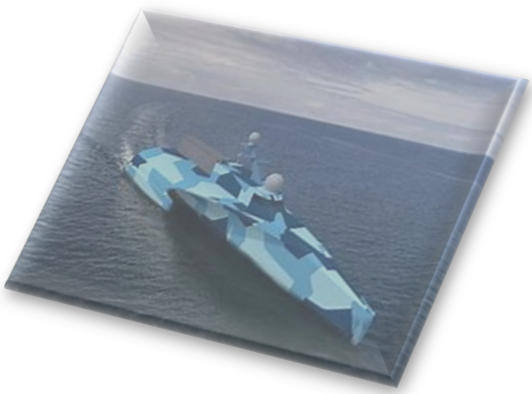

AUTONOMOUS MILITARY SYSTEMS

Defining the Requirements: Part One

ABSTRACT

While autonomous vehicle capabilities have advanced at an incredible rate in both the civilian and military spheres, DoD struggles with clearly discerning an analytical tool useful for proposing, assessing, evaluating, and determining the requirements for the application of autonomous systems across the military. Part One of this Whitepaper series defines autonomy and provides an overview of the state of play, both in and outside DoD, of autonomy as a military capability. Part Two of this series revisits the elements necessary for creating a common taxonomy for just such a process called "Standards of Autonomy in Military Application" (SAMA).

Matthew Dooley, MMAS, and Grant Highland, Ph.D.

Fidelium, LLC

Autonomous Military Systems: Defining the Requirements

"I don't know what the hell this 'logistics' is that Marshall is always talking about, but I want some of it."

-Attributed to Admiral E. J. King

To paraphrase the ADM King epigraph above in the current context, it just as easily could state, "I don't know what the hell this 'autonomy' is that everyone is talking about, but I want some of it." In the current push for Artificial Intelligence (AI) and autonomous vehicle capability, militaries across the globe are in a race for adoption of these powerful new technologies. But as the technology advances at a blistering pace, military practitioners and strategists still do not yet have a common, Department-wide understanding of what autonomy can bring to U.S. military operations and national security. Often only stove-piped strategies exist among service, agency, and commercial applications for specific platforms or use cases. In other words, development is taking place at the micro-level without an updated corresponding macro-level strategic view of how these new capabilities can be incorporated, why these new capabilities are necessary, what these new capabilities ought to do, where these capabilities should be employed, when they should be utilized, and who should be responsible for their development and use.

Despite the technological, philosophical, ethical, and budgetary debates surrounding the military use of AI, autonomous vehicles/systems, and other components necessary for networked and algorithmic warfare, the fact remains these capabilities are an imperative for national security now and into the future. Like the gift of fire bequeathed to humanity by Prometheus in Greek mythology, AI and the interrelated systems powered by artificial intelligence has been loosed upon the world. There is no putting the technological genie back in the bottle, so this paper aims to embrace the reality of autonomy. This paper describes the current state of play regarding autonomous military systems, and outlines the challenges and opportunities surrounding adoption of autonomous systems into new concepts of military operations and application. This study then proposes an approach toward better defining what systems should be used, where, when, why, and how, through a taxonomy of autonomous capabilities and behaviors for given operational domains and imperatives.

What is Autonomy?

Definitions

The now six-year-old Joint Concept for Robotics and Autonomous Systems (JCRAS) published by the Joint Staff has the only joint imprimatur on DoD definitions for the various systems necessary for the use of robotics and autonomous systems (RAS):

- **Robot**: A powered machine capable of executing a set of actions by direct human control, computer control, or both. It is composed minimally of a platform, software, and a power source.

