Maximizing the Utility of Naval Unmanned Systems

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Abstract— **The expanding use of armed, unmanned systems is not only changing the face of modern warfare, but is also altering the process of decision-making in combat operations. These systems have been used extensively in the conflicts in Iraq and Afghanistan, and will continue to be equally relevant—if not more so—as the United States' strategic focus shifts towards the Asia-Pacific region and the high-end warfare this strategy requires.**

The Department of Defense's vision for unmanned systems is to integrate these systems into the Joint force for a number of reasons, but especially to reduce the risk to human life in high threat areas, to deliver persistent surveillance over areas of interest, and to provide options to warfighters that derive from the inherent advantages of unmanned technologies—especially their ability to operate autonomously.

The U.S. Navy has been on the forefront of UxS development. The 28th CNO Strategic Studies Group (SSG) spent one year examining this issue, and its report spurred increased interest in—and emphasis on—unmanned systems Navy-wide. Leveraging the SSG's work, recent Navy focus has emphasized the need to enhance UxS command and control (C2) capabilities to allow one sailor to control multiple systems in an attempt to lower Total Ownership Costs (TOC) of unmanned systems. This link between increased autonomy and decreased TOC has become an important theme in Navy UxS development.

One of the most pressing challenges for the DoD is to reduce the prohibitively burdensome manpower requirements currently necessary to operate unmanned systems. Military manpower makes up the largest part of the total ownership cost of systems across all the Services. But how expensive *is* military manpower? To better understand this compelling need to reduce these manpower requirements, it is important to understand the costs of manpower to the U.S. military writ large.

With the prospect of future flat or declining military budgets, the rapidly rising costs of military manpower, and the increased DoD emphasis on total ownership costs, the mandate to move beyond the "many operators, one-joystick, one-vehicle" paradigm for UxS that has existed during the past decades for most unmanned systems is clear and compelling. But this drive for autonomy begs the question as to what this imperative to increase autonomy comports and what, if any, downside occurs if we push UxS autonomy too far. Is there an unacceptable "dark side" to too much autonomy? There are concerns regarding the extant of autonomy military systems ought to have. Unless or until these concerns are addressed, these systems may never reach their full potential.

While we accept advances in other aspects of UxS improvements such as propulsion, payload, stealth, speed, endurance and other attributes, we are still coming to grips with how much autonomy is enough and how much may be too much. This is arguably *the* most important issue we need to address with unmanned systems over the next decade.

Unmanned systems become more autonomous in direct proportion to their ability to sense the environment and adapt to it. This capability enables unmanned systems to achieve enhanced speed in decision making and allows friendly forces to act within an adversary's OODA (Observe, Orient, Decide, and Act) loop. But while we need unmanned systems to operate inside the enemy's OODA loop, are we ready for them to operate without our decision-making, to operate inside *our* OODA loops?

The Defense Science Board report, *The Role of Autonomy in DoD Systems*, put it this way: Instead of viewing autonomy as an intrinsic property of unmanned systems in isolation, the design and operation of unmanned systems needs to be considered in terms of human-systems collaboration…A key challenge facing unmanned systems developers is the move from a hardware-oriented, vehicle-centric development and acquisition process to one that emphasizes the primacy of software in creating autonomy. Unless or until these issues are addressed, the full potential naval unmanned systems may never be realized.

Keywords—unmanned systems, autonomy, artificial intelligence

I. INTRODUCTION

In his best-selling book, *War Made New*, military historian Max Boot notes, "My view is that technology sets the parameters of the possible; it creates the potential for a military revolution." One of the most rapidly growing areas of innovative technology adoption involves unmanned systems. The exploding use of military unmanned systems (UxS) is already creating strategic, operational, and tactical possibilities that did not exist a decade ago.

The expanding use of armed, unmanned systems is not only changing the face of modern warfare, but is also altering the process of decision-making in combat operations. These systems have been used extensively in the conflicts in Iraq and Afghanistan, and will continue to be equally relevant—if not more so—as the United States' strategic focus shifts towards the Asia-Pacific region and the high-end warfare this strategy requires.

At the highest levels of U.S. strategic and policy documents, unmanned systems are featured as an important part of the way the Joint force will fight in the future. The 2014 *Quadrennial Defense Review* notes, "Continuing a trend that began in the late 1990s, U.S. forces will increase the use and integration of unmanned systems."

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Outside observers have highlighted the importance of unmanned systems in achieving U.S. strategic goals. In his article in *Foreign Policy*, "The New Triad," Admiral James Stavridis identified unmanned systems as one of the three pillars of this New Triad, noting, "The second capability in the New Triad is unmanned vehicles and sensors. This branch of the triad includes not only the airborne attack "drones"…but unmanned surveillance vehicles in the air, on the ground, and on the ocean's surface…Such systems have the obvious advantage of not requiring the most costly component of all: people."

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Going forward, the U.S. Department of the Navy (DoN) has stated strongly that it intends to prioritize the development and fielding of unmanned and autonomous systems. In a recent Navy study assessing alternative Fleet architectures, a Navy team recommended increasing the number of unmanned surface and subsurface systems in the Fleet circa 2030 from the currently planned 10 to a total of 136[1]. Similar fleet architecture studies undertaken by MITRE and the think tank Center for Strategic and Budgetary Assessments (CSBA) also recommended significantly increasing the numbers of unmanned system in the future fleet[2].

