] Rising China is investing heavily in foreign companies including U.S. firms to acquire intellectual property and access to sensitive technology to feed its continued advancement.[47] Additionally, culture, policy, and legal challenges will restrain the U.S. growth potential in areas such as autonomy, as evidenced by the current regulatory environment and activities of advocacy groups such as the

ACLU over privacy issues[48] and the Campaign to Stop Killer Robots over the development of autonomous weapons systems.[49]

Despite these challenges, the U.S. RAS Enterprise is still in a preeminent position in the global marketplace today. The current glide path however will not maintain that preeminence. If the Government does not take action to facilitate the industry by removing non-value added bureaucracy and outdated legal structures, and encourage the defense industrial base by removing barriers to entry such as sparse funding consolidated into only a handful of multi-year contracts, it will find itself in one of two situations. Either the DoD will face significant affordability issues due to having to maintain numerous product variants as they "spinoff" from commercial ventures, or the DoD will have to specify system specifications reminiscent of the old "mil-spec" model that will inevitably leave the military with capabilities that seriously lag behind commercial state-of-the-art (and potentially other countries' militaries).

GOVERNMENT GOALS AND ROLES

The robotics and autonomous systems industry has an endless role in society. Commercial companies are developing autonomous technologies in areas such as delivery drones, vehicles and advanced manufacturing, just to name a few. Daily, inventors and engineers create breakthrough innovations. Because of the vast effectivity and efficiency opportunities associated with robotics and autonomy, the government has an obligation to participate in this industry for both economic and security reasons. The quest for advanced automation is an endeavor the U.S. must lead, and the government working in conjunction with industry provides the best chance for success. To ensure global leadership, the U.S. government must achieve goals associated with autonomy and understand its role in addressing the challenges with industry.

The first goal for government is to foster innovation in autonomy. Because of the economic potential and security considerations involved with autonomous systems, the government needs to develop an autonomy-savvy industrial base, ready to fully maximize the benefits of robotics and autonomous systems. To achieve those benefits, the government can play a vital role by providing targeted research grants to universities and research-oriented organizations towards autonomy.

The potential for robotics and autonomous systems is still in its infancy, where the science in basic research still needs much development. While investments in basic research often fall short, the government is the one entity that can afford to make big bets on disruptive and undeveloped technologies. DARPA, DoD research laboratories and Lawrence Livermore National Laboratory provide examples where the government targets specific basic research efforts, including those in autonomous systems. The DoD's proposed fiscal year 2017 budget allocates $71.8 billion for R&D, of which the department directs $3.6 billion towards the third offset strategy and $18 billion spread over the Future Years Defense Program.[50] Within that budget, autonomy will plays a significant role. By continuing these investments, the U.S. seeks to create and pursue unique advantages that it can exploit across the security and eventual commercial sectors.

The people who do the basic and applied research are critical to achieving a third offset. To meet the intended goals of the offset, the government has an obligation to create a large pool of young talent, eager and capable of creating breakthrough technologies and innovations. To gain further insight to this issue, in 2012 the President's Council of Advisors on Science and

Technology concluded that the U.S. would require one million additional STEM graduates over the next decade to retain technological primacy.[51] To meet this requirement, the Obama administration published a 5-year strategic plan to revitalize STEM education, detailing steps for addressing student recruitment and attrition.[52] Initiatives like the 5-year plan will help, but the U.S. also needs to rethink how it creates new engineers. New to the education scene in 1997, Olin College created an experience-based approach to teaching engineers. There, students work in teams of five to solve real-world engineering problems and then are taught relevant theory on an "after-need" basis. This technique creates an appetite for information not replicated in traditional educational models. As a result, companies actively seek out Olin 4-year graduates, typically receiving the same compensation as a graduate with a Master's degree. To increase the talent pool required for the RAS Enterprise, the U.S. must continually evolve its educational policies and methods.

Another way for government to foster innovation is to update or create new laws that encourages industry to pursue advancements in autonomous systems. One example are the current Federal Aviation Administration regulations, which stifle businesses looking to pursue advances through the use of unmanned aerial systems. According to a study by the Association of Unmanned Vehicle Systems International, the U.S. loses more than $10 billion per year that it fails to adequately integrate UASs into the national airspace system.[53] While many of the uses for UASs are not DoD related, the technologies pursued such as software, command and control, and sense and avoid correlate to military applications. Similarly, the U.S. government needs to lead the effort to update the International Regulations for Preventing Collisions at Sea law, which will allow unfettered growth and use of unmanned maritime systems. Finally, the government can help facilitate the use of unmanned ground systems by creating laws that encourage auto consumers and manufacturers to pursue driverless vehicles, a capability that will enable future ground forces. By changing laws, the government will show its commitment to autonomous systems, adequately posturing the U.S. for the future.

