Operationalizing Robotic and Autonomous Systems in Support of Multi-Domain Operations White Paper

Prepared by:

Army Capabilities Integration Center – Future Warfare Division

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14. ABSTRACT

Operationalizing robotic and autonomous systems and artificial intelligence allows the Army to better understand the potential impact of those technologies on the nature and character of war. Describing how Army formations may employ RAS in the future operational environment helps illustrate its impact on war's violent, interactive, and fundamentally political nature as well as war's continuously evolving character. This white paper provides a description of the organizational employment of RAS in time, space, and purposeful tasks.

15. SUBJECT TERMS

Robotics and autonomous systems, RAS, Artificial Intelligence, Multi-Domain Operations, MDO

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Foreword

From the Director
United States Army Capabilities Integration Center

The Multi-Domain Operations (MDO 1.5) concept describes how the Army will fight in a complex environment against peer competitors across all domains (land, air, maritime, space, and cyberspace), the electromagnetic (EM) spectrum, and the information environment. Robotic and autonomous systems (RAS) will play a pivotal role in the future force's ability to calibrate force posture, employ multi-domain formations, and converge capabilities.

The *Operationalizing Robotic and Autonomous Systems in Support of Multi-Domain Operations White Paper* provides an operational description for RAS employment allowing the Army to understand better the potential impact of those technologies on the nature and character of war. Describing how Army formations may employ RAS in the future operational environment helps illustrate its impact on war's violent, interactive, and fundamentally political nature as well as war's continuously evolving character. Operationalization serves as the next logical extension of the Joint Concept for Robotic and Autonomous Systems (JCRAS) and the U.S. Army's RAS Strategy.

This white paper provides a broad perspective of the application of RAS within the MDO concept. It builds upon the concept by indicating how the force applies RAS technologies across the operational battlespace and the campaign continuum. It provides the capability development community with operational perspective and fidelity to the broadly stated precepts and required capabilities described by the JCRAS. It also provides capability developers a basis from which to develop scenarios or vignettes for capability based assessments or cost-benefit analyses. The paper provides the science and technology community with operational context for RAS developmental research and prototyping. Lastly, this paper provides the Army a vision for employing emerging RAS in the future operating environment to inform formation equipping.

Eric J. Wesley
Lieutenant General, U.S. Army
Director, Army Capabilities
Integration Center

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Executive Summary

Robotic and Autonomous Systems (RAS) and artificial intelligence (AI) are fundamental to the future Joint Force realizing the full potential of Multi-Domain Operations (MDO 1.5). These systems, in particular AI, offer the ability to outmaneuver adversaries across domains, the electromagnetic (EM) spectrum, and the information environment. The employment of these systems during competition allows the Joint Force to understand the operational environment (OE) in real time, and thus better employ both manned and unmanned capabilities to defeat threat operations meant to destabilize a region, deter escalation of violence, and turn denied spaces into contested spaces. In the transition from competition to armed conflict, RAS and AI maneuver, fires, and intelligence, surveillance, and reconnaissance (ISR) capabilities provide the Joint Force with the ability to deny the enemy's efforts to seize positions of advantage. Improved sustainment throughput combined with the ability to attack the enemy's anti-access/aerial denial networks provides U.S. Forces the ability to seize positions of operational, strategic, and tactical advantage. Increased understanding through an AI-enabled joint Common Operating Picture (COP) allows U.S. Forces the ability to orchestrate multi-domain effects to create windows of advantage. Post-conflict application of RAS and AI offer increased capacity to produce sustainable outcomes and the combat power to set conditions for deterrence.

Developing an operational concept for RAS allows the Army to understand better the potential impact of those technologies on the nature and character of war. Describing how Army formations may employ RAS in the future OE helps illustrate its impact on war's violent, interactive, and fundamentally political nature as well as war's continuously evolving character. This white paper provides a description of the organizational employment of RAS to inform the potential development of an overarching U.S. Army RAS concept, operational and organizational concepts, formation-based concepts of operation, and system-of-systems or individual system concepts of employment.

During competition, armed conflict, and return to competition formations employ RAS and AI to conduct a number of tasks that support MDO components of the solution enabling Army forces to execute MDO and succeed in the evolving operating environment. The table on the following page aligns key **RAS and AI-enabled tasks** to three *tenets of Multi-Domain Operations* to illustrate the expected impact RAS and AI will have on Multi-Domain Operations.

Operationalizing RAS impacts how future forces will operate, conduct operations against adversaries, and how commanders, using military art and science, might employ force capabilities to achieve desired effects and objectives. The most significant issues associated with a future RAS/AI enabled force coalesce around mission command, sustainment, and organizational design. This paper uses the terms mission command and sustainment in a broad sense and not in an effort to assign responsibility to a particular proponent or center of excellence (CoE).

RAS and AI Enabled Tenets of Multi-Domain Operations		
Calibrated Force Posture	*Multi-Domain Formations*	*Convergence*
Conduct wide-area persistent ISR – *forward presence forces (prepare the environment; challenge adversary's anti-access/area-denial system)*; *expeditionary forces (enable maneuver while in contact, enable joint forcible entry); national-level capabilities (prepare the environment, enable maneuver while in contact); authorities (tailored authorities)*	**Conduct wide-area persistent ISR** – *conduct independent maneuver (empower initiative, self-protection); employ cross-domain fires (layered reconnaissance)*	**Conduct wide-area persistent ISR** – *cross-domain synergy (optimize capabilities); layered options (expand capacity); mission command (achieve effects at a decisive space)*
Develop targeting data and provide fires and non-lethal effects – *forward presence forces (prepare the environment; challenge adversary's anti-access/area-denial system)*; *expeditionary forces (enable maneuver while in contact, enable joint forcible entry); national-level capabilities (prepare the environment, enable maneuver while in contact); authorities (tailored authorities)*	**Develop targeting data and provide fires and non-lethal effects** – *conduct independent maneuver (achieve positions of advantage); employ cross-domain fires (defeat or neutralize enemy fires systems, provide protection); maximize human potential (improve human decision making)*	**Develop targeting data and provide fires and non-lethal effects** – *cross-domain synergy (achieve maximum effects); layered options (multiple methods of striking); mission command (achieve effects at a decisive space); mission command (converge capabilities, allocate resources)*
Process, exploit and disseminate massive amounts of data and information – *forward presence forces (prepare the environment; integration with existing structures/systems)*; *expeditionary forces (force deployment and integration); national-level capabilities (prepare the environment); authorities (tailored authorities)*	**Process, exploit and disseminate massive amounts of data and information** – *employ cross-domain fires (defeat or neutralize enemy fires systems, provide protection); maximize human potential (improve human decision making, augment understanding)*	**Process, exploit and disseminate massive amounts of data and information** – *cross-domain synergy (optimize capabilities, achieve maximum effects); layered options (multiple methods of striking); mission command (achieve effects at a decisive space, converge capabilities)*
Conduct high-value asset recovery – *forward presence forces (integration with existing structures/systems)*; *national-level capabilities (prepare the environment); authorities (tailored authorities)*	**Support, defend, extend resilient networks** – *conduct independent maneuver (multiple sustainment networks), employ cross-domain fires (network extension and protection)*	**Support, defend, extend resilient networks** – *layered options (multiple methods of synchronizing capabilities); mission command (preserve mission command technical architecture, exploit initiative)*
Provide mobility, counter-mobility, survivability – *forward presence forces (prepare the environment; challenge adversary's anti-access/area-denial system)*; *expeditionary forces (enable maneuver while in contact, enable joint forcible entry); national-level capabilities (prepare the environment, enable maneuver while in contact); authorities (tailored authorities)*	**Provide mobility, counter-mobility, survivability** – *conduct independent maneuver (enable maneuver and survivability); employ cross-domain fires (provide protection and sustainment)*	**Deliver information operations products** – *cross-domain synergy (optimize capabilities, achieve maximum effects); layered options (present enemy with multiple dilemmas); mission command (achieve effects at a decisive space, converge capabilities, create cognitive windows of advantage)*
Provide force protection – *forward presence forces (prepare the environment; challenge adversary's anti-access/area-denial system)*; *expeditionary forces (enable maneuver while in contact, enable joint forcible entry); national-level capabilities (prepare the environment, enable maneuver while in contact); authorities (tailored authorities)*	**Execute health service support and force health protection** – *conduct independent maneuver (protection and sustainment)*	**Enable situational understanding and decision making** – *cross-domain synergy (optimize capabilities, achieve maximum effects); layered options (multiple methods of synchronizing capabilities); mission command (dynamic cooperation, rapid integration of capabilities, resource allocation, operational sequencing)*

Mission Command - The proliferation of unmanned systems requires a new approach to command and control (C2) of RAS enabled formations. The future force requires the capability to execute tactical, operational, and strategic communications and data sharing beyond-line-of-sight through a secure, autonomous, self-healing, and intelligent network. Maneuver battalions will employ hundreds of unmanned systems (unmanned ground and air) at the section, platoon, and company levels challenging a staff's ability to employ effectively the systems. The future force at the tactical through strategic level requires the ability to maintain a COP that captures all systems in real time and systems that enable mission command of multiple manned and unmanned systems. The development of AI that supports the employment of unmanned platforms and networks within formations, particularly at the tactical level, is essential. In a communications denied environment, the future force must employ *autonomous* RAS to be effective. Assured communications and sufficient network bandwidth are critical to sustaining a RAS-enabled formation's operational speed and tempo as the number of unmanned platforms operating within its system-of-manned/unmanned systems increases. U.S. future force requirements to transition from a RAS-enabled force to a RAS-centric force can occur after developments for assured communications and greater levels of autonomy are sufficiently complete. The future force requires the capability to maintain assured positioning, navigation, and timing for unmanned systems and munitions to operate and navigate in a global positioning system satellite denied environment. The Army must determine and designate new or modified staff tasks required to facilitate mission command of RAS-enabled formations. The future force requires the capability to collect, assess, analyze, and fuse data through the employment of AI, and disseminate the information autonomously to the appropriate commands at the speed of the battle. Artificial intelligence decision support technologies must be able to explain recommendations, and in the case of autonomous systems provide data that explains decisions. System integration, interchangeability, and communication require that the Joint Force define standards for architecture, language, and protocols between RAS platforms and payloads.