The Navy recognizes, however, that simply increasing the number of unmanned systems that it fields will not be sufficient—the systems themselves must become more advanced. To that end, the Naval Research and Development Framework makes clear that technology development must focus on maximizing these systems' capabilities. Specifically, it calls for increasing the "flexibility and reach of the naval force through incorporation of autonomous and disaggregated systems," while also enhancing "dynamic, synchronized actions across forces."[3]

One of the most pressing challenges for the DoD is to reduce the prohibitively burdensome manpower requirements currently necessary to operate unmanned systems. Military manpower makes up the largest part of the total ownership cost of systems across all the Services. But how expensive *is* military manpower? To better understand this compelling need to reduce these manpower requirements, it is important to understand the costs of manpower to the U.S. military writ large.

Military manpower accounts comprise the largest part of the TOC of military systems across all the Services. Additionally, military manpower costs are the fastest growing accounts, even as the total number of military men and women *decrease*. According to a 2012 Office of Management and Budget report, military personnel expenditures have risen from $74 billion dollars in 2001 to $159 billion dollars in 2012, an increase of almost 115 percent.

With the prospect of future flat or declining military budgets, the rapidly rising costs of military manpower, and the increased DoD emphasis on total ownership costs, the mandate to move beyond the "many operators, one-joystick, one-vehicle" paradigm for UxS that has existed during the past decades for most unmanned systems is clear and compelling. But this drive for autonomy begs the question as to what this imperative to increase autonomy comports and what, if any, downside occurs if we push UxS autonomy too far. Is there an unacceptable "dark side" to too much autonomy? There are concerns regarding the extant of autonomy military systems ought to have. Unless or until these concerns are addressed, these systems may never reach their full potential.

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[1] Navy Project Team, "Report to Congress: Alternative Future Fleet Platform Architecture Study," October 27, 2016.
[2] MITRE, "Navy Future Fleet Platform Architecture Study," July 01, 2016 and CSBA, "Restoring American Seapower: A New Fleet Architecture for the United States Navy," January 23, 2017.

[3] Department of the Navy, "Naval Research and Development: A Framework for Accelerating to the Navy & Marine Corps After Next," July 2017.

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II. THE PLAN FOR MILITARY UNMANNED SYSTEMS

At the highest levels of U.S. policy and strategy documents, unmanned systems are featured as an important part of the way the Joint Force will fight in the future. The most recent Quadrennial Defense Review (QDR) notes, "Continuing a trend that began in the late 1990s, U.S. forces will increase the use and integration of unmanned systems." Elsewhere in the QDR, unmanned systems are identified as: "Maintaining our ability to project power." Importantly, the QDR highlights unmanned systems as a key part of the DoD's commitment to innovation and adaptation.

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Because unmanned systems are used by all the military Services, the Department of Defense publishes a biennial roadmap to provide an overarching vision for the military's use of unmanned systems. The most recent roadmap singled out the need for enhanced UxS autonomy, noting, "DoD envisions unmanned systems seamlessly operating with manned systems while gradually reducing the degree of human control and decision making required for the unmanned portion of the force structure."   As Dyke Weatherington, the DoD Director for Unmanned Warfare and Intelligence, Surveillance and Reconnaissance noted, "The roadmap articulates a vision and strategy for the continued development, production, test, training, operation and sustainment of unmanned systems technology across DoD…This roadmap establishes a technological vision for the next 25 years."

As the QDR and Unmanned Systems Integrated Roadmap both note, unmanned systems are especially important assets in those areas where the U.S. military faces a peer competitor with robust defenses. The Joint Operational Access Concept identifies, "Unmanned systems, which could loiter to provide intelligence collection or fires in the objective area," as a key capability that is especially valuable in areas where an adversary has robust defenses that can limit access to U.S. and coalition forces. And unmanned systems are a key component in executing the United States AirSea Battle Concept (now re-branded as the Joint Concept for Access and Maneuver in the Global Commons, or JAM-GC) in high threat areas such as the Western Pacific, where adversary defensive systems pose an unacceptably high risk to manned aircraft and surface platforms.

III. THE NEED FOR OFFSET STRATEGIES

The Department of Defense has initiated a "Third Offset Strategy," to ensure that the United States retains the military edge against potential adversaries. An "offset" strategy is an approach to military competition that seeks to asymmetrically compensate for a disadvantaged position. Rather than competing head-to-head in an area where a potential adversary may also possess significant strength, an offset strategy seeks to shift the axis of competition, through the introduction of new operational concepts and technologies, toward one in which the United States has a significant and sustainable advantage.

The United States was successful in pursuing two distinct offset strategies during the Cold War. These strategies enabled the U.S. to "offset" the Soviet Union's numerical advantage in conventional forces without pursuing the enormous investments in forward-deployed forces that would have been required to provide overmatch soldier-for-soldier and tank-for-tank. These offset strategies relied on fundamental innovation in technology, operational approaches, and organizational structure to compensate for Soviet advantage in time, space, and force size.

The first of these offset strategies occurred in the 1950's, when President Eisenhower sought to overcome Warsaw Pact's numerical advantage by leveraging US nuclear superiority to introduce battlefield nuclear weapons—thus shifting the axis of competition from conventional force numbers to an arena where the United States possessed an asymmetrical advantage. This approach provided stability and offered the foundation for deterrence.

The second of these offset strategies arose in the late 1970's and early 1980's with the recognition that the Soviet Union had achieved nuclear parity. The Second Offset Strategy sought to create an enduring advantage by pursuing a new

approach to joint operations—leveraging the combined effects of conventional precision weapons, real-time, long-range, ISR sensor capabilities that supported real-time precision targeting, and the joint battle networks that permitted these capabilities to be synchronized and executed over the full breadth of the battlespace.