- **Autonomy:** The level of independence that humans grant a system to execute a given task. It is the condition or quality of being self-governing to achieve an assigned task based on the system's own situational awareness (integrated sensing, perceiving, analyzing), planning, and decision-making. Autonomy refers to a spectrum of automation in which independent decision-making can be tailored for a specific mission, level of risk, and degree of human-machine teaming.
- **Robotic and Autonomous Systems (RAS):** RAS is an accepted term in academia and the science and technology (S&T) community and highlights the physical (robotic) and cognitive (autonomous) aspects of these systems. For the purposes of this concept, RAS is a framework to describe systems with a robotic element, an autonomous element, or more commonly, both.
- **Automated Weapons System (AWS):** 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.[1]

While these definitions are useful for a basic understanding of RAS, they lack the nuance necessary for effective application of these systems in the military context. To truly understand levels of autonomy it is important to note there are three dimensions associated with those systems: **the type of task the machine is performing; the relationship of the human to the machine when performing that task; and the sophistication of the machine's decision-making when performing the task**.[2] Many within DoD would understand these dimensions as they apply to colonel John Boyd's OODA Loop (Orient, Observe, Decide, Act). Within that context, the following terminology is generally understood and accepted as it applies to human-machine teaming:

- Human-in-the-Loop: **Semi-autonomous operation** where the machine performs a task and then waits for the human user to take an action before continuing. In other words, human operators "break" the OODA Loop by inserting themselves into the 'Act' phase of the cycle. As such, the system can sense the environment and recommend a course of action but cannot carry out the action without human approval.

- Human-on-the-Loop: **Supervised autonomous operation** where the machine can sense, decide, and act on its own. The human user supervises its operation and can intervene, if desired. Once put into operation, the machine can perform all the actions within the OODA Loop on its own, but a human user can observe the machine's behavior and intervene to stop or alter its behavior if necessary; "riding," or on the loop to intervene when needed.

- Human-out-of-the-Loop: **Fully autonomous operation** where the machine can sense, decide, and act on its own. The human cannot intervene in a timely fashion. In other words, once the

[1] Chairman of the Joint Chiefs of Staff, *Joint Concept for Robotics and Autonomous Systems (JCRAS),* Washington, DC: October 16, 2016, pg. 2

[2] Scharre, Paul, *An Army of None: Autonomous Weapons and the Future of War,"* W.W. Norton and Company, New York, NY: 2018, pg. 27

mission parameters are set and the machine is tasked, there is no further communication between the machine/system and the human user; the human user is totally out of the loop.[3]

These definitional terms will become important later in the paper as we suggest a clearer taxonomy for Standards of Autonomy in Military Application (SAMA) as they apply to the task and purpose associated with various platforms and domains, the relationship of the human to machines in the performance of those tasks, and the sophistication of the machine's decision-making needed for the accomplishment of those tasks.

System Requirements

The components necessary for the various autonomous vehicles being developed for military applications are varied, but the one common denominator is the complexity required to realize autonomous operations in a military context. While commercial applications have been adopted in limited markets across the planet, and while autonomous commercial vehicles are increasingly becoming more prevalent and desired as time goes on, the complexity of the military domain remains unique in the world of autonomous vehicle application. The fog and friction of war, contested and denied environments, or cross-terrain environments through unprepared, urban, or otherwise cluttered domains all require sophisticated sensing, communication, optics, and self-defense capabilities not required by commercial vehicles. While describing all the various components for the different vehicle domains (Uncrewed Ground Vehicles – UGV, Uncrewed Aerial Systems/Vehicles – UAS/V, Uncrewed Surface Vessels – USV, Uncrewed Underwater Vehicles – UUV, as well as the cyber and space variants) is beyond the scope of this paper, an examination of a UGV example should prove illustrative.