The Army must develop and refine policies such as rules of engagement (RoE) as well as tactics, techniques, and procedures regarding the employment of RAS and artificial intelligence. Leaders will have to consider the impact of RAS amongst indigenous populations, particularly when local nationals have little or no exposure to autonomously operating unmanned systems. Future RoE must address the use of RAS employed via artillery and rockets particularly during competition and return to competition. Individual RAS and AI concepts of employment must take into consideration host nation legal restrictions (particularly during competition and return to competition), operational security requirements, and escalation regimes controlled by existing alliance structures.

Sustainment - Sustaining RAS enabled formations will require a common concept-based, technically integrated system-of-system solutions approach. This approach will enable the reduction of Soldiers engaged in material handling tasks as well as potentially enable individual RAS systems to self-load. Artificial intelligence and RAS will enable precision logistics within the sustainment enterprise. An AI-enabled system-of-systems will provide commanders the ability to resupply platforms and Soldiers without request, at the point of need, based on intent driven priorities. The future force will utilize ground and aerial RAS within this system-of-systems to resupply formations. The future force requires RAS-enabled vehicles that can self-load and employ all relevant classes of supply (III/V) if humans are to remain out of a formation's resupply process. RAS must be maintainable (or self-maintaining) and employable by soldiers, enabled to prevent enemy exploitation, and have the ability to generate, store, and distribute sufficient power across formations and RAS platforms.

Concepts of employment for medical evacuation and casualty treatment RAS need to address issues concerning remote patient care, patient abandonment, and expansion of clinical practice guidelines and medical-practice authorities for forward-located medics. Casualty evacuation (CASEVAC) doctrine will require modification to support unmanned evacuation and delay of first responder intervention. The Army will also need to address Army Health System and Army doctrine supporting extended duration of movement of casualties via autonomous systems. The future force requires medical RAS that is interoperable with the Joint Operational Medical Information System and Genesis medical systems for documentation and communication of patient care. The future force requires the capability for operators to adjust unmanned ground vehicle (UGV) and unmanned aircraft system (UAS) payloads installed on teamed unmanned platforms. This requirement includes UAS (Category 3+) and UGV that can adjust payloads in a field environment to conduct CASEVAC missions.

Organizational Design - The proliferation of RAS and the use of AI significantly increase the complexity of a staff's C2 requirements. The Army will identify new staff tasks and modify old ones as RAS spread throughout the force. This trend warrants an examination of staffs' compositions and responsibilities. The changing nature and type of information generated by RAS and AI impacts the required skills and attributes the Army will need in future leaders and Soldiers. The near ubiquity of RAS and AI envisioned for the future force will require technically skilled maintenance personnel currently un-forecasted in organizational designs. Professional education and training will need to address the operation and maintenance of RAS and AI systems. Artificial intelligence and platform autonomy must enable a future formation's support structure to sustain subordinate formations with minimally manned or autonomous support vehicles; otherwise, growth of the formation's "tail" occurs commensurate with the increased fielding of RAS into the formation. Initially, and counter intuitively, the number of personnel in the operational area will increase because of RAS. Continued fielding of RAS into a formation increases the complexity of its mission command and sustainment.

The cumulative effect of RAS and AI may demand new military occupational specialties to conduct mechanical, electronic, and software maintenance. The need to increase the number of higher paid and better technically trained maintenance personnel required to conduct repairs and services on a RAS-heavy fleet may offset some of the force related benefit of unmanned systems.

The future force requires RAS and AI to implement MDO fully. These systems allow the future force to conduct information collection and analysis to increase situational understanding in time constrained and information competitive environments. This enables rapid, informed, and sound decision-making. RAS will lighten the warfighter's physical workload and increase mobility, protection, lethality, and sustainment effectiveness allowing for movement and maneuver along multiple axes of advance to contest aggression and defeat the enemy. Unmanned systems enabled by AI will detect, identify, and penetrate high-risk areas to increase capacity to conduct operations and protect the force, populations, and resources. Robotic and autonomous systems will conduct precision supply operations that extend operational reach and prolong endurance.

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Introduction

At the January 2016 Unified Quest (UQ) Future Force Design (FFD) II Seminar the Army Chief of Staff posited that capabilities projected for the force in the 2030-2050 timeframe could potentially have a significant impact on the nature and character of war. Future technologically enabled capabilities could make the operational environment (OE) much more lethal thereby precipitating the need for the Army to examine the conceptual implications of this type of environment. The speed of development of future technologies, such as robotic and autonomous systems (RAS), will most certainly have a reciprocal accelerating effect on the evolution of war; the effect could be revolutionary if the force's formations become predominantly, or even completely, unmanned. The challenge the Army currently faces is the ability to understand the impact of its increased investment in, and future use of, RAS on the legality, economics, and social interactions of war.

In October 2016, the Joint Chiefs of Staff (JCS) published the *Joint Concept for Robotic and Autonomous Systems (JCRAS)* to describe the JCS vision of RAS in use by 2035 and to guide development across the Joint Force. The concept's central idea is "By 2035, the Joint Force will employ integrated Human-RAS teams in a wide variety of combinations to expand the Joint Force commander's options."[1] Three precepts enable this:

- Precept #1. Employ Human-RAS teams
- Precept #2. Leverage autonomy as a key enabler
- Precept #3. Integrate RAS capabilities to develop innovative concepts of operation

The JCRAS identifies ten concept required capabilities comprised in two areas: develop manned-unmanned teaming (MUM-T), and leverage technology development. The concept proposes to "…change from incremental RAS development to a more comprehensive process and replaces approaches that merely add new capabilities to existing systems and formations".[2]

In March 2017, the Army published *The U.S. Army Robotic and Autonomous Systems Strategy*. The strategy identifies five capability objectives: (1) increase situational awareness; (2) lighten the warfighters' physical and cognitive workloads; (3) sustain the force with increased distribution, throughput, and efficiency; (4) facilitate movement and maneuver; and, (5) increase force protection. The RAS strategy articulates a policy for the human control of autonomous systems by stating, "The Army seeks to maintain human control over all (Army) autonomous systems."[3] It recognizes that artificial intelligence (AI) will contribute to faster and improved decision-making by:

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[1] United States. Joint Chiefs of Staff (JCS). *Joint Concept for Robotic and Autonomous Systems (JCRAS)*. (Washington, D.C.: Department of Defense [DoD], 2016): 6.
[2] Ibid: 12.
[3] United States. Department of the Army. Training and Doctrine Command (TRADOC). Army Capabilities Integration Center (ARCIC). Maneuver, Aviation, and Soldier Division (MAS-D)., *The U.S. Army Robotic and Autonomous Systems Strategy*, (Fort Eustis, VA: TRADOC, 2017): 3. Parenthetical added for clarification.

- identifying strategic indications and warnings
- advancing narratives and countering adversarial propaganda
- supporting operational and campaign-level decision-making
- enabling leaders to employ "mixed" manned-unmanned formations
- enhancing the conduct of specific defensive missions in which functions of speed, amount of information, and synchronization might overwhelm human decision-making

The Army seeks common control in future RAS acquisitions. This requirement allows a single software package to control multiple and varied systems. The last two essential requirements for future RAS are cyber protection and mission assurance. The strategy prioritizes autonomy, AI, and common control as key efforts necessary to achieve the five capability objectives.

Why must the Army operationalize robotic and autonomous systems?

Operationalizing, or rather, developing an operational description for RAS employment allows the Army to understand better the potential impact of those technologies on the nature and character of war. Describing how Army formations may employ RAS in the future OE helps illustrate its impact on war's violent, interactive, and fundamentally political nature as well as war's continuously evolving character.[4] Operationalization serves as the next logical extension of the JCRAS and the U.S. Army's RAS Strategy by providing additional context to required capabilities identified in concepts, and capability objectives. In December 2017, the ARCIC's Future Warfare Division conducted a seminar to better understand the concept, capabilities, and organizational design implications of the Army's potential application of 2030 RAS technologies.[5] Subject matter experts from the U.S. Army Training and Doctrine Command's (TRADOC) Capability Development and Integration Directorates, the Unified Quest (UQ) Science Advisory Group (SAG), and the TRADOC G-2 collaborated using the Multi-Domain Operations (MDO) operational framework and the campaign continuum (competition, armed conflict, and return to competition) as the physical and temporal means by which to operationalize 2030 robotic and autonomous systems.[6] The outcome of this event was the visualization and description of the organizational employment of RAS in time, space and purposeful tasks according to five employment variables:

- the MDO operational framework area from which a formation employs the system
- the types of formations employing the system and the system's tasks

[4] In *The Operational Environment and the Changing Character of Future Warfare*, the TRADOC G-2 projected the character of war in 2035 to be highlighted by: the ascendency of the moral and cognitive dimensions; integration across the elements of national power (diplomatic, information, military, and economic [DIME]); limitation of military force; primacy of information; expansion of the battle area/hyper destruction; ethics of warfare shift.
[5] Unified Quest 2018, Future Force Design IV Seminar at the U.S. Army War College, Carlisle Barracks, PA. For this event, 2030 RAS technologies were those systems the Army could develop at Technology Readiness Level 6 by 2030.
[6] The UQ SAG consists of representatives from the various Army research and development centers and laboratories who advise UQ designers, cadre, and participants on potential future force technologies.

- operational benefits from the formation's employment of a system
- system interdependencies
- system vulnerabilities

Describing RAS employment in this way allowed the subject matter experts to identify system concept, capability, and force design considerations and issues requiring further assessment.

Why operationalize RAS using MDO as the context?

The purpose of the MDO concept is to describe how the Army as a part of the Joint Force will operate, fight, and campaign across all domains, the electromagnetic (EM) spectrum, and the information environment against a peer adversary in the 2025-2040 timeframe. The concept will drive change and organizational design for the future Army. It will provide the foundation on which TRADOC conducts capabilities-based assessments to refine required capabilities, identify gaps, and determine potential capability and policy solutions for future forces. This document describes the future vision of how the Army will fight; follow-on doctrine will describe a more specific approach.

Multi-Domain Operations requires the military to view the OE, potential adversaries, and their capability sets from a different perspective. The Army must define the warfighting problem based on the complexities of the modern battlefield, the rate of change in terms of information access and decision, and the role that non-traditional, proxy, or hybrid actors play to shape operations, especially during competition. Multi-Domain Operations requires the ability to maneuver and deliver effects across all domains to develop and exploit battlefield opportunities across an operational framework. It must include whole-of-government approaches and solutions to military problems and address the use of multinational partner capabilities and capacity.