At the time of the introduction of the Second Offset Strategy in the early 1980's, the United States was the only nation with the knowledge and capacity to develop, deploy, and successfully execute the intelligence, surveillance and reconnaissance capabilities, the space-based systems, and the precision weapons that supported this approach. Today, competitors such as Russia and China (and countries to which these nations proliferate advanced capabilities) are pursuing and deploying advanced weapons and capabilities that demonstrate many of the same technological strengths that have traditionally provided the high-tech basis for U.S. advantage, such as precision-guided munitions. This growing symmetry between U.S. technical capabilities and near-peer potential competitors was seen during Russian power-projection operations in Syria.

The emergence of increasing symmetry in the international security environment suggests that it is again time to begin considering the mix of technologies, system concepts, military organizations, and operational concepts that might shift the nature of the competition and give the United States an edge over potential adversaries. This set of capabilities provides the basis for a Third Offset Strategy. As was true of previous offset strategies, a Third Offset Strategy seeks, in a budget constrained environment, to maintain and extend the United States' competitive technological and operational advantage by identifying asymmetric advantages that are enabled by unique U.S. strengths and capabilities. A Third Offset Strategy ensures that our conventional deterrence posture remains as strong in the future as it is today and establishes the conditions to extend that advantage into the future.

In explaining the technological elements of the Third Offset Strategy, Deputy Secretary of Defense Robert Work has emphasized the importance of emerging capabilities in autonomy and artificial intelligence. He pointed out that these technologies offer significant advantage to the Joint Force, enabling the future force to develop and operate advanced joint, collaborative human-machine battle networks that synchronize simultaneous operations in space, air, sea, undersea, ground, and cyber domains. Artificial intelligence will allow new levels of autonomy—the limited delegation of decision-making authority—within joint battle networks, leading to entirely new opportunities for human-machine collaboration and combat teaming.

It is difficult to overstate the prominence of technologies such as unmanned systems and artificial intelligence in the Third Offset Strategy and especially in the Strategy's Long Range Research and Development Plan (LRRDP). That said, there is strong component of this strategy that emphasizes keeping humans in the loop when using unmanned systems with increasingly sophisticated artificial intelligence capabilities. Indeed, human-machine collaboration is an imperative that is emphasized in extant Third Offset Strategy documentation as well as in speeches and interviews with senior DoD officials. While a deep-dive into the full details of the technology thrusts of the Third Offset Strategy is beyond the scope of this paper, it is important to note that the Strategy's primary technical line of effort is focused on the concept of Human-Machine Collaboration and Combat Teaming. The five basic building blocks of this concept are:

• Autonomous deep learning systems, which will leverage machine learning to operate "at the speed of light" in areas where human reaction time is too slow, such as cyber-attacks, electronic warfare attacks, or large missile raid attacks.

• Human-machine collaboration, which will allow machines to help humans make better decisions faster. Secretary Work cited the F-35 Joint Strike Fighter and the Naval Integrated Fire Control Counter-Air (NIFC-CA) as examples of these concepts.

• Assisted human operations, which will focus on the ways in which man and machines can operate together, through tools such as wearable electronics, exoskeletons, and combat applications to assist warfighters in every possible contingency.

• Advanced human-machine combat teaming, which will focus on humans working with unmanned systems in cooperative operations; one example is the operation of the Navy's P-8 Poseidon with an MQ-4C Triton. Going forward, the next level of teaming will examine swarming tactics and cooperative autonomy.

• Network-enabled, cyber-hardened autonomous weapons, which will be resilient to operate in an electronic warfare and cyber environment. A current example includes the tactical Tomahawk Block IX, whose targets can be updated in-flight.

Knowledgeable outside observers have referenced the Third Offset Strategy and have highlighted the importance of unmanned systems in achieving U.S. strategic goals. In his article in Foreign Policy, "The New Triad," Admiral James Stavridis, former SACEUR, identified unmanned systems as one of the three pillars of this New Triad, noting, "The second capability in the New Triad is unmanned vehicles and sensors. This branch of the triad includes not only the airborne attack "drones"…but unmanned surveillance vehicles in the air, on the ground, and on the ocean's surface…Such systems have the obvious advantage of not requiring the most costly component of all: people."

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Clearly, the Navy's leadership is committed to unmanned systems. The former-Chief of Naval Operations Sailing Directions noted, "Over the next 10 to 15 years…unmanned systems in the air and water will employ greater autonomy and be fully integrated with their manned counterparts." The importance of unmanned systems to the U.S. Navy was highlighted the in an article in U.S. Naval Institute Proceedings' where Admiral Jonathan Greenert noted that payloads, including unmanned systems, will increasingly become more important than platforms themselves.

IV.   THE CHALLENGES FOR UNMANNED SYSTEMS – TOTAL OWNERSHIP COSTS

Well over a decade ago, in their report, Roles of Unmanned Vehicles, the Naval Research Advisory Committee highlighted the bright future and enormous potential for unmanned systems, noting, "The combat potential of UVs (unmanned vehicles) is virtually unlimited…There is no question that the Fleet/Forces of the future will be heavily dependent upon UVs." In the years following the NRAC report, the U.S. military has been working with industry and academia to make unmanned vehicles more-and-more autonomous. There are compelling reasons for this effort.