The following images depict the various components necessary for autonomous UGV operation:

[3] Ibid., pp. 29-30

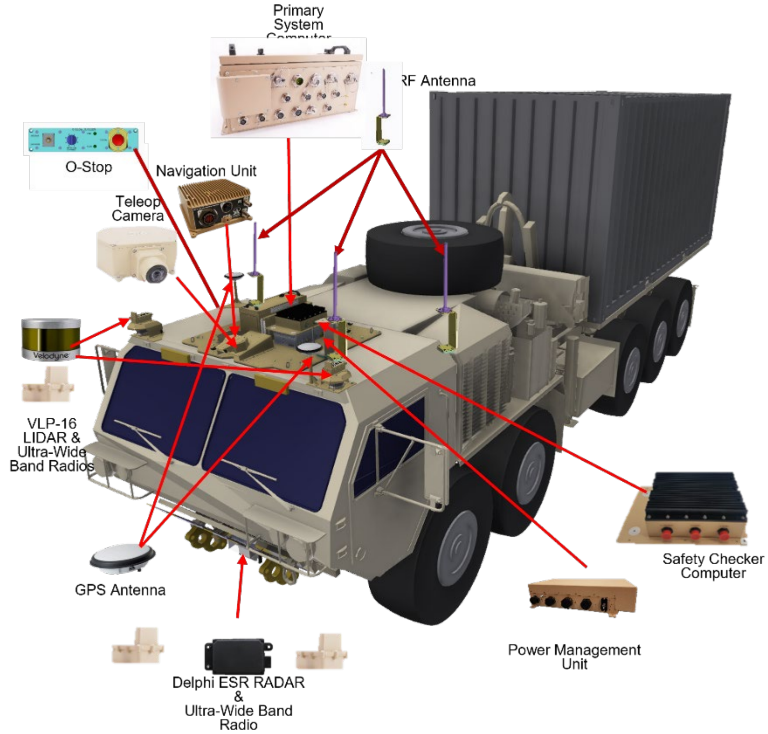

Figure 1 Source- US Army DEVCOM, GVSC Autonomy Powerpoint Presentation, 10 Aug 2021

- **ESR Radar:** Electronically Scanning RADAR (ESR) combines a wide field of view at mid-range with long-range coverage to provide two measurement modes simultaneously. The mid-range coverage (60m, +/-45 deg) not only allows vehicles cutting in from adjacent lanes to be detected but also identifies vehicles and pedestrians across the width of the equipped vehicle. The long-range coverage (175m, +/-11 deg) provides accurate range and speed data with powerful object discrimination that can identify up to 64 targets in the vehicle's path.
- **LIDAR:** Lidar, which stands for *Light Detection and Ranging,* is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by airborne systems — generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.
- **UWB Radio:** The low spectral density, below environmental noise, ensures a low probability of signal detection and increases the security of communication. High data rates can be transmitted over a short distance using UWB. UWB systems can co-exist with already-deployed narrowband systems.
- **GPS Antenna:** For geolocation in non-contested or denied environments.
- **Teleoperated Camera:** an electro-optical remote viewing camera used for remote control of the platform
- **Navigation, Power, Safety, and Primary System Computers:** The computational and system actuation boxes which translate sensor data into vehicle control manipulation.