Multi-Domain Operations extend the battlespace to strategic areas for both friendly and enemy forces. It expands the targeting landscape based on the extended ranges and effects delivered at range by integrated air defenses (IAD), cross-domain fire support, and cyber and electronic warfare (EW) systems. The Army must solve the physics of this expanded battlespace and understand the capabilities available in each domain in terms of echelonment, speed, and reach. While each Service's view of the operational framework may vary, advances by peer adversaries drive a requirement for the Services to adopt a common framework to achieve a continuing advantage in a contested, degraded, and operationally limited environment.[7]

Multi-Domain Operations depicts the future OE as being more lethal and complex. The future adversary will be more lethal and better able to challenge deterrence. These projections demand capabilities that future RAS can provide. Robotic and autonomous systems will provide increased Soldier protection by spoofing, jamming, and destroying enemy systems. It can serve in the vanguard of efforts to penetrate enemy anti-access and area denial (A2/AD) efforts. It will allow for greater dispersion, permitting the future force to mitigate the increased use of massed

[7] David G. Perkins and James M. Holmes, "Multidomain Battle Converging Concepts Toward a Joint Solution," *Joint Forces Quarterly* 88 (January 2018): 56.

artillery, rockets, and weapons of mass destruction. Artificial intelligence and RAS can fuse data from networked intelligence, surveillance, and reconnaissance (ISR) sensors, maneuver to an advantageous location, and act more quickly than the adversary. Advanced data analytics, real-time processing, and alternate decision-making frameworks will enable commanders to decide and act faster than adversaries. Future RAS will enhance awareness by collecting, processing, and prioritizing information from advanced sensor networks that provide a more comprehensive understanding of the battlespace.

Multi-Domain Operations specifically envisions forces employing RAS and AI to:[8]

- conduct preparatory intelligence activities and map EM spectrum and computer networks
- build partners' capacities and capabilities to defeat increasingly sophisticated adversary information warfare
- visualize and command a battle in all domains and shift capabilities rapidly between domains and organizations to mass combat power against adversary vulnerabilities
- extend sustainability of systems and formations by leveraging a sustainment enterprise that is supported by predictive analysis tools and able to resupply without request
- prepare the operational environment for competition and conflict by building understanding of select urban areas of particular operational or strategic importance
- converge capabilities to attack specific adversary vulnerabilities

What does operationalize RAS mean?

Operationalize is a description of an organization's employment of a system or systems informed by an understanding of the system's characteristics, to perform specific tasks. To operationalize means to put a system into operation within its spatial or temporal boundaries or framework. Army Doctrinal Publication (ADP) 1-01 defines *operational framework* as a cognitive tool used to assist commanders and staffs in clearly visualizing and describing the application of combat power in time, space, purpose, and resources in the concept of operations.[9] In social sciences, *operationalization* refers to the process of specifying the extension of a concept - describing what is and is not an instance of that concept. *Operational definition* helps determine the nature of a phenomenon and its properties. An operational definition is the application of operationalization used in defining the terms of a *process* (or set of validation tests) needed to determine the nature of an item or *phenomenon* (e.g., a variable, term, or object) and its *properties* such as duration, quantity, extension in space, chemical composition, etc. During the Unified Quest 2018 Future Force Design IV seminar, RAS subject matter experts described a formation's application of RAS (phenomenon) using certain operational variables (properties) – benefits, interdependencies, and vulnerabilities. The MDO operational framework

[8] United States. Department of the Army. TRADOC. ARCIC. "*The U.S. Army in Multi-Domain Operations, 2028"* Initial Coordinating Draft, Version 0.7k3 (Fort Eustis, VA: United States Army TRADOC, September 2018): 43-44 and Appendix B.
[9] United States. Department of the Army. *ADP 1-01 Doctrine Primer*. (Washington, D.C.: Headquarters Department of the Army, 2014): 4-8.

and temporal model provided context for this process. The combination of operational definition with the MDO operational framework provides the operationalization of RAS described in this paper.

This white paper provides a broad perspective of the application of RAS within the MDO concept. It builds upon the MDO concept by indicating how the force applies RAS technologies similarly and differently across the operational battlespace and the campaign continuum. It provides the capability development community with operational perspective and fidelity to the broadly stated precepts and required capabilities described by the Joint Concept for Robotic and Autonomous Systems. It also provides capability developers a basis from which to develop scenarios or vignettes for capability based assessments or cost-benefit analyses. The paper provides the science and technology community with operational context for RAS developmental research and prototyping. Lastly, this paper provides the Army a vision for employing emerging RAS in the future operating environment to inform formation equipping.

Robotic and Autonomous Systems Employed to Enable Multi-Domain Operations

The MDO operational framework transcends the traditional "deep, close, and rear areas" to capture the complexities of the multi-domain environment better. It divides the battlespace into seven areas and accounts for all domains (Figure 1), extending to space and cyberspace, as well as the electromagnetic spectrum and information environment. The mixture of both enemy and friendly capabilities available for use defines these areas. Despite its geometrical depiction, geographic space or relationships do not define the framework. The MDO framework allows commanders to arrange operations and reference Joint Force, partner, adversary, and enemy actions across all domains. [10]

MDO modifies the *Joint Concept for Integrated Campaigning's* competition continuum (cooperation, competition below armed conflict, and armed conflict) by focusing the construct on potential adversaries. This modified continuum describes the United States as being in a perpetual state of competition (competition and return to competition) only interrupted by periods of armed conflict. During competition, the adversary's primary aim is to isolate friendly forces politically to limit an allied response, politically destabilize target states, and achieve objectives below armed conflict. The adversary during competition may already consider itself engaged in a national conflict and employ all elements of national power to achieve its objectives. An adversary primarily relies on reconnaissance, unconventional warfare (UW), and information warfare (IW) forces to achieve these objectives. During armed conflict, the enemy seeks a rapid outcome to limit risk to its forces and civil stability. The enemy will attempt to fragment the employment of Joint Force elements and prevent the deployment of reinforcements. In armed conflict, conventional forces are the main effort supported by UW, IW, and nuclear capabilities.

[10] United States. Department of the Army. TRADOC. ARCIC. "*The U.S. Army in Multi-Domain Operations, 2028*.": 4.

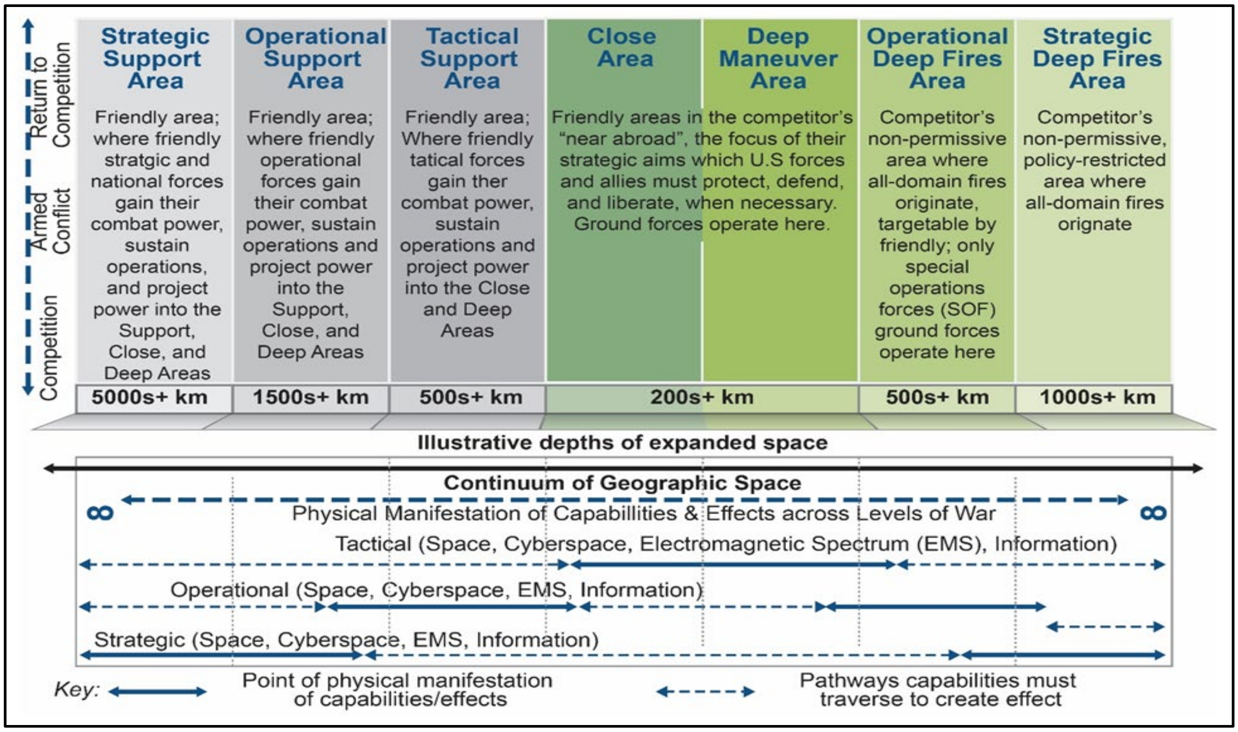

Figure 1: The MDO Operational Framework[11]

Widespread violence characterizes the initial stages of the return to competition. The enemy will likely retain significant lethality and occupy some friendly terrain. Enemy action will rely on UW, IW, and potentially nuclear capabilities focused on creating conditions that allow for a negotiated settlement.[12] The Army, as a part of the future Joint Force, will employ RAS in the conduct of MDO to contest adversaries in competition and, when required, defeat them in armed conflict. These operations and activities will take place in the adversary's homeland, in the close and support areas, and in the continental United States.

RAS in the Deep Fires Area

The Deep Fires Area is beyond the feasible range of movement for conventional (ground) forces but where the Joint Force Commander employs joint fires, special operations forces (SOF), information and virtual capabilities. Friendly force efforts here are typically transitory. The Deep Fires Areas consists of the Operational Deep Fires and Strategic Fires areas.[13] The physical and virtual capabilities permitted by law or policy and that can operate in the heart of enemy defenses limit the potential operations in the Deep Fires Areas. This limited accessibility and the inherent difficulty of operating deep within enemy territory place a premium on the ability to combine and employ all available capabilities from across all domains.