A second goal for government is to leverage technological advances in the RAS commercial market in order to create an asymmetric military advantage. To effectively tie in with industry, the government must maintain a close and cooperative relationship based on trust and understanding. For the government, providing clear policy guidance to industry is the first step for establishing a solid relationship. DoD Directive 3000.09 provides policy for the use and development of current and future autonomous systems, but lacks the strategic direction needed for long-term acquisition implementation. Current guidance allows autonomous weapon systems to conduct non-lethal, non-kinetic attacks, but requires human supervision when selecting and engaging targets.[54] Furthermore, the directive does not allow autonomous weapon systems to select humans as targets.[55] To achieve the full benefits of autonomy, the DoD needs to create policy that calls for weapon systems to perform the dull, dirty and dangerous missions in the A2/AD environment, giving them autonomous lethal decision-making capability in the most contested and consequential battles. Providing this direction allows industry to develop autonomous lethal technologies knowing that a return on investment is possible.

In addition to communicating clear policy, the DoD also owes industry clear requirements and a smoother acquisition process. Because of the rapid changes in commercial RAS technologies, the DoD struggles to keep up with relevant applications. To prevent the DoD from being "out of the loop," Secretary Carter established the first Defense Innovation Unit – Experimental (DIUx) in Silicon Valley. Providing a DoD presence, DIUx aims to create and facilitate relationships with new innovators while scouting for breakthrough and emerging technologies.[56] By locating in Silicon Valley, the DoD surrounds itself in the STEM talent pool and venture capitalism, where companies spend large amounts of R&D by leading researchers and innovators. Increasing awareness in the RAS sector, DoD representatives become more aware of the potential capabilities applicable to the DoD, potentially resulting in clearer requirements for industry. Conversely, the DoD should incorporate DIUx into the acquisition process as subject matter experts on emerging commercial capabilities.

Because of the arduous and slow acquisition system, companies struggle to make financial targets and must accept financial risk when dealing with the DoD. To help industry, the DoD must remain committed to constant improvement to its acquisition system, as well as upholding its end of the contracts. During industry visits, we found two companies that commented on how the DoD consistently missed payments in excess of 60 days. This is a poor business practice and requires smaller companies to develop a financial fortitude that may be unrealistic, deterring other companies from contracting with the DoD. Moving forward, the DoD must continue to refine its processes.

Another method for leveraging advances in the commercial sector is for the DoD to create a collaborative environment that connects operators, research laboratories, academia and industry. DARPA does a great job working with all of those entities by awarding contracts, but often does so in stovepipes. To avoid those stovepipes, the National Network for Manufacturing Innovation (NNMI) is an initiative that coordinates public and private investment in emerging advanced manufacturing technologies, bringing industry, academia and government partners together.[57] Currently, six institutes comprise NNMI, where each institute allows for intellectual property sharing among partners, facilitating faster technological growth. In the case of Next Flex, an institute for flexible hybrid electronics manufacturing, the Air Force Research Laboratory oversees $75 million dollars of government investment. Using this model of collaboration, the DoD can create an initiative that focuses the RAS industry on autonomous systems, increasing the possibility of achieving technologies associated to the third offset.

An International Perspective – RAS in Japan

When thinking about robots, Japan is an innovative and a culturally accepting country with a knack for introducing new forms and functions to include manufacturing, pets, and humanoids. Japan's strength is currently in industrial robots, where it is the top supplier in the world. As of 2012, Japan accounted for approximately 50% of the global share of robots, as well as more than 90% worldwide in the field of key robot elements such as precision reduction gears, servo motors and force sensors.[58]

Japan requires drastic changes due to three major issues: an aging due to low birth rates; problems with the percentage of young workers in the workforce; and the amount of social health entitlements drawn by its citizens. Additionally, other nations, to include the U.S., China, and those in Europe, are investing heavily into robotics for economic growth and national defense. Included in those investments are advances of complementary technologies such as information technology, networking, and artificial intelligence software.

Japan developed its "Three Pillars" strategy to realize its intent to address those three issues. The pillars include; "becoming the robot innovation hub of the world; [being] the world's leading robot utilization society, (SME, nursing/medical care, infrastructure, etc.); and leading the world with robotics in [Internet of Things] era (Robot with IT utilizing big-data, network and AI)."[59] Additionally, Japan's recent change to their defense posture allowing for a more defensive posture alongside collateral allied support, could open up additional possibilities for the inclusion of military robotics investments and none closely align collaboration efforts in the future.

PART II ESSAYS ON MAJOR ISSUES

A. LEVERAGING CENTERS OF INNOVATION AND DIUX WITH RESPECT TO RAS CAPABILITIES

Our seminar toured several centers of innovation, universities, and start-up incubators in Boston, Pittsburgh, and Silicon Valley. For RAS, the bulk of future breakthroughs in technology and capability will proliferate from these locations. RAS is beginning to transform non-defense industries such as healthcare, transportation, and retail through rapid efficiencies in automation and risk reduction. The coming decades signal a profound change in the way that humans interact and conduct their daily lives. RAS technologies will bring greater autonomy and artificial intelligence into every corner of our lives. These same technologies represent significant opportunities for DoD to leverage but it must partner and cooperate with centers of innovation, academia, and industries and articulate its needs to these parties. There is a clear and compelling need for DoD to expand its influence and current innovation initiatives with Silicon Valley and beyond.