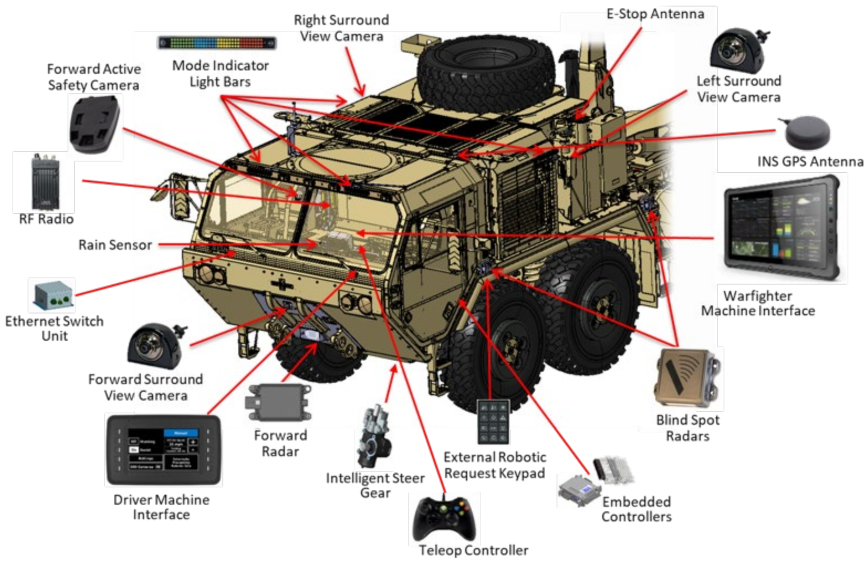

Figure 2 US Army DEVCOM, GVSC Autonomy Powerpoint Presentation, 10 Aug 2021

- **Forward, Left, Right, Rear Surround View Cameras:** Provides optical reference to back-up radar and Lidar signals.
- **Blind Spot Radars:** Similar to systems currently used in new vehicle warning systems but applied to vehicle control systems and actuators.
- **INS GPS Antenna**: Provides orientation data, roll pitch and heading, and update rates at a much higher rate than the GPS. Additionally, INS GPS provides sensor fusion for terrestrial positioning and vehicle orientation.

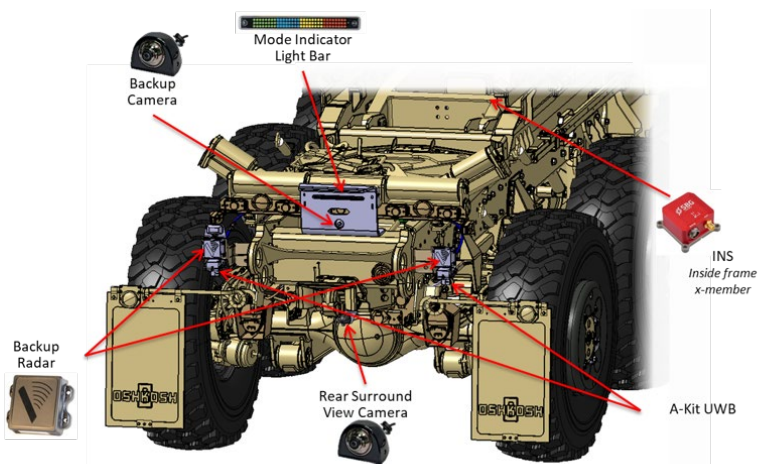

Figure 3 US Army DEVCOM, GVSC Autonomy Powerpoint Presentation, 10 Aug 2021

- **INS Unit:** An autonomous system with good concealment, which is not dependent on any external information, nor radiates energy to external space, making it applicable in airspace, sea, or underground. Since the INS updates the data rapidly and possesses the advantages of high short-term accuracy and stability with small size and light weight, it can provide comprehensive navigation data, such as the location, speed, or the attitude of the carrier. Therefore, INS plays a very important role in military field and civilian navigation.
- **Road Following Camera:** Optical sensor used to complement radar and lidar inputs to the vehicle control systems. Depending upon the level of vehicle autonomy, the camera can either be viewed by a human-on-the-loop through a teleoperated data link, or the vehicle can include the optical data in a fully autonomous, human-out-of-the-loop manner.
- **By-Wire Processor:** Human-on-the-loop, or human-in-the-loop processor which allows for operator input.

- **Autonomy Processor:** Sensor data amalgamator which processes sensor data, transmits signals to the vehicle systems control CPU which then actuates vehicle controls based on those signals.