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[11] United States. Department of the Army. TRADOC. ARCIC. "*The U.S. Army in Multi-Domain Operations, 2028*.": 4.

[12] For a detailed discussion on competition, armed conflict, and return to competition see United States. Department of the Army. TRADOC. ARCIC. "*The U.S. Army in Multi-Domain Operations, 2028*.": 23-41.

[13] United States. Department of the Army. TRADOC. ARCIC. "*The U.S. Army in Multi-Domain Operations, 2028*.": C-2.

Types of Formations and Tasks

During competition, armed conflict, and return to competition, echelons above brigade (EAB) formations employ RAS to support resilient networks, conduct wide-area persistent surveillance, and improve mission command and decision making from the Operational Support to the Deep Fires areas. Echelons above brigade, joint, and interagency assets establish a common operational picture (COP) using networked ISR RAS to create a constellation of multi-spectrum sensors in all domains. These sensors will detect enemy long-range fires, air defense systems, radars, and command and control (C2) nodes/networks. They will also serve as potential cyber inject points for offensive cyber operations. The RAS in Military Intelligence (MI) formations (Theater, Aerial Intelligence, and Expeditionary MI brigades), perform processing, exploitation, and dissemination (PED) of data gathered throughout the OE and across multiple domains.[14] Autonomous and intelligent systems enabling mission command will have the following characteristics:

- network provided access for commercially available devices[15]
- frequency agile, capable mobile networks to form reliable and secure command posts
- standardized and modular architectures simplifying integration of commercial devices
- multi-functional device(s) supporting convergence of tasks and transport mechanisms
- interference cancelation and mitigation techniques for spectrum management
- network security level permissions based on credential authentication
- scaled network availability based on user demand
- distributed command posts bringing higher echelon services to a more tactically integrated battlespace

At EAB, narrow AI software will exploit large sets of data provided by other government agencies or unified action partners, and/or developed by other means.[16] The ability to analyze large amounts of data quickly will allow the commander and staff to understand the OE and apply or support the application of the instruments of national power to shape it.

Echelons above brigade signal and cyber formations manage autonomous narrow AI active cyber defense capabilities across the operational framework and at multiple echelons.[17] These systems

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[14] The U.S. DoD has placed PED as the top priority for AI development, see: Robert O. Work, *Memorandum Subject: Establishment of an Algorithmic Warfare Cross-Functional Team (Project Maven)*, (Washington, D.C.: DoD, 2017), https://www.govexec.com/media/gbc/docs/pdfs_edit/establishment_of_the_awcft_project_maven.pdf.

[15] The Nett Warrior System currently provides this capability. See: United States. DoD. Director, Operational Test and Evaluation., *FY 2013 Annual Report*, (Washington, D.C.: DoD, 2013).: 119-120.

[16] For a discussion on a current intelligent agent (Warfighter Associate) see: Norbou Buchler et al., "The Warfighter Associate: Objective and Automated Metrics for Mission Command" (Paper presented at 18th International Command and Control Research and Technology Symposium, Alexandria, VA, June 19, 2013).

[17] Automated systems and advanced algorithms will reduce time and effort involved in identifying and patching vulnerabilities, detecting attacks, and defending against active attacks. A GAO report on AI identifies two approaches to accomplish this – autonomous exploit detection and repair and machine learning with human feedback (United States. Government Accountability Office (GAO)., Report to the Committee on Science, Space,

discover, define, analyze, and mitigate cyber threats and vulnerabilities without direct human intervention. The Space Brigade, operating from the Operational Support Area, deploys stratospheric/high-altitude (HA) platforms capable of carrying tailorable payloads. Positioned to maximize their capabilities while minimizing vulnerabilities, they provide capabilities to formations across the operational framework. These systems can conduct reconnaissance, surveillance, and target acquisition (RSTA); relay data for command, control, communications, computers and intelligence, surveillance, and reconnaissance (C4ISR), and provide positioning, navigation, and timing (PNT).

Echelons above brigade engineer and intelligence formations provide persistent surveillance within the Deep Fires Area by using highly dispersible, low cost, expendable unattended sensors that will lay dormant until triggered by a particular threat signature, event, or activity.[18] Examples of potential enemy activity that this RAS could monitor include long-range fires, air defense system employment, and radar detection. Unit intelligence sections at all echelons employ AI enablers such as software agents, intelligent agents, multi-agent systems, machine learning, computer vision, and natural language processing.[19] The sections will use these enablers to overcome the challenges of time and massive quantities of data to provide opportune, accurate, relevant, and predictive intelligence in support of operations and mission command. This massive quantity of data will also change and improve how engineers provide mapping to the force. The Theater Engineer Command also manages an automated, integrated sensor common operational picture. The sensor COP enables real-time visibility of all aspects of collection and processing of data to answer priority intelligence requirements (PIR) and information requirements (IR). The COP also allows the staff to see the difference between planned and actual collection and to see gaps in sensor coverage.

During competition, armed conflict, and return to competition at the Special Forces Group level, Tactical Unmanned Aircraft Systems (UAS) Platoons operating in the tactical support area employ Group 3 UAS in the Deep Fires and Deep Maneuver areas to provide: [20]

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and Technology, House of Representatives: Technology Assessment: Artificial Intelligence – Emerging Opportunities, Challenges, and Implications, (Washington, D.C.: GAO, 2018): 59-60). The same report defines narrow AI as "…applications that provide domain-specific expertise or task completion." (Ibid: 10).

[18] These sensors utilize a mesh network to communicate internally and externally to single or multiple receivers. See Robert Poor, "Wireless Mesh Networks," Sensors Online, February 1, 2003, https://www.sensorsmag.com/components/wireless-mesh-networks. Capability developers have not determined the sensors' deployment methods, but airdrop or a cluster munition is a likely solution.

[19] *Natural language processing* refers to a computer's ability to understand conversational language akin to Apple's Siri or Amazon's Alexa. *Computer vision* is a system's ability use the electromagnetic spectrum to produce an image. Computer vision is essential technology for autonomous systems. See: United States. Defense Science Board. Task Force on the Role of Autonomy in DoD Systems, Task Force Report: The Role of Autonomy in DoD Systems, (Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2012): 33.

[20] The U.S. Army Roadmap for UAS 2010-2035 defines a Group 3 UAS as systems that "…operate at medium altitudes and usually have medium to long range and endurance. They usually operate from unimproved areas and may not require an improved runway.": 13. The UAS envisioned the U.S. Army Special Operations Command combines the payload capacity of a Group 4 UAS with the ability to utilize unimproved takeoff areas from Group 3. See Appendix C for definitions of specific UAS Groups or the *U.S. Army Roadmap for UAS 2010-2035* for a detailed discussion.

- C4ISR
- psychological operations messaging
- persistent internet
- high-value asset recovery
- resupply capabilities

Special Operations aviation platoons employ future rotary wing systems teamed with organic and joint UAS assets. These UAS will employ mission dependent interchangeable or multi-functional payloads that increase situational awareness, lethality, survivability, and reduce detection by manned aircraft in the Deep Fires and Maneuver areas. The aviation platoons employ UAS in a MUM-T role to counter enemy UAS, or as hunter-killer teams in the battlespace. Artificial intelligence-enabled wingman UAS provide cover and support for manned aircraft during vulnerable flight attitude changes such as takeoff or landing. At the Special Forces battalion, company, and detachment levels, Special Forces operators employ Group 1 and 2 UAS from the Close and Deep Maneuver areas. These UAS perform ISR, enhance force protection, and provide communications relay. The Joint Precision Airdrop System (JPADS) resupplies SOF within the Deep Fires Area in combination with autonomous unmanned ground vehicles (UGV).[21] The autonomous UGV moves the JPADS delivered cargo to prevent enemy detection of SOF during their rendezvous with aerial resupply assets. The locations of theater SOF elements govern the prepositioning of UGVs, unmanned maritime systems (Unmanned Surface Vehicles and Unmanned Undersea Vehicles) during competition or early in armed conflict. Special operators summon these systems as needed to perform resupply, surveillance, and extraction of high value materials from the Deep Fires Area to the Close, Tactical Support, or Operational Support areas in littoral and riverine environments. Subsurface systems may also transport payloads for other maritime, aerial, or ground autonomous systems. These systems may transition between subsurface, surface maritime, and land environments for payload delivery.

During armed conflict, SOF can employ UGVs in an offensive role during assaults on high-value targets such as airfields, critical supply points, surface-to-air missile sites, long-range fires batteries, and vital enemy infrastructure. These systems can provide firepower overmatch at the point of attack, surveillance and cover dead space or anticipated approaches by enemy reinforcements, and provide covering fire during a ground force assault.

During competition, armed conflict, and return to competition, Operational Fires Commands (OFC) and Division Fires Commands (DFC) in the Operational Support Area employ runway-independent Group 3 UAS and dedicated stealth Group 4 UAS to perform ISR of strategic

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[21] EAB sustainment assets prepare JPADS payloads in the Strategic or Operational Support areas. Manned or unmanned aircraft systems (UAS) deliver the JPADS over or outside the Deep Fires Area (geography and weather conditions dependent). See: Richard Benney et al., "The Joint Precision Airdrop System Advanced Concept Technology Demonstration," in 18th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar (Munich: American Institute of Aeronautics and Astronautics, 2005). The K-MAX UAS successfully delivered JPADS payloads during test flights in January 2011. See: Army Technology, "K-MAX Unmanned Aircraft System," Army Technology, accessed May 29, 2018, https://www.army-technology.com/projects/k-max-unmanned-aircraft-system/.

targets within the Deep Fires and Maneuver areas. Joint Precision Strike Teams (JPST) maintain and operate runway-independent UAS consisting of one launcher-catcher with four drones per team. Unmanned aircraft systems' target acquisition capabilities form part of the OFC and DFC sensor-to-shooter network. The JPSTs operate as deep as possible in the corps and divisional battlespace while maneuver or reconnaissance forces provide security and sustainment to the teams.[22] They direct the employment of UGVs, artillery delivered drones, or other robotic systems. The JPSTs control these systems once they deploy via air, ground, or sea through virtual technology to locate targets. They initiate fire missions upon unmanned systems' acquisition of targets. The UAS platoon in the OFC's Observation Battery consists of four stealth UAS (Group 4) with RQ-170-like capabilities.[23] These stealth-capable RAS identify targets and transmit target control quality data through extended-range communications networks for processing on the integrated fires network (IFN). This UAS is programmable and capable of getting to the target area through inertial navigation in a global positioning system (GPS) denied environment. Its stealth technology allows it to operate in a robust integrated air defense systems (IADS) environment.