Long recognized by DoD, Silicon Valley has been the front of military and now predominantly commercial innovation. With flagship companies, like Google in Mountain View California, investing in autonomous cars, a large number of high tech companies and startups, Silicon Valley is an obvious RAS innovation center that DoD is reaching out to with its Defense Innovation Unit Experimental (DIUx).

In Cambridge and the greater Boston area, Massachusetts Institute of Technology, Lincoln Laboratories and other universities have spawned a large innovation ecosystem with RAS companies like Boston Dynamics and iRobot representing some of the best- known fruits. The Boston and greater Massachusetts area is home to a number of small business incubators, including the largest, MassChallenge, who's model was so successful in Boston that they are exporting it to London, Israel, Mexico and Switzerland.

Less known, except perhaps within the RAS communities, Pittsburgh is also a dynamic innovation center. Centered on research at Carnegie Mellon's Robotics Institute, Pittsburgh is home to a number of research and engineering organizations and companies. Similarly, Pittsburgh has small business incubators or accelerators such as Innovation Works to assist entrepreneurs to start and link up with mentors and venture capital investment.

Other innovation centers are located in Texas with the University of Texas in Austin and Arlington with their on-going research in autonomy and robotics; Atlanta with Georgia Tech's Institute for Robotics & Intelligent Machines and its high tech incubator; and even in Columbia, South Carolina around the University of South Carolina, its Robotics Research Lab and incubators such as ITology. Common to all innovation centers are research universities coupled with entrepreneurs, small business mentorship and investors. For RAS, DoD must ensure its policies and actions to achieve The Third Offset Strategy include these innovation centers.

DoD is encouraging broader communication through its Defense Innovation Market (DIM) website, notably with its recent LRRDP, where it is seeking "novel ideas to shape its future, and officials are looking to industry, small business, academia, start-ups, the public – anyone really – to boost its ability to prevail against adversaries whose access to technology grows daily."[60] As DoD culls these ideas, the first focus is on near-term, game-changing concepts. LRRDP represents a significant opportunity for DoD to communicate needed shared awareness of its capability needs for The Third Offset Strategy and it must foster strong partnerships and cooperation with both defense and commercial industries, academia, and centers of innovation if it is to be successful in pursuing the Third Offset Strategy.

It is also clear that DoD must clear communicate its need for centers of innovation to Congress. Recently, the House Armed Services Emerging Threats and Capabilities subcommittee as part of the draft 2017 National Defense Authorization Act (NDAA) has included language to limit the DIUx budget to 80% of the President's budget request and included a mandate to "report to the congressional defense committees on the charter for the Defense Innovation Unit Experimental (DIUx) and the use of funds to establish and expand it." [61]

While the committee was otherwise supportive of the effort, Congress may be positioning to influence placement of future DIUx sites. The committee also noted they are "concerned by the pinpoint focus on one geographic region" and the use of "significant funding" in the organization's "nascent period."" [62] The current director of DIUx, Mr. George Duchak, noted in October 2015 "once the local unit has determined the best ways to engage the innovation community, he said, DIUx-like units could open in other major tech innovation hubs such as Boston, Austin, Cincinnati, Seattle and others." Within Congress, there will be great interest in where DoD choses to locate their next DIUx offices and some locations are potentially more fruitful than others for the RAS enterprise. Silicon Valley is not the only innovation center and DoD is limiting their influence if they do not seek out and engage as many RAS innovation centers as possible throughout the U.S.

As DoD addresses the technological imperatives of the Third Offset, RAS will play a key role in their evolving strategies over the next 20 years and beyond. Ability to innovate and speed of innovation will be the key discriminators, not the technology itself which is available worldwide. No technology will maintain a competitive advantage for long. To build on DoD's policy changes to enhance innovation and adaptation of commercial technology, DoD should take steps to improve current policies to leverage RAS innovation centers:

- DoD should articulate their strategy or strategies for The Third Offset, in particular with respect to RAS, to the maximum extent possible to guide investment internal to DoD as well as investment by companies seeking to do business with DoD.
- DoD should expand outreach to, communication with and presence in RAS innovation centers beyond Silicon Valley, such as Boston, Pittsburgh, Atlanta and Austin.
- DoD should foster dual defense and commercial models with start-up firms within these innovation centers.