As described in the most recent Unmanned Systems Roadmap, there are four levels of autonomy: Human Operated, Human Delegated, Human Supervised, and Fully Autonomous. However, the Roadmap notes that in contrast to automatic systems, which simply follow a set of preprogrammed directions to achieve a predetermined goal, autonomous systems "are self-directed towards a goal in that they do not require outside control, but rather are governed by laws and strategies that direct their behavior."

One of the most pressing challenges for the DoD is to reduce the prohibitively burdensome manpower footprint currently necessary to operate unmanned systems. Military manpower makes up the largest part of the total ownership cost of systems across all the Services. But how expensive is military manpower? To better understand this compelling need to reduce these manpower requirements, it is important to understand the costs of manpower in the U.S. military writ large.

Military manpower accounts comprise the largest part of the TOC of military systems across all the Services. Additionally, military manpower costs are the fastest growing accounts, even as the total number of military men and women decrease. According to a 2012 Office of Management and Budget report, military personnel expenditures have risen from $74 billion dollars in 2001 to $159 billion dollars in 2012, an increase of almost 115 percent. Mackenzie Eaglen and Michael O'Hanlon have noted that between fiscal year 2001 and 2012, the compensation cost per active-duty service member increased by 56%, after being adjusted for inflation.

More recently, a 2016 HSI-Jane's analysis of the U.S. Defense Budget highlighted the high—and growing—costs of military manpower, as well as the factors driving these costs. Jane's analysis highlighted the fact that in spite of predicted decreases in the number of military personnel across the Future Years Defense Plan (FYDP), military manpower costs are predicted to rise at least through FY-21. The report noted:

"Since the nadir of US defence spending in 1999, personnel expenditures have increased faster than other categories of expenditure, save RDT&E, rising by 39% in real terms by FY06. Military Personnel have enjoyed: five years of pay rises at or around 1.5% - higher than those in the general economy and the pay hike requested for FY16 was 1.3% and for FY17 it is 1.6%; increases in pay for middle grades to improve retention of skilled personnel; improved housing benefits; and substantial increases in retirement benefits…These personnel figures do include mandatory military pensions, but they do not include DoD civilian pay, which is accounted for in the O&M accounts in the US. DoD FY16 Military Personnel funds were USD148.5 billion in constant dollars or 23.9% of the budget and MilPers percentage is expected to rise to 25.5% by FY21."

Lessons learned throughout the development process of most unmanned systems—especially unmanned aerial systems—demonstrate that unmanned systems can actually increase manning requirements. Indeed, the Air Force has estimated that the MQ-1B Predator requires a crew of about 168 personnel, while the MQ-9 Reaper requires a crew of 180 and the RQ-4 Global Hawk relies on 300 people to operate it. As General Philip Breedlove, then-Vice Chief of Staff of the Air Force, emphasized, "The number one manning problem in our Air Force is manning our unmanned platforms." An article in the Armed Forces Journal summed up the dilemma in a sentence, noting, "The military's growing body of experience shows that autonomous systems don't actually solve any given problem, but merely change its nature. It's called the autonomy paradox: The very systems designed to reduce the need for human operators require more manpower to support them."

An article by a U.S. Marine Corps officer who worked with unmanned military robots in Afghanistan in the U.S. Army's Acquisition, Logistics and Technology Journal highlighted the

challenges involved in trying to reduce the personnel footprint required to operate military unmanned vehicles:

"In recent years, unmanned systems (UMS) have proliferated by the thousands in our Armed Forces. With increasing pressure to cut costs while maintaining our warfighting edge, it seems logical that UMS could reduce manpower and its associated costs while ensuring our national security. Unfortunately, while the recent UMS proliferation has improved our warfighting edge, it has not led to manpower reductions. Instead, UMS have increased our manpower needs—the opposite of what one might expect.

Two primary reasons that the proliferation of UMS has increased manpower needs are, first, that the priority for UMS is risk reduction, not manpower reduction; and, second, that current UMS are complementary to manned systems. Instead of replacing manned systems, UMS have their own manpower requirements, which are additive overall."

Compounding the TOC issue, the data overload challenge generated by the proliferation of unmanned aircraft and their sensors has created its own set of manning issues. In fact, the situation has escalated so quickly that many doubt that hiring additional analysts will help ease the burden of sifting through thousands of hours of video. A former Vice Chairman of the Joint Chiefs of Staff complained that a single Air Force Predator can collect enough video in one day to occupy nineteen analysts, noting, "Today an analyst sits there and stares at Death TV for hours on end, trying to find the single target or see something move. It's just a waste of manpower." The data overload challenge is so serious that it's widely estimated that the U.S. Navy will soon face a "tipping point," after which the Navy will no longer be able to process the amount of data that it's compiling.

Looking to the future of unmanned systems development, while acknowledging that technology breakthroughs may reduce the manning footprint of some military unmanned systems, some see a continuation—or even an increase—in manning required for unmanned systems. Here is how a Professor of Military and Strategic Studies at the United States Air Force Academy put it:

"The corresponding overhead costs in training for pilots, sensor operators and maintainers, fuel and spare parts, maintenance, and communications are not cheaper for unmanned systems than for manned alternatives. Advances in ISR will increase manpower costs as each additional sensor will require additional processing and exploitation capacity…The manpower and infrastructure costs associated with UAVs will prevent it from becoming the universal replacement to all manned military aircraft missions."