During armed conflict, the OFC and DFC employ rocket and missile-delivered UAS and loitering projectile systems to perform ISR, extend the communications network, conduct offensive EW, and enable targeting. Both organizations retain these capabilities during the return to competition. A significant function of the corps Fires Cell is to integrate all available sensors supporting collaborative intelligence gathering, analysis, coordination, and dissemination. Artificial intelligence will enable sensor integration.[24]

Operational Benefits

The stratospheric/HA platforms may improve situational awareness in A2/AD environments and enhance ISR collection through long loiter periods and ability to transit between areas of the Multi-Domain battlefield. The low radar cross-section and low visual signature of the stratospheric/HA platform increases survivability while situational awareness benefits from the sensor payload's wide field of view to collect information on adversaries.

Autonomous active cyber defense reduces the cognitive load on cyberspace operators by assuming many of the inherent tasks currently done by humans. This system responds at computer speed to a barrage of simultaneous threat intrusions.

[22] Joint precision strike teams will primarily operate in the Close Area and occasionally as far forward as the Deep Maneuver Area.

[23] RQ-170 is a high altitude (50,000 feet AGL) long endurance UAS capable of providing real time imagery and gathering multispectral intelligence. See: "RQ-170 Sentinel Unmanned Aerial Vehicle." In *Air Force Technology*. n.d. Accessed May 2, 2018. https://www.airforce-technology.com/projects/rq-170-sentinel/.

[24] The corps Intelligence Section (G-2) develops and manages the information collection plan and conducts all-source analysis and production. The section coordinates with joint, interorganizational, and multinational (JIM) intelligence elements for the employment of ISR into targeting efforts to facilitate strikes. The corps G-2 Geospatial Intelligence (GEOINT) Cell provides imagery analysts and develops GEOINT products. The GEOINT Cell fuses intelligence data, synchronizes imagery intelligence production, and provides geospatial analysis to facilitate a data-rich and unified COP improving corps targeting efforts.

Meshed sensors, AI applications, and a sensor COP enable formations by reducing the Soldier's cognitive workloads and increasing situational awareness. Artificial intelligence systems process massive data sets, accomplishing tasks in minutes that once took hours or days, and provide an exponential increase in analytical rigor. A sensor COP manages sensor networks and identifies gaps in sensor coverage. Low-power meshed sensor networks will expand operational reach into dense urban environments and other denied areas through agile and flexible emplacement tactics and procedures. A mesh network distributes sensor data so if the environment or adversary obstructs any pathways or gateways the network will find another transmission route.[25] Ultimately, these systems enable Soldiers to not only satisfy the commander's PIR and inform timely decisions, but also help staffs discover insights about the adversary they were not explicitly seeking.

Unmanned systems provide a range of operational benefits to formations operating in the Deep Fires Area including providing situational awareness through persistent ISR, extending operational reach, and improving sustainment efficiency and efficacy. The ability to detect and precisely identify targets further aids situational awareness as well as lethality. The stealth UAS is capable of reaching the target area using inertial navigation in a GPS-denied environment, and its stealth technology allows it to operate in a robust IADS environment as well. Survivability and sustainability of SOF units will improve as precision resupply can pre-position caches. Formations employing RAS in this area further extend operational reach by increasing access to, and support from, host nation populations.

Interdependencies

Stratospheric/HA platforms require a human controller and communication network to navigate and control altitude. However, autonomous programming of these platforms may be possible enabling them to fly to waypoints, and for the platforms to utilize onboard navigation capabilities to optimize their routes and positions. Artificial intelligence, the sensor COP, and cyber threat alerts are all interdependent. They require access to data networks, data transport from a myriad of pre-existing observational and sensing sources and modalities, and MUM-T and training concepts that will build trust in algorithmic outputs. Artificial intelligence-enabled automated cyber defense is dependent on human intervention for on-going operation and/or verification of attacks.[26] Artificial intelligence enablers are dependent upon reliable and high quality data to realize machine learning.[27]

Unmanned aircraft systems/UGVs/UMS are dependent upon air-ground-maritime management and extended range communications networks. They also depend upon other RAS or manned systems for insertion to the Deep Fires Area, as well as operator (local or long-distance) control to transport, repair, launch, operate, and recover the systems. The IFN serves as the primary means of airspace management by disseminating munitions flight paths to all joint,

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[25] For an explanation of how RAS incorporates mesh networks see: Adin Dobkin, "Next Generation of Robots Will Use Mesh Networking," *Defense Systems*, November 29, 2017, https://defensesystems.com/articles/2017/11/28/army-robots.aspx.
[26] United States. GAO., "Artificial Intelligence.": 5.
[27] Ibid: 11.

interorganizational, and multinational (JIM) partners.[28] Fires ISR systems use a JIM IFN and depend on reliable, rapid, and agile linkages between sensors and shooters that provide targeting data. Aerial RAS identify targets, transmitting target control quality data through extended range communications networks for processing through the IFN. These network-enabled fires engage the enemy with a speed and accuracy that exceed human abilities. The IFN enables automated effects assessment and updates to the COP to improve situational understanding across the Joint Force. The IFN relies on assured communications to function.

Vulnerabilities

All UAS/UGV/UMS and stratospheric/HA platforms controlled through extended range communications networks are subject to spoofing, jamming, and electronic attack. Other vulnerabilities include communications link degradation, environmental effects on the seeker head or sensor array, and kinetic attack. All aircraft are susceptible to surface-to-air and air-to-air interdiction. The ability to generate and/or store power affects the range of the runway-independent unmanned aircraft systems. Meshed sensors are susceptible to weather and environmental conditions that may obscure their sensors.

Weather may limit the operational window for launch and transit to altitude (> 60,000 feet) of the stratospheric/HA platform. Launching the platform during benign conditions in anticipation of later needs can mitigate this vulnerability. Inclement weather can also force the RAS off station or obscure and degrade sensor performance. This platform is slow to move from the launch point in the support zone to its area of utilization.

The AI-enabled active cyber defense capability is vulnerable to compromise or malfunction which could cause a segment of the defensive array to fail. The cyber threat may also evolve or change in ways unaddressed by the autonomous defensive capabilities. Adversaries can employ AI designed to identify and exploit vulnerabilities in algorithms.[29]

The AI systems developed specifically to assist in decision making have a number of vulnerabilities. An AI system's reliance on data is vulnerable to the tendency of "second wave" systems to form maladaptation based on skewed data.[30] Adversaries can exploit AI's reliance on data by manipulating or corrupting data. Artificial intelligence is subject to bias based on the quality and accuracy of its source data. Examples of this are indications of racial bias in AI systems employed in the criminal justice system for parole decisions and predictive policing.[31]

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[28] At this point, neither the services nor DoD have identified a joint solution to the IFN.
[29] United States. GAO., "Artificial Intelligence.": 46.
[30] Launchbury, John. "A DARPA Perspective on Artificial Intelligence." Defense Advanced Research Projects Agency. Last modified October 3, 2016. https://www.darpa.mil/about-us/darpa-perspective-on-ai. Second Wave AI refers to systems that are capable of "statistical learning, perceiving and prediction systems…" (United States. Government Accountability Office., "Artificial Intelligence.": 16.)
[31] Osoba, Osonde A., and William Wesler IV. *An Intelligence in Our Image – The Risks of Bias and Errors in Artificial Intelligence*. (Santa Monica: RAND, 2017): 24.

RAS in the Deep Maneuver Area

The Deep Maneuver Area is the highly contested area where ground and maritime maneuver is possible but requires significant multi-domain capability support. The capabilities available to employ in this area allow the Joint Force Commander greater flexibility than in the Deep Fires Area to establish and maintain persistent effects.

Types of Formations and Tasks

During competition, armed conflict, and return to competition SOF and forward deployed conventional force (CF) formations employ aerial, ground, and human-assist RAS, including decision-support AI, to:

- improve situational awareness and understanding
- generate targetable data through ISR[32]
- conduct sustainment (in coordination with brigade combat teams [BCT])[33]
- create specific mission effects

Special Forces operators employ the Soldier Augmentation System, a human assist robotic system that functions as a load-bearing exoskeleton capable of increasing the individual user's ability to lift and carry equipment. Conventional forces episodically employ similar systems in the Deep Maneuver Area but primarily in the Close and Tactical Support areas. The exoskeleton houses the operator and provides control through human movement, as well as through a control console integrated in the exoskeleton itself or worn by the operator.

Combat Aviation Brigades (CAB) operating from the Operational Support, Tactical Support, or Close areas employ UAS to detect, acquire, identify, and prioritize targets in support of ground maneuver during all operational phases. Systems will range from small, platform-launched systems to larger vertical take-off and landing UAS designed to enhance the capabilities of future vertical lift (FVL) through manned-unmanned teaming.

As it does in the Deep Fires Area, the corps Fires Cell integrates all available sensors for collaboration on intelligence gathering, analysis, coordination, and dissemination. During armed conflict and return to competition, the OFC and DFC employ a rocket and missile-delivered UAS loitering projectile system to perform:

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[32] The United States Marine Corps MUM-T Wargame demonstrated the ability to employ company level UAS to generate targetable data. See: United States. Department of the Navy. United States Marine Corps (USMC). Marine Corps Warfighting Laboratory (MCWL). Wargaming Division., *Manned Unmanned Teaming Wargame - Final Report,* (Quantico, VA: Marine Corps Warfighting Laboratory, 2017): B-1 and B-2.

[33] The Joint Tactical Aerial Resupply Vehicle (AKA Picatinny Pallet) can transport 300 pounds of cargo up to 60 kilometers. The Robotic Vehicle Modular (RV(M)), an UGV, has a total range of 50 miles and can carry a payload of up to 10,000 pounds. See: United States. Department of the Navy. USMC. MCWL. Wargaming Division., "Manned Unmanned Teaming.": D-5 and D-6.