RAS technology will evolve and multiply. Leveraging innovation centers continuously over the coming decades will be key to achieving the U.S.'s continued competitive advantage.
(Author: Ms. Johanna Eliot)

B. ISSUES FOR CONSIDERATION: DIVERSITY, ETHICS, CIVIL-MILITARY DIVIDE, AND TALENT MANAGEMENT

The Value of Cognitive Diversity

The complex technical nature of RAS demands people with diverse experiences and skillsets. Whether people are operators, programmers, designers, and engineers of RAS technologies, diverse experiences allow them to solve problems through collaboration and thinking "outside the box." Strong educational backgrounds in Science, Technology, Engineering, and Mathematics (STEM) foster the ability to understand, design, operate, and constantly improve RAS. Cultural diversity is equally important as it fosters a comprehensive understanding of the global economy and the interdependence of nations to foster peace, security, and prosperity. Corporate executives worldwide recognize the importance of diversity in the workforce. Forbes Insights reported that senior executives believed "diversity is crucial to encouraging different perspectives and ideas that foster innovation."[63]

While most organizations value diversity from racial, socio-economic, and gender perspectives, one cannot ignore the importance of cognitive diversity, especially with respect to the RAS enterprise. Cognitive diversity is "the extent to which the group reflects differences in knowledge, including beliefs, ideas, viewpoints, opinions, assumptions, preferences and perspectives."[64] An important subcomponent of cognitive diversity is cognitive style diversity, which relates to the differences in how people process information.[65] Cognitive style diversity is a key contributor to members of a team ascertaining different factors from the same piece of information. It can directly influence how those individuals react to data, and any underlying assumptions that they may make on how the group should move forward. Technological disciplines that enable the innovation and progress within RAS rely heavily on cognitive diversity. Education is a foundational element in achieving a high level of cognitive diversity.

One challenge within the U.S. is the retention of those with the educational backgrounds needed in the RAS industry. In 2014, more than 99,000 students graduated with an Engineering bachelor's degree, a 6-percent increase from the previous year. Likewise, graduation rates for an Engineering Master's degree increased by 4 percent, with 51,690 students. Doctoral degrees had a 5 percent increase from 2013-2014 with a total of 11,309. What's even more impressive is that this is a 35 percent increase compared to 2005. While the upward trend in Engineering degrees is beneficial to the U.S. economy, it is important to note that a portion of those graduates are students from other countries. Also known as nonresident aliens, these students increased their participation rates over previous years. 47 percent of Master's degrees and nearly 55 percent of Doctoral degrees were earned by nonresident aliens.[66]

The participation of a high number of nonresident alien students, and subsequent graduates, does not necessarily bode well for the RAS industry. "Many won't remain in the United States, either because of improved opportunities in their home countries, U.S. restrictions on immigration, or family responsibilities."[67] For those graduates who are interested in continuing their studies or joining the workforce within the United States, their non-resident alien status will likely limit their ability to work for defense-related companies. This could have a significant impact on defense companies as they compete for future talent.

In our visits to both Boston and Pittsburgh, we noted that strong affiliations exist between robotics companies in those areas and the universities within the local region. One explanation given for this connection was that graduates from those programs were a "known commodity" in that companies were well aware of the academic programs and comfortable with the knowledge and capabilities that graduates would demonstrate. Another observation was that institutions affiliated with universities were very likely to hire individuals who graduated from their programs. In both cases, while this would certainly help post-graduation placement rates, it does not necessarily afford cognitive diversity, if most new hires come from similar program. As with

cognitive diversity, overall diversity characteristics are likely damped by repetitive hiring practices of organizations. If the businesses repeatedly hire graduates who assimilate from the same few universities, their opportunity to expand and create a diverse workforce is limited. In order to benefit from the diversity of perspective, companies must be willing to expand their hiring practices to ensure that they cast a wide net in their search for talent as they build their teams for the future.
(Author: CDR Suzanne Johnson, USN)

Ethics and the Use of Autonomous Weapons Systems

The use of Lethal Autonomous Weapons Systems (LAWS) in warfare directly relates to the Just War Theory of *Jus in bello* ("justice in war). *Jus in bello* are the set of ethical, moral, and legal principles that determine how war is fought, both in terms of how the state conducts its internal affairs and how the enemy is engaged externally. Understanding the ethical use of autonomous weapons systems requires an understanding of its definition. DoD Directive 3000.9 defines an autonomous weapon system as-"a weapon system 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."[68]

There are two key principles of *Jus in bello* applicable to the use of LAWS in armed conflict. The first principle requires that states make a distinction between combatants and non-combatants, and that the latter are not a justifiable military target. This principle most certainly applies to LAWS. In the case of UAS, the U.S. currently uses human operators to identify and engage targets of military significance, to include individual human combatants. Very often, an actual strike on such a target occurs many days before airborne surveillance to ensure that the target is legitimate. DoD policy states that UAS will have human interaction to ensure that the combatant and non-combatant distinction is appropriately made, through the use of semi-autonomous systems where the target is either selected or preselected by a human.[69] The second principle is the use of minimum force to achieve the military ends. In the context of UAS, the U.S. goes to great lengths to meet this ethical responsibility. Typical UAS carry a small payload and conduct targeted strikes rather than destroying large swaths of land as was previously done in the 20th century.