With the prospect rising costs of military manpower, and the increased DoD emphasis on total ownership costs, the mandate to move beyond the "many operators, one-joystick,

one-vehicle" paradigm that has existed during the past decades for most unmanned systems is clear and compelling. The DoD and the Services are united in their efforts to increase the autonomy of unmanned systems as a primary means of reducing manning and achieving acceptable TOC. But this drive for autonomy begs the question as to what this imperative to increase autonomy may comport and what, if any, downside occurs if we push autonomy too far. Is there an unacceptable "dark side" to too much autonomy?

V.   THE DARK SIDE OF UNMANNED SYSTEMS AUTONOMY

One of the most iconic films of the last century, Stanley Kubrick's 2001: A Space Odyssey had as its central theme, the issue of autonomy of robots (the unmanned vehicles of the time). Few who saw the movie can forget the scene where astronauts David Bowman and Frank Poole consider disconnecting HAL's (Heuristically programmed ALgorithmic computer) cognitive circuits when he appears to be mistaken in reporting the presence of a fault in the spacecraft's communications antenna. They attempt to conceal what they are saying, but are unaware that HAL can read their lips. Faced with the prospect of disconnection, HAL decides to kill the astronauts in order to protect and continue its programmed directives.

While few today worry that a 21st century HAL will turn on its masters, the issues involved with fielding increasingly-autonomous unmanned systems are complex, challenging and contentious. Kubrick's 1968 movie was prescient. Almost half-a-century later, while we accept advances in other aspects of unmanned systems improvements such as propulsion, payload, stealth, speed, endurance and other attributes, we are still coming to grips with how much autonomy is enough and how much may be too much. This is arguably the most important issue we need to address with respect to military unmanned systems over the next decade.

Unmanned systems will become more autonomous in direct proportion to their ability to sense the environment and adapt to it. This capability enables unmanned systems to achieve enhanced speed in decision making and allows friendly forces to act within an adversary's OODA (Observe, Orient, Decide, and Act) loop. As the environment or mission changes, the ability to sense and adapt will allow unmanned systems to find the optimal solution for achieving their mission, without the need to rely on constant human operator oversight, input and decision-making. But while we need unmanned systems to operate inside the enemy's OODA loop, are we ready for them to operate without our decision-making, to operate inside our OODA loops?

In an article entitled, "Morals and the Machine," The Economist addressed the issue of autonomy and humans-in-the-loop this way:

"As they become smarter and more widespread, autonomous machines are bound to end up making life-or-death decisions

in unpredictable situations, thus assuming—or at least appearing to assume—moral agency. Weapons systems currently have human operators "in the loop", but as they grow more sophisticated, it will be possible to shift to "on the loop" operation, with machines carrying out orders autonomously.

As that happens, they will be presented with ethical dilemmas. Should a drone fire on a house where a target is known to be hiding, which may also be sheltering civilians? Should a driverless car swerve to avoid pedestrians if that means hitting other vehicles or endangering its occupants? Should a robot involved in disaster recovery tell people the truth about what is happening if that risks causing a panic?

Such questions have led to the emergence of the field of "machine ethics," which aims to give machines the ability to make such choices appropriately—in other words—to tell right from wrong. More collaboration is required between engineers, ethicists, lawyers and policymakers, all of whom would draw up very different types of rules if they were left to their own devices."

Bill Keller put the issue of autonomy for unmanned systems this way in his Op-ed, "Smart Drones," in the New York Times:

"If you find the use of remotely piloted warrior drones troubling, imagine that the decision to kill a suspected enemy is not made by an operator in a distant control room, but by the machine itself. Imagine that an aerial robot studies the landscape below, recognizes hostile activity, calculates that there is minimal risk of collateral damage, and then, with no human in the loop, pulls the trigger.
Welcome to the future of warfare. While Americans are debating the president's power to order assassination by drone, powerful momentum—scientific, military and commercial—is propelling us toward the day when we cede the same lethal authority to software."

More recently, while it may seem counterintuitive, concerns about autonomous machines and artificial intelligence are also coming from the very industry that is most prominent in developing these technological capabilities. The author of a New York Times article entitled, "Robot Overlords? Maybe Not," Alex Garland of the movie "Ex Machina" talks about artificial intelligence and quotes several tech industry leaders.

"The theoretical physicist Stephen Hawking told us that 'the development of full artificial intelligence could spell the end of the human race.' Elon Musk, the chief executive of Tesla, told us that A.I. was 'potentially more dangerous than nukes.' Steve Wozniak, a co-founder of Apple, told us that 'computers are going to take over from humans" and that "the future is scary and very bad for people.'"

The Department of Defense is addressing the issue of human control of unmanned systems as a first-order priority and is beginning to issue policy direction to ensure that humans do remain in the OODA loop. A November 2012 directive by then-Deputy Secretary of Defense Ashton Carter issued the following guidance:

"Human input and ongoing verification are required for autonomous and semi-autonomous weapon systems to help prevent unintended engagements. These systems shall be designed to allow commanders and operators to exercise appropriate levels of human judgment over the use of force. Humans who authorize the use of, or operate these systems, must do so with appropriate care and in accordance with the law of war, applicable treaties, weapon system safety rules and applicable rules of engagement. An autonomous system is defined as a weapon system that, once activated, can select and engage targets without further intervention by a human operator."

These are the kinds of directives and discussions that are—and should be—part of the dialogue between and among policy makers, military leaders, industry, academia and the science and technology community as the design and operation of tomorrow's unmanned systems are thoughtfully considered. As Deputy Secretary of Defense Robert Work noted during his remarks at the Center for New American Security Defense Forum, "We believe, strongly, that humans should be the only ones to decide when to use lethal force. But when you're under attack, especially at machine speeds, we want to have a machine that can protect us."