- ISR
- extension of communication networks
- offensive EW
- targeting

During competition and armed conflict, maneuver support formations employ aerial, ground, and human-assist RAS technologies to provide early warning of explosive hazards, limited clandestine breaching capabilities, and improved mobility to forces operating in the Deep Maneuver Area. Formations will use UGV RAS to perform explosives detection and defeat tasks to gain access to regions denied by the enemy. During armed conflict and potentially return to competition, forward deployed forces will employ aerial or artillery delivered robotic minefields to fix, attrite, and defeat critical enemy capabilities while isolating specific threat formations and separating echelons. Unmanned aircraft and ground systems and human-assist technologies enable maneuver support during return to competition to shape threat activities, provide early warning of explosive hazards, provide limited breaching capabilities, and improve mobility. Formations employ autonomous RAS to monitor for chemical, biological, radiological, and nuclear (CBRN) employment indicators from competition to return to competition and across the operational framework from the Strategic Support Area to the Deep Maneuver Area.

Robotic and autonomous systems conduct limited sustainment activities in the Deep Maneuver Area during competition. Many of these operations support the development of robust SOF presence and gain access to indigenous partner formations through the provision of sustainment. Through the competition to conflict continuum, sustainment formations in the Operational and Tactical Support areas and SOF employ unmanned JPADS, potentially combined with an autonomous UGV, to execute precision resupply. During armed conflict and return to competition, maneuver battalions' Forward Support Elements (FSE) and Brigade Support Battalions employ Group 2 and 3 UAS to deliver large pre-packaged classes of supply. Tactical maneuver formations employ Squad Mobility Equipment Transporter (SMET) systems to execute supply and mobility operations during both armed conflict and return to competition.

During competition and armed conflict, medical commands and medical brigades located in the Operational Support Area employ UAS, UGV, and human-assist RAS that execute health service support and force health protection tasks including:

- delivery of medical logistics (Class VIII)
- casualty evacuation (CASEVAC) and patient medical evacuation (MEDEVAC)[34]
- remote and assisted Role 2/3 casualty care

[34] CASEVAC – the unregulated movement of casualties that can include movement both to and between medical treatment facilities (United States. Department of the Army. ADRP 1-02 Terms and Military Symbols. (Washington, D.C.: Headquarters Department of the Army, 2016): 1-12). MEDEVAC – the process of moving any wounded, injured, or ill to and/or between medical treatment facilities while providing en route medical care (Ibid: 1-61).

- development of a medical COP to optimize employment of EAB Army Health System formations
- detection and characterization of toxic industrial materials and chemicals, industrial threats, and environmental threats
- development of comprehensive medical information preparation of the operational environment
- delivery of vector control applications including biologics and chemical control measures
- collection and transportation of soil, air, water, and biologic samples for analysis

Through the competition to conflict continuum, EAB and SOF formations, in conjunction with corps and below medical formations, employ human-assist tele-surgery capability from higher-to-lower roles of care to formations in the Deep Maneuver Area. During armed conflict and return to competition, AI and remote systems enable expeditionary combat medics and other medical providers to improve survivability and clinical outcomes of larger casualty pools.

Operational Benefits

The primary operational benefit of the exoskeleton is the ability to increase Soldier load carriage. It will enable a higher level of performance during mission execution. Exoskeleton and UGVs will improve SOF and CF mobility by increasing self-sufficiency and reducing reliance on resupply operations. Rocket and missile-delivered UAS, employed during armed conflict, are difficult for adversary IADS to intercept and provide increased lethality through precision targeting with indirect fires or armed unmanned aircraft systems. Autonomous mobility, limited AI, and the sensor network will enhance the lethality of robotic minefields to fix or disrupt enemy formations. Chemical, biological, radiological, and nuclear detection systems (either dedicated or as an add-on payload):

- improve sustainability and persistence of forces
- decrease the number of personnel exposed to CBRN threats
- increase accuracy of threat assessments
- improve warning timeliness
- reduce time to understand the CBRN environment

Robotic and autonomous system resupply operations in the Deep Maneuver Area provide a number of operational benefits to the employing formations. The JPADS improves sustainability through precision delivery of critical supplies and reduces the physical load Soldiers must carry thereby improving formation mobility. Autonomous UGV employed by SOF and forward deployed CF further enhances survivability by allowing movement of cargo upon landing to prevent enemy detection during rendezvous with resupply unmanned ground vehicles. These unmanned systems extend SOF operational endurance and increases access to, and support from, host nation populations. The medical RAS and tele-surgery RAS greatest operational benefit is the enhanced survival of formations. These health service support RAS provide medical force multiplication (i.e., one care giver can attend multiple casualties), enhanced combat casualty care, and a higher survival rate for sick and wounded personnel due to rapid medical intervention and evacuation of casualties. Lastly, utilizing robotic surrogates to conduct resupply, CASEVAC or MEDEVAC increases safety by reducing personnel exposure to hazardous environments.

Interdependencies

All unmanned systems that are not to some degree autonomous require advanced control systems. Combat Aviation Brigade UAS and FVL will cooperate to enhance each other's capabilities. Disrupting this relationship could adversely affect the optimal execution of these mutually enabling manned-unmanned teams. Control of UAS moving to and in the Deep Maneuver Area will require capable automated systems for airspace management and awareness; the IFN must integrate robotic and autonomous systems.[35] Other UAS dependencies include their need for PNT data and data transport systems between manned and unmanned transport, repair, launch, operation, and recovery enabling systems.

The employment of robotic minefields, primarily during armed conflict, is dependent on a delivery system and sensor network. Use of RAS for CBRN detection depends upon on long-range, secure communications as well as a tailored operating environment database of emerging threats to mitigate false positive readings by detection systems.

Unmanned systems (UAS, UGV, UMS) conducting resupply operations are dependent on secure communications networks, sustainment logistics formations' ability to move supplies to the point of distribution, and survival of the air-delivery platforms. This dependency may require integration of fires capabilities to suppress enemy air defenses and significant intelligence preparation to ensure accurate delivery and receipt of critical supplies. Joint Precision Airdrop System-delivered UGVs are dependent upon delivery capabilities for insertion, as well as a controller's guidance during mission execution. Medical RAS will depend upon assured communications and access to mission command and intelligence networks. This access is critical for collection, transmission, and analysis of data to support:

- a COP and resource optimization[36]
- integration into joint and Army common and medical logistics systems
- the Army Health System enterprise for the movement and treatment of casualties

Tele-surgery RAS depends on telemetry and secure communications systems to ensure human-to-RAS interface to maximize optimal clinical outcomes

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[35] The USMC Manned Unmanned Teaming Wargame identified UAS employed at the company level that could operate at 15,000 feet mean sea level. See: See: United States. Department of the Navy. USMC. MCWL. Wargaming Division., "Manned Unmanned Teaming.": 13.

[36] *Resource optimization*, in this case, refers to the ability of a distribution system to minimize logistics footprint, eliminate (where feasible) inter-service redundancy, and maximize resource visibility. See Robert Mann's *Improving Intratheater Joint Distribution* and Engels et al's *Improving Visibility in the DOD Supply Chain*.

Vulnerabilities

An exoskeleton is vulnerable primarily to cyber threats, electromagnetic pulse weapons, EW attack, and direct and indirect fires. Corrosive chemicals may affect the exoskeleton system, and would likely adversely affect the operators. Difficult terrain (e.g., rivers, streams, ponds, dense forest) may reduce the ability of Soldiers to traverse terrain due to reductions in maneuverability and agility. The largest potential vulnerability for the exoskeleton will be sufficient power storage to meet mission needs. Robotic minefields are vulnerable to defeat by cyber, EW, and obstacle clearance systems.

Medical RAS providing autonomous or remote casualty care or tele-surgery are susceptible to cyber-attack and spoofing of the medical networks. Formations providing and supporting the point of patient surgical care cannot move for the duration of a surgical procedure (typically two to four hours) as doing so induces significant risk of a negative clinical outcome for the patient.

RAS in the Close and Tactical Support Areas

The Close Area is where formations, forces, and systems are in imminent physical contact and will contest each other for control of physical space. They typically include land, maritime littorals, and the airspace over these areas. Given the proximity of forces, the Close Area presents significant challenges to cross-domain integration. Joint forces conduct operations in this area to create windows of advantage so that maneuver forces can defeat enemy forces, disrupt enemy capabilities, physically control spaces, and protect and influence the population. The Tactical Support Area directly enables operations in the Close, Deep Maneuver, and Deep Fires areas; it contains many friendly sustainment, fires, maneuver support, and mission command capabilities. Enemy forces will target both military and civil assets in this area during the armed conflict with IW, UW, maneuver forces, and tactical and operational fires.

Types of Formations and Tasks

Commands at the battalion level and above will employ aerial, ground, and human-assist RAS to provide a range of operational mission command benefits to formations. Robotic and autonomous systems enable mission command primarily through increased data accumulation and processing thereby reducing the cognitive load on the Soldier. The availability of RAS across the Close area will increase situational awareness at all levels and provide commanders and staff the ability to gather real time information, first hand, to improve estimates, adjust plans, and prepare to support tactical units. Organic and EAB RAS assets rapidly map urban terrain in near-real time. Additionally, RAS-enabled COPs allows higher echelons to rely less on direct reporting from subordinate units. Intelligence, surveillance, and reconnaissance sensors will proliferate across the battlefield. Mounted on manned and unmanned systems, as well as in stand-alone mode, they will generate massive amounts of data. Artificial intelligence will perform PED to assist analysts and staff by improving human productivity and enabling rapid decision-making. Artificial intelligence will reduce the time required to execute individual and collective MI tasks from hours to minutes or less.

Maneuver formations at EAB employ aerial, ground, and human assist RAS that perform reconnaissance, targeting, and communications tasks to provide situational awareness for commanders, and assist in mission planning. These systems will allow commanders and staff at higher echelons to observe the Close Area and conduct appropriate functions with the accumulated data.