While the U.S. military strives to adhere to the principles of *Jus in bello,* there are strong opinions of caution for DoD to consider with respect to the ethical use of LAWS. The Campaign to Stop Killer Robots is a non-profit organization that advocates for an international ban on use of LAWS in warfare. Their central position is that autonomous weapon systems are inherently immoral, they lack the decision-making capability of humans under highly dynamic circumstances, and strategically, they could make the decision to go to war imprudently more convenient.[70] This position has merit, though inherent weaknesses. Principally, it relies on an assumption that the technology of AI is inferior to human in terms of distinguishing between combatants and non-combatants on the battlefield. This may be the case presently, but it will not likely be so for much longer. Their latter position on the ease of going to war is certainly worth study and discussion, but is ultimately a public policy question, rather than a military one. Human Rights Watch, an international non-governmental organization that advocates for human rights, holds a similar position. In essence, it supports a ban on fully-autonomous weapons systems, and an accompanying requirement that unmanned systems have "meaningful human control" over any weapons functionality.[71] Our seminar had the opportunity to discuss this issue with another subject matter expert who argued that a fully-autonomous weapon system presents a strategic risk in that such a system could fail in ways that cannot not be predicted, leading to disastrous outcomes. In this view, the human becomes an agent of moral decision-making and as a fail-safe against such possibilities, however unlikely. Our seminar's position is that there needs to be further dialogue on the ethical use of LAWS amongst the international community and that the DoD will be an important stakeholder in this dialogue as it pursues the Third Offset Strategy. (Author: Mr. Sam Harmon)

The Civil-Military Divide

While DoD's outreach in schools across the nation represents a key way to encourage interest in STEM and therefore helping to cultivate future cognitive diversity, DoD must recognize the implications of a growing civil-military divide. In pursuit of the Third Offset Strategy, DoD must prioritize the human dimension and focus efforts to address the growing civilian-military divide by expanding recruiting efforts, overcoming isolation from the American people and better understand the impacts on both academia and industry. The key challenge is how to attract the right personnel to both help develop the ideas and leverage the technology associated with the Third Offset Strategy. This requires a deliberate review of the growing divide between the military and the civilian sector, essentially a cognitive disconnect with the DoD and the general American populace. DoD must address three primary areas of concern to ensure that the DoD has the right personnel in its ranks.

The first is the overdependence on recruiting within the military family. A 2013 DoD survey highlights that four out of five recruits have a close relative in uniform. For more than 25% of 2012 to 2013 recruits across the country, the relative is a parent who has served. As the military faces budget constraints and continued reduction if force structure this pool of personnel will likely produce less of the talent required to employ the eventual third offset strategy. To be successful in this endeavor will require a deliberate approach to address the second largest concern and to fundamentally shift where and who the military recruits.

The second concerns the small percentage of the population that currently serves in the military. While this is arguably a bi-product of the shift to an all-volunteer force in the 1970s, reinstating the draft is not likely the best solution. Former Chairman of the Joint Chiefs of Staff, Admiral Mullen reinforces the concern from a different perspective. "The disconnect between the civilian and military worlds is partially because only a fraction of the population serves and those in uniform increasingly hail from fewer, primarily rural, areas of the country. To the degree we are out of touch I believe it is a very dangerous force," Mullen said in a speech to a conference on military professionalism at the National Defense University in Washington.[72] Figure 2 below reinforces this point and highlights precisely where the military is achieving the preponderance of its recruiting. In order to capitalize on the right talent to achieve the third offset, the military will need to expand its recruiting areas that are more in line with areas that are fostering the STEM talent and innovation in America.