The images above do not represent an exhaustive list of the components necessary for semi- or fully autonomous vehicle operation, but they do highlight the many systems needed for this capability. It is important to note, though, these images depict what is required for a "simple" Army truck which could be applied to logistics missions. When autonomy is applied to Lethal Autonomous Weapons Systems (LAWS) which will be needed to traverse various terrains in differing environmental and EW conditions while locating, identifying, and engaging enemy combatants, then the sensor, processing, and data demands increase dramatically. Along with this, DoD's latest strategy, the *Department of Defense Responsible Artificial Intelligence Strategy and Implementation Pathway* (DoD RAI S&I Pathway) published in June 2022, highlights six tenets the Department will follow as it pursues AI adoption across the services. Of those tenets, four in particular are important aspects this paper seeks to address:

1. Exercise appropriate care in the AI product and acquisition lifecycle to ensure potential AI risks are considered from the outset of an AI project, and efforts are taken to mitigate or ameliorate such risks and reduce unintended consequences, while enabling AI development at the pace the Department needs to meet the National Defense Strategy.
2. Use the requirements validation process to ensure that capabilities that leverage AI are aligned with operational needs while addressing relevant AI risks.
3. Promote a shared understanding of RAI design, development, deployment, and use through domestic and international engagements.
4. Ensure that all DoD AI workforce members possess an appropriate understanding of the technology, its development process, and the operational methods applicable to implemention.[4]

These tenets and this paper's contributions are important for several reasons. First, educating DoD leadership, congressional leaders and policymakers, the U.S. public, and our international partners is critical to dispel erroneous and ill-informed perceptions regarding the use of AI and autonomous systems. Second, aligning AI and autonomous system requirements with operational needs is a necessary and critical step for moving the Department toward programs of record for implementation DoD-wide. Finally, educating service members and the units/operators needed to incorporate and employ AI and autonomous systems, while simultaneously seeking input from those unit level operators, will ensure both a top-down and a bottom-up collaboration where the creativity of the many will far exceed the wisdom or wishes of the few.

With these definitions and a description of the various components necessary for autonomous operation of military vehicles, it is important to discuss where the U.S. is regarding its adoption of these capabilities and juxtapose that against what is known of Chinese advancements in the field. As our current pacing challenge in strategic competition, this analysis of Chinese versus U.S. advancement may

[4] Hicks, Kathleen, *Responsible Artificial Intelligence Strategy and Implementation Pathway,* Department of Defense, Office of the Deputy Secretary of Defense, Washington, DC: June 2022, pg. 2

outline the necessity and urgency with which the DoD should push for adoption of these technologies moving forward.

State of Chinese and U.S. AI and Autonomy Advancements

China: Since the 1980's, China has embarked upon three distinct military modernization programs:

- **Mechanization**: China sought to equip PLA units with modern platforms, including electronic warfare systems, as well as motorized, armored personnel carriers and infantry fighting vehicles. Mechanization emphasized fixed boundaries and armor operations, primarily for troops stationed along China's land borders, at the expense of naval and air operations. In 2020, the PLA announced it had "basically achieved" mechanization.[5]
- **Informatization**: Since the 1990s, the PLA's dominant push has been informatization, in which wars are won through information dominance, and the space and cyber domains are the "commanding heights of strategic competition." PLA operational concepts today emphasize the need to win "informatized local wars" by using long-range, precision, smart, and unmanned weapons and equipment. In 2020, the PLA announced its goal to become a "fully mechanized and informatized" force by its centenary, the year 2027.[6]
- **Intelligentization**: First mentioned in China's 2015 Defense White Paper, intelligentization represents "a new round of military revolution" characterized by networked, intelligent, and autonomous systems and equipment. It endeavors to build on mechanized and informatized systems, creating "ubiquitous networks" in which "'human-on-human' warfare will be replaced by 'machine-on-human' or 'machine-on-machine warfare.'" In particular, AI forms the basis of the PLA's push toward intelligentization and tops the list of emerging technologies prioritized in recent Chinese strategy documents and development plans.[7]

Due to the occluded nature of Chinese reporting on defense related topics, the Center for Security and Emerging Technologies studied PLA contracting to determine as much as possible where AI expenditures were being awarded, and for which applications the Chinese were pursuing. Their analysis found seven key areas of PLA focus:

---

[5] "The Ministry of National Defense confirmed for the first time that the PLA has basically achieved mechanization" 国防部首次证实：解放军已经基本实现机械化], NetEase News, November 27, 2020, https://perma.cc/Q79Y-GCC4 (Accessed October 4, 2022)