At the BCT and below levels, armor, infantry, Stryker, and SOF formations employ aerial, ground, human assist RAS that perform reconnaissance, targeting, and communications tasks as part of manned and unmanned teamed force to increase effectiveness within the Close Area. In MUM-T, RAS perform many traditional movement and maneuver tasks in concert with Soldiers to optimize their respective capabilities.
The theater, OFC and DFC and tactical formations will employ aerial, ground, and human assist RAS using manned-unmanned teaming and autonomous employment methods to perform the following tasks:

- ISR
- target identification
- attack
- battle damage assessment
- communications
- logistics

At the BCT and below levels, engineer and CBRN formations employ aerial, ground, and human assist RAS to perform a range of tasks including reconnaissance, mobility, and counter mobility. Manned and unmanned teams will conduct synchronized execution of maneuver support tasks to increase the overall effectiveness of the brigade combat team.

Maneuver Enhancement Brigade (MEB), Chemical Brigade, Engineering Brigade and Military Police Brigade formations employ aerial, ground, and human assist RAS to conduct integrated security operations in the Tactical Support Area. Individual RAS and systems of RAS will synchronize activities to understand and shape the environment, mitigate hazards and obstacles, and protect personnel and critical assets. Formations will employ manned and unmanned teams to conduct synchronized execution of maneuver support tasks. The combined RAS and manned-equipped formations will provide a range of operational capabilities in the Tactical Support Area. Robotic and autonomous systems will provide security in support of maneuver operations. These RAS, both stationary and mobile, will detect, classify, recognize, identify and engage threats. During the return to competition period, maneuver support formations employ RAS to detect and remove unexploded munitions, mines, and improvised explosive devices along lines of communication and in areas where returning populations live and work. In addition to dismounted and mounted threats, RAS will detect, classify, identify and mitigate effects of CBRN and high yield explosive (CBRNE) hazards and obstacles. The RAS-enabled integrated early warning capability will provide additional time and maneuver space to mitigate the effects of these hazards and obstacles. The ability to 3-D print construction components from indigenous materials to form protective structures will increase protection of critical assets.

Mobility tasks will focus on route clearance, lines of communication (LOC) surveillance, and repair. Maneuver support formations can continue to employ these capabilities as a part of overall stability operations and during the return to competition. Formations will remotely deliver smart munitions to fix or disrupt threat units penetrating into the Tactical Support Area.

Sustainment organizations from the Forward Support Company to EAB sustainment organizations employ aerial and ground RAS to perform key logistics support tasks across the sustainment warfighting function. Specifically, RAS employed in the Close Area across multiple domains (air, ground, cyber and maritime) will execute transportation support, supply support and distribution tasks supporting resupply operations. Echelons above brigade sustainment organizations predominately employ RAS from the Operational Support and Tactical Support Areas. The RAS operate in these areas, in the Close Area, and beyond. For example, a small tactical unit (e.g., SOF team) requests emergency resupply. Supporting EAB units then prepare JPADS loads in the Operational Support Area for aerial resupply. Aviation units will deliver air-droppable loads into the Close Area using manned and unmanned systems. The corollary is also true for ground-based operations utilizing RAS such as leader-follower (LF) and autonomous convoy operations (ACO).[37]

Medical formations at every echelon employ aerial, ground, and human-assist RAS that perform tasks including robotic patient extraction in complex or denied entry environments, and emergency just-in-time resupply of sensitive Class VIII materiel including whole blood. Semi-autonomous and autonomous RAS further provide: (1) critical care in the field and onboard evacuation vehicles; (2) tele-surgery from higher to lower roles of care; and, (3) robotic assistance for mobile medical treatment facilities to include administrative, logistical, patient care operations; medical systems sterilization and decontamination; and, perimeter surveillance and security.

Operational Benefits

Robotic and autonomous systems provide a range of operational benefits to formations executing operations in the Close and Tactical Support areas.

These benefits include:

- reduced Soldier physical and cognitive workloads
- improved mobility
- increased speed and accuracy of logistical delivery
- reduced threat exposure
- enhanced lethality through improved acquisition and increased engagement range
- increased duration of operations

[37] For a detailed concept of employment see Timothy Hope, *Robotics Technology Research and Development Effort Cost Benefit Analyses Report*: Unclassified/FOUO, (Arlington, VA: Office of the Secretary of Defense AT&L LW&M, 2014): 26-27 and Appendix G.

- increased situation awareness
- improved data management

Using RAS as an extension of military intelligence analysts expands collection and analytical capability and capacity, thereby enhancing the intelligence community's core competency to assess the battle space. These systems also allow extended operations and faster, more effective decisions. Intelligence RAS increase the capability to simulate and assess a wider variety of mission options. As a result, RAS intelligence gathering and analysis increases the commander's flexibility to engage with the enemy at a particular time, place, and with specific systems to produce the desired effects on the battlefield.
The use of RAS as an extension of the Soldier increases both the capability and capacity of the Soldier to engage with the enemy. Robotic and autonomous systems increase observation and fields of fire for friendly forces and limits the effectiveness of enemy cover or concealment, allowing friendly forces to maintain the initiative and tactical advantage. These systems also increase Soldier survivability by increasing the standoff range for engagement, improving situational awareness on the battlefield, and employing RAS to engage the enemy first in the close fight. In addition, these systems increase the options of the maneuver commander to engage with the enemy at a particular time, place, and with a specific system.

Robotic and autonomous systems will increase the geographical area a formation can cover with sensors. They will enable access to previously inaccessible areas and significantly increase situational awareness of the presence of explosive and CBRN hazards while providing an integrated early warning capability. The synchronized breaching of explosive hazards by a RAS system-of-systems will increase Soldier survivability while maintaining freedom of action. The RAS breaching capabilities include the understanding of and ability to shape the environment, mitigate obstacles and hazards, and protect personnel and critical assets. Additionally, formations will use RAS to employ terrain-shaping obstacles to deny enemy freedom of action.

Robotic and autonomous systems provide responsive supply and services to highly dispersed, often-inaccessible units operating in high-risk environments. Additionally, these RAS capabilities provide flexible and organic distribution modes to enable a reduction in the load placed on individual Soldiers thus enabling greater mobility.

Other benefits include:

- flexibility – additional options and alternatives to support movement and maneuver
- velocity and tempo – increases speed and responsiveness of resupply and maintenance support from resupply in days to resupply in hours or minutes
- optimized distribution – reduce human touch points to stream line the distribution process
- visibility – integrates C2 capabilities for in-transit awareness and asset tracking

Robotic and autonomous systems provide sustainment commanders and staffs with additional options in executing their concept of support plans. If a ground domain window of advantage closes due to unacceptable risk, sustainment organizations have additional aerial platforms to execute sustainment operations. Robotic and autonomous systems increase the ability for sustainment formations to protect sustainment personnel. Leader-follower and ACO removes Soldiers from wheeled vehicles and allows organization to task organize to provide organic convoy security.

Medical RAS enhance the survival of formations. Health service support RAS provide medical force multiplication, enhanced combat casualty care, and higher survival rates of sick and wounded personnel due to the rapid reaction and evacuation.

Interdependencies

Robotic and autonomous systems (UAS, UGV) will rely on an externally provided secure communication network to transmit data and establish positioning, navigation, and timing. This network will depend on Army and joint cyber assets for its protection. The UAS and UGVs are dependent on external assets for EM spectrum management. The proliferation of aerial and ground RAS within formations challenges a staff's or small unit's ability to employ the systems effectively. During the Unified Quest 2018 (UQ18) Deep Future Wargame (DFWG), a combined arms battalion staff planned maneuver and sustainment of a formation (i.e., Strike Battalion) composed of 82 UAS (four variants) and 166 UGV (two variants). Employing this many systems, managing the battalion's operational airspace, de-conflicting use of electromagnetic spectrum within its battlespace, and maneuvering the battalion's networks significantly increases the complexity of a staff's C2 requirements.

Increased rates and volumes of fire within RAS-enabled formations, combined with an increase in the number of systems with a "kinetic" capability in those formations, may increase the demand on the sustainment system. The numbers of machines, processors, and computing systems in emerging RAS-heavy formations, such as the Next-Generation BCT used at the UQ18 DFWG, will require technically skilled maintenance personnel currently un-forecasted in these organizations' designs. The ground and air platforms formations used for patient extraction are not organic to medical organizations. Therefore, medical support payloads are dependent upon availability of common user ground or air platforms and force protection systems residing in other organizations. Employment of medical RAS requires significant coordination with supported and supporting units. Autonomous ground-based robotic logistics convoys depend on a secure reliable network for tracking and control.[38]

Vulnerabilities

Over reliance on the myriad RAS in the Close Area may significantly affect unit combat effectiveness if those RAS are disabled. Artificial intelligence systems are vulnerable to engineer bias inherent in human designed algorithms, adversary manipulation of algorithms, or the inability to provide appropriate data to the system. Systems controlled remotely may provide an access point for enemy forces to penetrate the network and conduct attacks or deception operations. The risk associated with a compromised system increases with armed systems on the

[38] United States. Department of the Army. TRADOC. ARCIC and Army Material Command (AMC). Tank-Automotive Research and Development (TARDEC). Engineering Center Robotics Initiative. *Robotics Strategy White Paper*. (Fort Monroe, VA: United States Army TRADOC, 2009): 10.

battlefield and their proximity to friendly forces within the Close Area. Unmanned logistic convoys will require some form of security, as they are vulnerable to pilferage, particularly if they are completely unarmed, unmanned, and/or autonomous.

RAS in the Operational Support Area

The Operational Support Area contains key Joint Force mission command, sustainment, and fires/strike capabilities and serves as a primary space for friendly political-military integration. Enemy forces will target this area with substantial reconnaissance, IW, and operational fires capabilities. During armed conflict, this area will require significant multi-domain capacity to open windows of advantage.

Types of Formations and Tasks

Division, operational and theater fires command formations employ ground RAS that provide mobility to Multiple Launch Rocket System (MLRS) firing systems operating in the Operational Support Area during competition. This MUM-T system employs three-trucks with two of the three unmanned and capable of autonomous movement.

At EAB, maneuver support and medical brigade formations employ ground RAS to execute engineering tasks such as automated construction, repair, and maintenance. Other specific tasks include removal of physical obstacles, construction of obstacles using readily available on-site material (e.g., debris, soil, etc.), as well as build, repair and maintain infrastructure. At the BCT and below level, infantry, armor, engineer, and CBRN units employ ground RAS that perform construction, route clearance, protection, and investigation of CBRN events. Sustainment and engineer formations employ ground RAS to enhance mobility through utilization of systems that incorporate autonomous technology allowing UGVs to follow a manned lead vehicle without input from an operator. Additionally, installation of Autonomous Mobility Appliqué System (AMAS) kits on vehicles allows formations to employ existing manned ground vehicles as robotic systems based on mission and threat requirements.