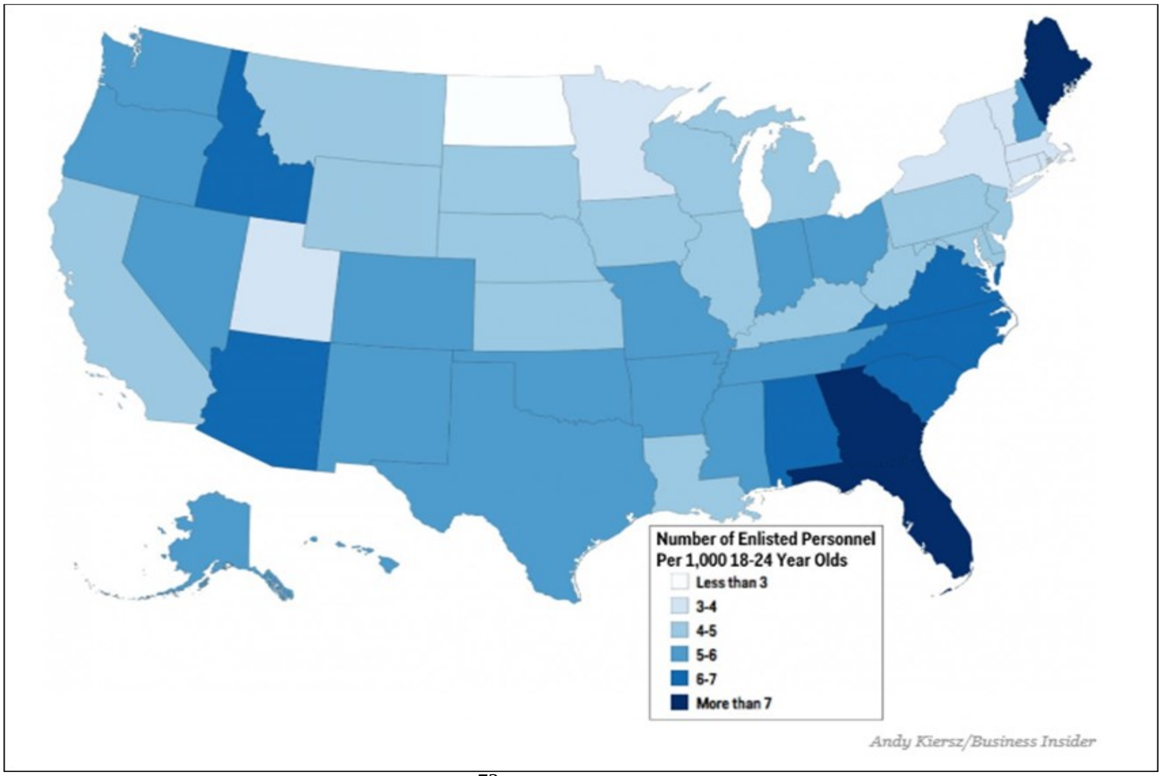

Figure 2. Map of Military Recruiting[73]

The third area of concern is the force posturing or basing in the United States and the impacts this has had on isolating the military community from the general American populace. Base closures have consolidated troop populations onto a dozen large "joint" bases and other huge installations like Ft. Bragg, home to 55,000 soldiers and their 74,000 dependents.[74] Large military bases in small and remote areas generally insulate military personnel and their families from major population areas. Local communities often are made of former military, and deeply connected to the military, thus are equally isolated. This separation is exasperating the growing disconnect with the American people as less connective tissue exists between the military and the American people. A lack of direct access to the innovation centers in America, a true understanding of the needs of the military with respect to the third offset coupled with the insulation of these military bases and communities has had a direct effect. The isolation impacts are compounded when you compare innovation centers against the fact that almost half of the 1.3 million active-duty service members in the U.S. are concentrated in just five states — California, Virginia, Texas, North Carolina and Georgia.[75]
(Author: LTC Theodore Shinkle, USA)

Talent Management

The R&D efforts of academic cadres and military engineers provided the intellectual foundation for the First and Second Offset Strategies. Today, the academic/military engineering population required to support the Third Offset Strategy is ostensibly insufficient. The problem extends beyond the narrow field of robotics. The country’s leaders are concerned with a national science, technology, engineering and mathematics (STEM) problem. In fact, in 2012 the President’s Council of Advisors on Science and Technology (PCAST) concluded that the US would require one million additional STEM graduates over the next decade to retain technological primacy.[76] High attrition rates exacerbate the STEM production issue in the first two years of undergraduate programs. Of all bachelor's degree candidates entering college from 2003-2009, only 28 percent entered STEM fields. In robotics education specifically, China produces 600 percent more robotics PhDs annually than the US, approximately 15,000 to 2500, respectively.[77] Further, robotics engineering curricula bears a more significant burden because it is multi-disciplinary in nature thereby requiring students to be functional in mechanical, electrical, and computer engineering, just to name a few.

In academia, robotics talent retention is becoming increasingly more difficult. Robotics and artificial intelligence experts are leaving university environments to join the ranks of industry-leading firms such as Google, Microsoft, IBM, and Uber. From a market demand perspective, companies are recruiting from academia in order to compete in an artificial intelligence application market expected to reach $11.1B by 2024.[78] From a supply standpoint, professionals transition from academia to commercial firms for numerous reasons to include higher salaries, entrepreneurial aspirations, reduced project timelines, customer validation, and overall job satisfaction. Many of these factors are a direct result of reductions in federal funding for research. For example, although R&D funding as a percentage of GDP has remained relatively flat over the years, the source of funding has shifted considerably. In the early 1960s, the federal government was the primary driver of U.S. R&D, accounting for approximately 65 percent of all funding. This trend continued until the end of the Cold War when business funding became the new driver as federal funding plummeted. Today, talented engineers are choosing to work for private firms to conduct research that historically occurred in government-funded facilities.