It is one thing to issue policy statements, but quite another to actually design unmanned systems to carry out the desired plan. This is a critical point from a policy perspective, because although one can choose to abdicate various levels of decision-making to an unmanned machine, one cannot escape responsibility for the resulting actions. In highly autonomous systems, the system becomes opaque to the operator and these operators frequently ask questions such as: What is it doing? Why is it doing that? What's it going to do next? It is difficult to see how an operator can fulfill his or her responsibility for the unmanned system's actions if these questions are being asked.

Trying to determine what degree of autonomy is desired and how to achieve it is not a trivial undertaking and—in Albert Einstein's words—will require a new way of "figuring out how to think about the problem." And importantly, most informed discussion begins with the premise that adversaries who intend to use UxS against United States' interests will not be inhibited by the kinds of legal, ethical and moral strictures the United States adheres to. Designing the right degree of autonomy into our unmanned systems is the central issue that will determine their success or failure.

VI. DESIGNING IN THE RIGHT DEGREE OF AUTONOMY

Most of us are familiar with the children's fable, *Goldilocks and the Three Bears*. As Goldilocks tastes three bowls of porridge she finds one too hot, one too cold, and one just right. As the DoD and the Services look to achieve the optimal balance of autonomy and human interaction—to balance these two often-opposing forces and get them "just right"—designing this capability into tomorrow's unmanned systems at the outset, rather than trying to bolt it on after the fact, may be the only sustainable road ahead. If we fail to do this, it is almost inevitable that concerns that our armed unmanned systems will take on "HAL-like" powers and be beyond our control will derail the promise of these important warfighting partners.

The capabilities required to find this "just right" balance of autonomy in military unmanned systems must leverage many technologies that are still emerging. The military knows what it *wants* to achieve, but often not what technologies or even capabilities it *needs* in order to field UxS with the right balance of autonomy and human interaction. A key element of this quest is to worry less about what attributes—speed, service ceiling, endurance, and others—the machine itself possesses and instead focus on what is *inside* the machine. The Defense Science Board report, *The Role of Autonomy in DoD Systems*, put it this way:

"Instead of viewing autonomy as an intrinsic property of unmanned systems in isolation, the design and operation of unmanned systems needs to be considered in terms of human-systems collaboration…A key challenge for operators is maintaining the human-machine collaboration needed to execute their mission, which is frequently handicapped by poor design…A key challenge facing unmanned systems developers is the move from a hardware-oriented, vehicle-centric development and acquisition process to one that emphasizes the primacy of software in creating autonomy.[4]"

One need only go to an industry conference where unmanned systems are being displayed at multiple booths to understand that today the emphasis is almost completely on the machine itself; what is inside is typically not a primary consideration. But as the Defense Science Board notes, it is software that is the primary driver of capabilities. For example, the manned F-35 Lightning has ten billion lines of computer code and there is human supervision by the pilot. How many lines of code will need to be built into an unmanned system to get the balance of autonomy and human interaction just right?

For the relatively small numbers of UxS that will engage an enemy with a weapon, this balance is crucial. Prior to firing a weapon, the unmanned platform needs to provide the operator—and there must be an operator in the loop—with a "pros and cons" decision matrix regarding what that firing

decision might entail. When we build that capability into unmanned systems we will, indeed, have gotten it just right and the future of military unmanned systems will be bright.

VII. INTO THE FUTURE WITH UNMANNED SYSTEMS AND ARTIFICIAL INTELLIGENCE

We began this paper with the thesis that unmanned and semi-autonomous systems and artificial intelligence have the potential to critical partners to the Joint warfighter. But this can only happen if the rapid—some would say galloping—technological advances in unmanned systems and artificial intelligence take into account valid moral and ethical considerations regarding their use. Perhaps most importantly, as senior U.S. Department of Defense officials have emphasized, from the U.S. DoD perspective, unmanned systems must *always* have the option for human control and verification, especially when it comes to the use of lethal force by unmanned systems with artificial intelligence.

These unmanned systems with artificial intelligence are especially important to the military users. Those responsible for the concepts, research, development, building, fielding and use of unmanned systems with artificial intelligence might be well-served to look into the commercial trade space, to the automobile industry, for best-practices examples. It is here that we may well find that vital customer feedback that indicates what drivers *really* want. And while not a perfect one-to-one match, this analogy can suggest what kinds of unmanned systems with artificial intelligence industry should offer to the military.

Automobiles are being conceived, designed, built and delivered with increasing degrees of artificial intelligence. It is worth examining where these trend lines are going. Put a bit simplistically, automobiles can be broken down into three basic categories:

- A completely manual car—something your parents drove
- A driverless car that takes you where you want to go via artificial intelligence
- A car with augmented intelligence

The initial enthusiasm for driverless cars has given way to second thoughts regarding how much a driver may be willing to be taken completely out of the loop. One article in particular, in the *New York Times*, "Whose Life Should Your Car Save?" captures the concerns of many. An excerpt from this article captures the essence of the public's concern with driverless cars, and by extension, with other fully autonomous systems:

"We presented people with hypothetical situations that forced them to choose between "self-protective" autonomous cars that protected their passengers at all costs, and "utilitarian" autonomous cars that impartially minimized overall casualties, even if it meant harming their passengers. (Our vignettes

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[4] Defense Science Board, *Task Force Report: The Role of Autonomy in DoD Systems*, July 2012.

featured stark, either-or choices between saving one group of people and killing another, but the same basic trade-offs hold in more realistic situations involving gradations of risk.)