[6] Dean Cheng, "Chinese Party Sets Bold Military Goal: 'Mechanized & Informationized' By 2027," Heritage Foundation, November 24, 2020, https://www.heritage.org/asia/commentary/chinese-party-sets-bold-military-goal-mechanized-informationized-2027 (Accessed October 4, 2022)

[7] Original CSET translation by Ben Murphy, "Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035" [中华人民共和国国民经 济和社会发展第十四个五年规划和2035年远景目标纲要], Xinhua, May 13, 2021, https://cset.georgetown.edu/publication/china-14th-five-year-plan/ (Accessed October 4, 2022) Of note, this section in its entirety was captured in a Center for Security and Emerging Technology (CSET) report written in October 2021 titled, *Harnessed Lightning: How the Chinese Military is Adopting Artificial Intelligence,* authored by Ryan Fedasiuk, Jennifer Melot, and Ben Murphy, where the authors focused on analysis of PLA contracts related to AI to extrapolate Chinese defense spending for achievement of intelligentization.

1. Intelligent and autonomous vehicles
2. Intelligence, Surveillance, and Reconnaissance (ISR)
3. Predictive Maintenance and Logistics
4. Information and Electronic Warfare
5. Simulation and Training
6. Command and Control (C2)
7. Automated Target Recognition[8]

It should come as no surprise that many of these areas mirror DoD priorities as well. While a more detailed budget analysis of Chinese and U.S. expenditures on AI is forthcoming in a later paper, the report concludes overall Chinese expenditure on AI-related systems has a floor of roughly $1.6 billion with perhaps more covered in their classified budget allocations. This figure represents yearly expenditure amounts from a $209 billion dollar defense budget per analysis of PLA contracting. While this may seem a small percentage of their overall defense budget – just .76% -- it nevertheless represents a larger percentage dedicated to AI-related advancement than that found in the FY 2022 DoD budget request. At $753 billion, with overall AI-related expenditures listed at $1.3 billion, the U.S. had allocated just .17% of its overall budget toward AI.[9] This simple comparison is not necessarily an accurate depiction of the two nations' AI spending or priorities, but it does indicate China's focus on intelligentized approaches to warfare as noted above, while the U.S. seemingly remains more focused on conventional legacy warfare models.

The greatest number of contracts awarded were let toward intelligent and autonomous vehicles, with most going toward UAS/V platforms. Of those, systems such as the ASN-301 (a reverse-engineered version of the Israeli Harpy loitering munition), the GJ-11 "Sharp Sword" combat UAV, and coordinated fixed- and rotary-wing swarming vehicles capable of self-organization and communication, group node management and control software, AI-based radar coincidence imaging, and collision avoidance sensors.[10]

In addition to their uncrewed aerial ambitions, China is also investing heavily in USV and UUV vehicles, to include deep submersible and intelligent ship integration technologies.[11] From what has been dubbed a multi-role mini-Aegis called JARI, capable of anti-submarine, air defense, and surface combat roles launched in 2020, to the first ever dedicated autonomous drone carrier ship named the Zhu Hai Yun launched in May 2022, it is clear China understands U.S. naval and air power and is developing AI-related technologies to protect its interests in the Pacific.

---

[8] Ryan Fedasiuk, Jennifer Melot, Ben Murphy, *Harnessed Lightning: How the Chinese Military is Adopting Artificial Intelligence,* Center for Security and Emerging Technology, Report, October 2021, pg. 13
[9] Department of Defense Fiscal Year 2022 Defense Budget, https://comptroller.defense.gov/Budget-Materials/ (Accessed October 4, 2022)
[10] CSET Report, pg. 15
[11] Ibid., pg. 16