A fundamental change must occur in the educational arena to grow the talent needed for RAS. Our seminar's visit to Olin College in Needham, Massachusetts afforded us considerable perspective into an educational model that if adopted in greater scale across the nation, could spur greater interest in STEM and robotics amongst American students. The Olin model is an experience-based model in which students learn engineering by building. Beginning in their first semester, students work in teams of five to solve real-world engineering problems. Typically, projects come from government agencies, corporations, and small businesses. Students are given problem sets and taught relevant theory on an 'after-needed' basis. This technique creates an appetite for information not found in traditional educational models. Additionally, the Olin model also provides the all-important context that is often missing from typical undergraduate engineering programs. As a result, students see the utility of course material first-hand and remain far more engaged in their curriculum. Further, the Olin model prepares students to be functional engineers from day one by incorporating the pressures of team dynamics, budget constraints, and timeline adherence. Upon graduation, Olin places 100 percent of its students with 40 percent continuing on to graduate-degree programs.[79]

The Olin model should be adopted across the country to help promote robotics engineering and artificial intelligence. To date, three major universities have examined the Olin model; however, the national goal should be to establish one or two programs in each state. Moreover, all service academies have limited robotics exposure. The academies should also develop robotics programs modeled after Olin's. Best case, the military can build a robotics/artificial intelligence cadre to assist in creating the technology of the future. Worst case, the military will build a core of operators who understand the logic behind the systems that conduct future warfare.

(Author: Lt Col Travolis Simmons, USAF)

C. THE VALUE OF AUTONOMY

Autonomy is often construed as a condition that either exists or does not. However, a more nuanced understanding of the term conceives of a range of authority delegated to a machine. At the low end of the spectrum, the computer merely assists in the decision making function of the human. At the other extreme, the computer has full discretion to make decisions, perform actions, and determine whether to notify the human that the decisions and actions have been taken.[80] Deputy Secretary Work described autonomy as "nothing more than saying we're going to delegate authority to an unmanned system."[81] However, he added "we will not delegate lethal authority for a machine to make a decision. The only time we'll delegate [such] authority [to an autonomous system] is in things that go faster than human reaction time, like cyber or electronic warfare."[82] This qualifier offers little substantive reassurance to those who oppose autonomous systems having lethal authority.

Autonomous systems are bound by synthetic reasoning. State-of-the art computing is powerful, fast, and precise. It is capable of performing calculations that are orders of magnitude greater than anything achievable by the cleverest human mind. Currently, computers are only capable of performing *deduction*; but they are very good at it. The human mind is capable of deduction, though at a slower and less powerful scale than a computer, but it can also perform both *induction* and *abduction*. This is why the most effective modern analytical systems involve the teaming of a human and a machine. To understand the distinction between these types of reasoning, it is useful to construe *analysis* as having three components: a rule, a case, and a result. Which type of reasoning is involved depends on the order in which these elements occur in the rational process. As illustrated in Figure 3 below, *deduction* begins with a rule (e.g. when I arrive at a red traffic light, I must stop the car), is followed by a case (I have arrived at a red traffic light), and then applies the rule to the case for the result (therefore I will stop the car). With *induction*, the analysis first observes a case (dark clouds have accumulated overhead), and then observes the concomitance of a result (droplets of water are falling from the sky), and from that follows a theory of causal correlation (I surmise the falling water is coming from the dark clouds). Thus, induction involves the mental correlation between two observed phenomena. *Abduction*, by contrast, involves the observation of a single phenomenon and imagines, or speculates, what unobserved conditions might pertain to that observation. An example of