A large majority of our respondents agreed that cars that impartially minimized overall casualties were more ethical, and were the type they would like to see on the road. But most people also indicated that they would refuse to purchase such a car, expressing a strong preference for buying the self-protective one. In other words, people refused to buy the car they found to be more ethical.[5]"

As the study referenced in this article—as well as an increasing number of studies and reports indicate—there growing consensus among consumers that drivers want to be "in the loop" and that they want semi- and not fully-autonomous cars. That may change in the future…but perhaps not. And it should inform how we think about military unmanned systems.

Extrapolating this every-day example to the military unmanned systems, we believe—and we think the available evidence, including some of the most cutting-edge work going on today—strongly suggests that warfighters want *augmented* intelligence in their unmanned machines. That will make these machines more useful and allow warfighters to control them in a way that will go a long way toward resolving many of the moral and ethical concerns related to their use.

This augmented intelligence would provide the elegant solution of enabling warfighters to use unmanned systems as partners, not separate entities. Fielding autonomous deep learning systems that enable operators to teach these systems how to perform desired tasks is the first important step in this effort. This will lead directly to the kind of human-machine collaboration that transitions the "artificial" nature of what the unmanned system does into an "augmented" capability for the military operator.

Ultimately, this will lead to the kind of advanced human-machine combat teaming that will enable warfighters—now armed with augmented intelligence provided by their unmanned partners—to make better decisions faster with fewer people and fewer mistakes. This will also keep operators in-the-loop when they need to be, for example, when lethal action is being considered or about to be taken, and on-the-loop in more benign situations, for example, when an unmanned aerial system is patrolling vast areas of the ocean during a surveillance mission.

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[5] Azim Shariff, Iyad Rahwan and Jean-Francois Bonnefon, "Whose Life Should Your Car Save?" *The New York Times*, November 6, 2016. See also Aaron Kessler, "Riding Down the Highway, with Tesla's Code at the Wheel," *The New York Times*, October 15, 2015.

But this generalized explanation begs the question—what would augmented intelligence *look like* to the military operator. What tasks does the warfighter want the unmanned system to perform as they move beyond artificial intelligence to provide augmented intelligence to enable the Soldier, Sailor, Airman or Marine in the fight to make the right decision quickly in stressful situations where mission accomplishment must be balanced against unintended consequences?

Consider the case of a ground, surface, subsurface, or aerial unmanned systems conducting a surveillance mission. Today an operator receives streaming video of what the unmanned systems sees, and in the case of aerial unmanned systems, often in real time. But this requires the operator to stare at this video for hours on end (the endurance of the U.S. Navy's MQ-4C Triton is thirty hours). This concept of operations is an enormous drain on human resource, often with little to show for the effort.

Using basic augmented intelligence techniques, the MQ-4C can be trained to deliver only that which is interesting and useful to its human partner. For example, a Triton operating at cruise speed flying between San Francisco and Tokyo would cover the five-thousand-plus miles in approximately fifteen hours. Rather than send fifteen hours of generally uninteresting video as it flies over mostly empty ocean, the MQ-4C could be trained to only send the video of each ship it encounters, thereby greatly compressing human workload.

Taken to the next level, the Triton could do its own analysis of each contact to flag it for possible interest. For example, if a ship is operating in a known shipping lane, has filed a journey plan with the proper maritime authorities, and is providing an AIS (Automatic Identification System) signal; it is likely worthy of only passing attention by the operator, the Triton will flag it accordingly. If, however, it does not meet these criteria (say, for example, the vessel makes an abrupt course change that takes it well outside normal shipping channels), the operator would be alerted immediately. As this technology continues to evolve, a Triton MQ-4C—or other UxS—could ultimately be equipped with detection and classification algorithms that can lead to automatic target recognition, even in unfavorable weather conditions and sea states.

For lethal military unmanned systems, the bar is higher for what the operator must know before authorizing the unmanned warfighting partner to fire a weapon—or as is often the case—recommending that higher authority authorize lethal action. Take the case of military operators managing an ongoing series of unmanned aerial systems flights that have been watching a terrorist and waiting for higher authority to give the authorization to take out the threat using an air-to-surface missile fired from that UAS.

Using augmented intelligence, the operator can train the unmanned aerial system to anticipate what questions higher

authority will ask prior to giving the authorization to fire, and provide, if not a point solution, at least a percentage probability or confidence level to questions such as:

- What is level of confidence this person is the intended target?
- What is this confidence based on?
    - Facial recognition
    - Voice recognition
    - Pattern of behavior
    - Association with certain individuals
    - Proximity of known family members
    - Proximity of known cohorts
- What is the potential for collateral damage to?
    - Family members
    - Known cohorts
    - Unknown persons
- What are the potential impacts of waiting verses striking now?

These considerations represent only a subset of the kind of issues operators must train their unmanned systems armed with lethal weapons to deal with. Far from ceding lethal authority to unmanned systems, providing these systems with augmented intelligence and leveraging their ability to operate inside the enemy's OODA loop, as well as ours, enables these systems to free the human operator from having to make real time—and often on-the-fly—decisions in the stress of combat. Designing this kind of augmented intelligence into unmanned systems from to outset will ultimately enable them to be effective partners for their military operators.