The JARI "Mini-Aegis" Multi-Role Autonomous Vessel

The Zhu Hai Yun Drone Carrier Autonomous Vessel

U.S.: The U.S. has been actively engaged in the development of AI-related technologies for decades, but only relatively recently has begun serious steps toward full implementation of AI capabilities across the department. Since 2017, the Department has published or written over 22 strategies, guidance documents, or answers to presidential and other guidelines, and has established Department, Joint, and service-related AI centers and offices.[12] Despite these efforts, the Government Accountability Office (GAO) has determined DoD efforts require greater oversight and governance structures to provide an overarching framework for DoD adoption of AI across the joint force and departmental agencies.[13] Similarly, it has found the Department needs to focus on data solutions unique to AI-related systems, to include cloud and edge computing measures for widespread adoption across DoD and Industry, has identified AI education as a necessity for all levels of DoD personnel, and has described how the current

[12] Brian Mazanec, "Artificial Intelligence: DOD Should Improve Strategies, Inventory Process, and Collaboration Guidance," *Government Accountability Office,* Washington, DC: March 2022, pg. 11
[13] Ibid., pg.

DoD budgeting and procurement processes are too linear and lengthy for adoption of the unique algorithmic tools necessary for effective AI measures across the DoD.[14]

As the GAO-22-104765 Artificial Intelligence Report notes, the majority of AI Capabilities in DoD's initial AI inventory are in the research and development stages of early testing and experimentation.[15] When the two reports are taken together, it is clear DoD is taking steps to provide top-level, overarching guidance and strategy for AI adoption across the Department, while the services are engaged in service specific, bottom-up work in attempts to define AI requirements and concepts of operation for use in future battle. Unfortunately, the middle ground where experiments and R&D meet program offices and weapons systems development has yet to be adequately addressed.

That said, all is not gloom and doom as juxtaposed against Chinese efforts. The United States military has been hard at work developing a wide variety of emerging autonomous programs, the most recognizable of which is the effort to develop, test and field autonomous resupply trucks. Know by various names like AMAS, AGR, Leader-Follower, ExLF, and now ATV or ATVS, the U.S. Army is close to fielding this capability in limited numbers. Other programs are under development and experimentation will soon follow. A few of these are listed here:

- Rogue Fires- An autonomous JLTV truck with a HIMARS rocket launcher
- Robotic Combat Vehicle (RCV)- A family of robotic combat platforms designed to integrate with manned combat vehicles as fighting teammates
- Autonomous Mobile Launcher (AML)- An autonomous HIMARS truck
- Optionally Manned Fighting Vehicle (OMFV)- Primarily a manned platform intended to replace the Bradley family of AFVs
- Long Range Unmanned Surface Vessel (LRUSV) System- a United States Marine Corps designed to increasing the lethality of U.S. maritime forces, with a network of unmanned vessels traveling autonomously for extended ranges and transporting loitering munitions to address targets at sea and on land
- Loyal Wingman- a US Airforce program using advanced unmanned aircraft with significant autonomous capabilities designed to work closely with manned combat aircraft
- A variety of US Special Operations Command program

Clearly, the DoD is committed to moving forward to field autonomy as an enabler across the Multi-Domain battlespace. There are critical questions however, centered around how should DoD better organize and synchronize its efforts for a more comprehensive approach toward AI adoption:

- For what military purpose will AI-enabled systems be used? **ENDS**
- Where will those capabilities best enhance that military purpose?
- How will those capabilities be integrated into existing service formations?
- How will those capabilities be integrated into joint operations? **WAYS**
- When will AI-related capabilities be ready for deployment?

[14] Jon Ludwigson and Candice Wright, "Artificial Intelligence: Status of Developing and Acquiring Capabilities for Weapon Systems," *Government Accountability Office,* Washington, DC: February 2022, pg. 43

[15] Ibid., pg. 16

- How will AI-related advancements be funded within the PPBES process?
- Who will be held responsible for the ethical use of these systems? **MEANS**

It is this paper's contention a useful taxonomy of AI-related requirements and application by domain will help the Department better understand and answer these important questions.