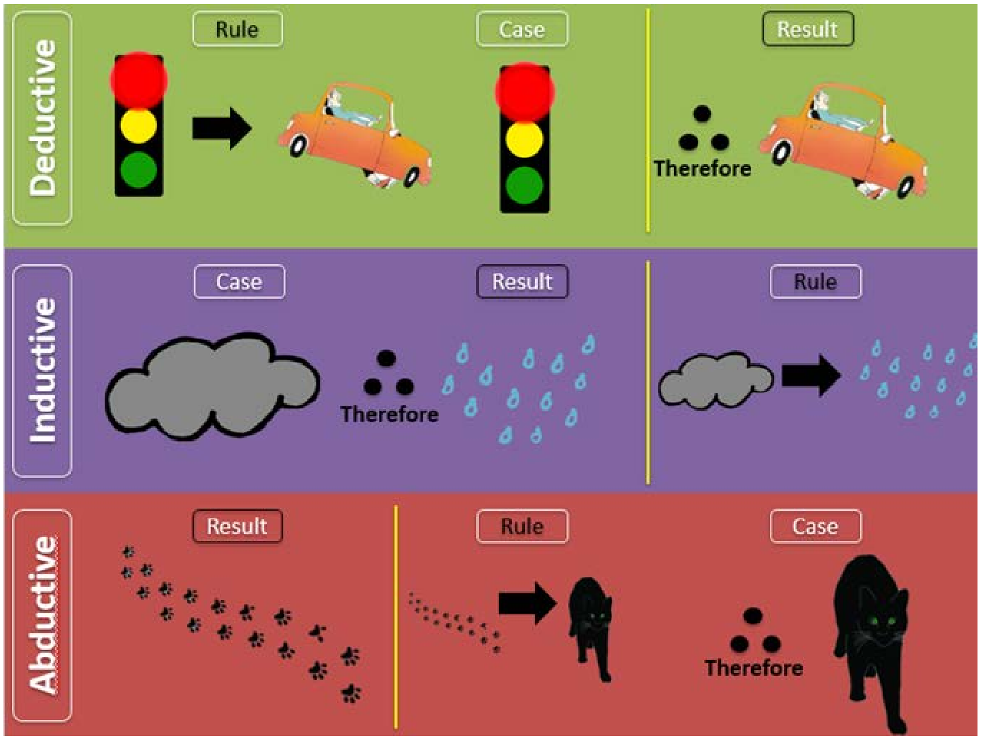

Figure 3-Deductive, Inductive and Abductive Reasoning

abduction, or hypothesis reasoning, proceeds as follows: first, the observation of a result (uniformly shaped impressions appear in a consistent pattern in the dirt), which leads to the formulation of a rule (I believe these are impressions caused by the feet of an animal ambulating in that direction), the predictive power of which is tested in an individual case (I will follow these footprints and believe they will lead to the animal).[1]

The Third Offset strategy properly considers increased autonomy as a central aspect of emerging technology that could remove or alter a numerical conventional force imbalance relative to a U.S. adversary. While autonomous technology has undeniable defense applications, it likewise will play a huge role in the commercial market. Due to the nature of autonomous technology, it will likely be a simple matter to repurpose civilian technology to military use. Given this, rather than call for a prospective ban, a superior approach is for the U.S. to pursue primacy in the field, maintain effective control of relevant intellectual property, pursue arms control-like regimes to contain proliferation, and to implement the technology in the most humane and responsible way possible. This will include adapting the optimizing such technology to enhance human judgment unless and until such systems become independently capable of inductive and abductive reasoning. When and if this occurs, the primary challenge will be to imbue such platforms with a value system that comports with our own. It is pleasant to imagine a future where the nations of the world unite, agree that autonomous weapons systems must never come about, and conspire to effectively ensure they never do. However, a more responsible course of action for the U.S. would be to soberly evaluate the trends and dynamics at play, make a forecast based on these, and prepare accordingly.
(Author: Lt Col Matthew Kent, USMC)

CONCLUSION

To achieve the necessary Third Offset RAS related capabilities, DoD must enhance understanding of the emerging RAS Enterprise to develop agile processes for leveraging advances in the private sector and academia. Our seminar had a unique opportunity to discuss RAS technologies with representatives from academia, industry, and government in both the U.S. and Japan. The RAS Enterprise is relatively healthy at this point, however now is the time for DoD to strategize and execute R&D and procurement investments in RAS technologies DoD must address changes in the Defense Acquisition System that facilitate innovation and rapid fielding of RAS capabilities. It must also forge stronger partnerships with academia and industry to ensure the cultivation of the necessary skills and talent required within the RAS Enterprise. A more detailed summary of our seminar's recommendations is included in the table below.

Challenges for RAS Enterprise:	**Recommendations**
Fostering cultural change to enable greater acceptance of emerging RAS capabilities	Promulgate DoD policy (e.g. DODI 3000.09) that provides for the use of offensive autonomous lethal decision-making capability in the most contested and consequential battles.
	DOD continue investment into basic research in autonomy. Create new laws, regulations and policies that encourage industry to pursue advancements in autonomous systems.
Navigating the defense acquisition system	Revise acquisition and security regulations and policies to allow broader international collaboration.
	Incorporate DIUx in the requirements and acquisition process as subject matter experts on emerging commercial capabilities.
	DoD should articulate their strategy or strategies for The Third Offset, in particular with respect to RAS, to the maximum extent possible to guide investment internal to DoD as well as investment by companies seeking to do business with DoD.
	DOD must be committed to constant improvement of DAS.
	DOD must consistently meet contract requirements (e.g. timely payments).
Managing talent within the RAS enterprise	Continue investment in STEM education to build the workforce of the future for DoD and industry.
	The Nation should rethink how it creates new engineers by investigating the Olin experiential learning model
	Ensure hiring processes facilitate cognitive diversity.
	Revise prohibition against non-US citizens working for US companies on DoD programs.
Capturing the breadth of innovation across the RAS enterprise	DOD continue investment into basic research in autonomy. Create new laws, regulations and policies that encourage industry to pursue advancements in autonomous systems.
	DoD create an initiative that focuses the RAS industry on autonomous systems using the NNMI model.
	DoD should articulate their strategy or strategies for The Third Offset, in particular with respect to RAS, to the maximum extent possible to guide investment internal to DoD as well as investment by companies seeking to do business with DoD.
	DoD should expand outreach to, communication with and presence in RAS innovation centers beyond Silicon Valley and Boston to Pittsburgh, Atlanta and Austin.
	DoD should foster dual defense and commercial models with start-up firms within these innovation centers.

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