This focus on augmented intelligence brings us full-circle back to some of the concerns raised by Deputy Secretary of Defense Robert Work. He noted that when the enemy is attacking us at "machine speeds," we need to exploit machines to help protect us. The importance of augmented intelligence in the man-machine symbiosis was highlighted in a recent U.S. Air Force *Technology Horizons* report which noted: "Although humans today remain more capable than machines for many tasks, natural human capacities are becoming increasingly mismatched to the enormous data volumes, processing capabilities, and decision speeds that technologies offer or demand; closer human-machine coupling and augmentation of human performance will become possible and essential."[6] Building unmanned systems with augmented intelligence that can partner with operators in this effort is what will ultimately ensure that the unmanned systems we build reach their full potential to help our warfighters win in combat.

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[6] *Technology Horizons: A Vision for Air Force Science and Technology 2010-2030*, accessed at:
http://www.defenseinnovationmarketplace.mil/resources/AF_TechnologyHorizons2010-2030.pdf

VIII. ENHANCING THE DIALOGUE AMONG UNMANNED SYSTEMS STAKEHOLDERS

Technology has driven mankind's progress, but each new advance has posed troubling questions. Unmanned machines and artificial intelligence are no different. The sooner the questions of moral agency discussed here are answered, the easier it will be for our warfighters to enjoy the benefits that unmanned systems will undoubtedly bring. As we noted earlier in the Economist article we cited, more collaboration is required between policymakers, engineers, ethicists and lawyers and all of whom would draw up very different types of rules if they were left to their own devices.

As one way of establishing and sustaining this kind of informed dialogue, in 2011, then-Undersecretary of the Navy Robert Work established the Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER). The impetus behind creating this organization was to establish and nourish a collaborative environment and community of interest for the advancement of unmanned systems (UxS) education and research endeavors across the Navy, Marine Corps, and Department of Defense.

CRUSER represents an initiative designed to build an inclusive community of interest around the application of unmanned systems in military operations. CRUSER seeks to catalyze these efforts, both internal and external to the Naval Postgraduate School, by facilitating active means of collaboration, providing a mechanism for information exchange among researchers and educators with mutual, collaborative interests. This process is designed to foster innovation through directed programs of operational experimentation, and supporting the development of educational ventures.

One of CRUSER's close partners in unmanned systems development is Space and Naval Warfare Systems Center Pacific (SSC Pacific). As the Navy's C4ISR (command, control, communications, computers, intelligence, surveillance and reconnaissance) Center of Excellence, SSC Pacific has a decades-long history of working with unmanned systems in all four domains: land, air, surface and undersea. Over four hundred scientists and engineers at SSC Pacific work on over forty distinct unmanned systems projects.

The primary focus of SSC Pacific's unmanned systems work involves equipping these ground, air, surface and undersea systems with C4ISR capabilities that will enable them to be useful tools – and partners - for our U.S. military warfighters. Key to this work is to enable our warfighters—especially those operating unmanned systems—to make better decisions faster with fewer people and fewer mistakes. Innovation plays a key role in this effort, and SSC Pacific's scientists and engineers are increasingly in demand to provide these state-of-the-art solutions. As The Honorable Frank Kendall,

Undersecretary of Defense for Acquisition, Technology and Logistics put it:

"SSC Pacific is one of the Department of Defense's most important engines of innovation. Our biggest investments in science and technology are in the laboratory systems, and they are going to accelerate technology."

Among the most important unmanned systems projects at SSC Pacific are those involving advanced autonomy, sensor fusion, communications pathways, air, sea, and subsurface integration, swarming, autonomous deep learning systems, human machine collaboration, assisted human operations, advanced human-machine combat teaming, network-enabled autonomous weapons, and autonomous systems test and evaluation.

Importantly, an increasing focus of SSC Pacific's unmanned systems work involves partnering with DARPA (Defense Advanced Research Projects Agency) and ONR (Office of Naval Research) on unmanned systems projects. This effort typically involves work in the basic sciences in support of the Department of Defense's Unmanned Systems Roadmap. As each project evolves, SSC Pacific scientists and engineers take the unmanned system effort to the next level, from modeling and simulation, to test and evaluation, to fielding of various capabilities.

While not comprehensive, a partial listing of SSC Pacific's current work with unmanned systems shows the scope of the Center's innovative efforts in this area. Of note, these projects involve a wide range of collaborators and feature unmanned systems work in all four unmanned systems domains.

- ACTUV (ASW Continuous Trail Unmanned Vessel) Sea Hunter project
- LDUUV (Large Displacement Unmanned Underwater Vehicle) project
- DARPA CODE (Collaborative Operations in Denied Environment) swarm project
- ONR UxS Common Control Station project
- DARPA Cross-Domain Maritime Surveillance and Targeting
- ONR HAMMER (Heterogeneous Autonomous Mobile Maritime Expeditionary Robots)
- ONR Integrated Ground Technology Technologies for Expeditionary Environments
- PMS 408 Mk18 UUV Program (EOD for UUVs)
- MOCU (Multi-Operator Control Unit) project
- SSC Pacific Human-Autonomy Teaming project
- U.S. Navy MQ-4 Triton Unmanned Aircraft Systems Integration project
- U.S. Air Force Global Hawk project integration efforts

SSC Pacific has the core, in-house expertise, as well as a wide range of industry partners to develop, integrate, test and evaluate unmanned systems technologies from basic research to operational fielding. Much of this work directly supports the unmanned systems initiatives that are part of the U.S. military's Third Offset Strategy.