At the theater, corps and division levels, medical brigades and combat support hospitals employ ground and human-assist RAS to conduct medical sustainment and transport tasks. Medical RAS capabilities include tele-surgical robotics and robotic assistants for mobile treatment facilities to enable theater hospitalization, combat casualty care, and medical logistics. Tele-surgical robots perform tabletop surgical procedures. Robotic assistants enable medical supply distribution, inventory management, drug medication dispensing, and patient assistance. Autonomous medical systems operate with a sliding scale of network capacity, from high bandwidth enabled-operations to partial task support in disconnected, intermittent, and latent (DIL) environments. Systems using low-level autonomy will enable task execution with some latency or loss of signal. Development of procedures for task execution under DIL conditions will include built in safety protocols. Non-medical UAS could perform time-critical CASEVAC missions. Robotic and autonomous systems will also support automated warehousing functions in both the Operational Support Area and the Strategic Support Area.[39]

Operational Benefits

Operational benefits of RAS-enabled MLRS are a reduction of the soldier's physical workload and an increase in sustainability of the force through improved operating efficiency. A fuel-electric hybrid engine enhances sustainability of the system. An operational benefit for LF technologies in transportation includes a reduction of personnel-to-vehicle ratio in a convoy with corresponding reduction in exposure to potential hazards. Furthermore, reduced manning increases sustainability of the force through reduced logistical footprint to feed, care and house additional vehicle crews.

Maneuver support RAS directly improves survivability through the fabrication of large construction components forward at the point of use. Light and heavy-duty robotic platforms lift and transport equipment and materials, and fabricate on-site concrete-based construction materials. Autonomous construction RAS expand engineer capacity and capability. Maneuver support RAS also decrease the number of required personnel, reducing logistic support requirements and exposure to hazardous conditions. Additionally, autonomous construction equipment can enable operations in a GPS-denied environment by utilizing local surveyed geological reference points.

Common to medical RAS is an increase in patient survivability through operational efficiency, operational endurance, and a reduction of medical errors in the field using remote surgical expertise.

Interdependencies

Systems such as the MLRS leader follower and AMAS depend upon advanced control systems similar to the unmanned systems discussed previously. Medical RAS are dependent upon an assured communications link integrated with medical network infrastructures, and may require a remote controller and local medical staff to perform enabling tasks. Medical RAS rely on higher-level clinical system interdependencies, such as the Joint Operational Medical Information System (JOMIS) or Genesis, as well as multinational partner medical systems. Currently, the medical community is investigating how to employ unmanned systems to augment manned MEDEVAC capacity.[40] Robotic and autonomous systems conducting CASEVAC depend upon forward deployed treatment assets for providing en-route medical care.

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[39] United States. Department of the Army. TRADOC. ARCIC. and AMC. TARDEC. Engineering Center Robotics Initiative. "Robotics Strategy White Paper.": pg. 11. For detailed concept of employment of RAS in warehousing and material handling functions see: Hope, "Robotics Technology.": 66-67, 76-78, 84-86 and Appendix J, K, and L.
[40] Nathan T. Fisher, Phone interview, Fort Eustis, VA September 13, 2018.

Vulnerabilities

Leader-follower and AMAS systems have vulnerabilities similar to non-autonomous UAS/UGV/UMS. Sustainment transported on unmanned, unprotected systems is at greater risk of interdiction or destruction by enemy forces. Transport RAS used for CASEVAC will need access to medical mission command systems. Network connectivity is a vulnerability particularly in when treating or transporting casualties who have rapidly changing or deteriorating conditions. Disrupting or denying access to the electromagnetic spectrum can affect medical sensors as well as their host vehicle platforms.

RAS in the Strategic Support Area

The MDO concept defines the strategic support area as "the area of cross-combatant command coordination, strategic sea and air lines of communication, and the homeland."[41] Most friendly nuclear, space, and cyber capabilities are controlled and located in the Strategic Support Area. Enemy attacks during armed conflict will focus on disrupting and degrading deployments emanating from and traversing through the strategic support area.

Types of Formations and Tasks

At the BCT and below level, MEB, Engineer Brigade, Chemical Brigade, and Military Police Brigade formations employ aerial, ground, and human-assist RAS to perform the following tasks:

- Defense Support to Civil Authorities (DSCA)
- construction support
- general engineering
- geospatial engineering

These RAS fall into two primary categories: systems that lift and transport items and systems that detect CBRN and toxic industrial chemicals and materials.

Operational Benefits

Robotic and Autonomous Systems that detect airborne CBRN materials can sample potentially contaminated environments over a wider range and altitude. Ground vehicles will operate for longer durations than airborne platforms and can easily sample systems to detect liquid hazards. Additionally, the Army can equip and program ground robotic systems for route clearance, traffic control, vehicle inspection, reconnaissance, and other hazardous tasks.

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[41] United States. Department of the Army. TRADOC. ARCIC. "*The U.S. Army in Multi-Domain Operations, 2028*.": C-4.

Interdependencies

Maneuver Support RAS are dependent upon operator control, communication systems, and payload integration for the execution of their tasks. A ground control station (GCS) operates both air and ground systems.

Vulnerabilities

Maneuver support RAS executing tasks at this echelon are vulnerable to mobility limitations, weather, cyber attacks, and EW threats. Electronic warfare threats can attack the datalink and an operator's control of their system(s), while cyber attacks can disrupt the ground control station. Weather may affect CBRN RAS detection as rain, fog or other precipitation degrades the sensor performance. Adverse weather may also influence an aerial RAS' ability to fly and therefore provide support.

Concept, Capabilities, and Organizational Design Implications

Robotic and autonomous systems and some level of AI will be ubiquitous across the operational framework of 2035. From the Strategic Support Area to the Deep Fires areas, these systems will play a critical role in the conduct of operations during competition, armed conflict, and return to competition. Operationalizing these systems requires the Army to adjust, develop, and refine concepts, required capabilities, and organizational design.

The preceding sections describe how Army forces could employ RAS and AI across the operational framework. The following is a short examination of how operationalizing RAS and AI could affect concepts, capabilities, and organizations' design. Concepts illustrate how future joint and Army forces will operate, describe the capabilities required to carry out unified land operations they are likely to conduct against adversaries in the expected OE, and how a commander, using military art and science, might employ these capabilities to achieve desired effects and objectives.[42] TRADOC Regulation 71-20 defines a capability as "The ability to execute a specified course of action."[43] The most significant of these coalesce around issues associated with mission command, sustainment, and organizational design. The following discussion uses the terms mission command and sustainment in a broad sense and not in an effort to assign responsibility to a particular proponent or center of excellence (CoE). The implications associated with RAS and AI cut across Army formations and the joint community.

Mission Command

The Army defines the Mission Command Warfighting Function as "the related tasks and systems that develop and integrate those activities enabling a commander to balance the art of command

[42] United States. Department of the Army. TRADOC., *TRADOC Regulation 71-20 Concept Development, Capabilities Determination, and Capabilities Integration,* (Fort Eustis, VA: TRADOC, 2013): 33.
[43] Ibid: 138.

and the science of control in order to integrate the other warfighting functions."[44] The introduction of RAS and AI will affect commander and staff tasks as well as the entire mission command system.

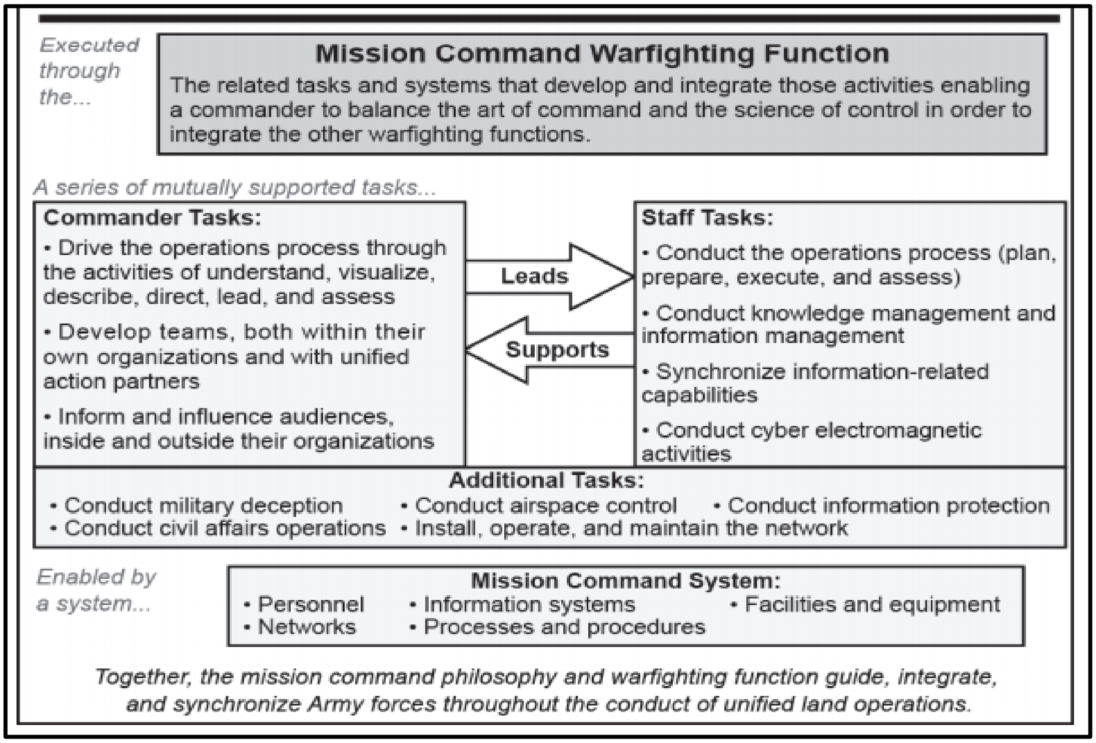

Figure 2: Mission Command Warfighting Function[45]

Mission Command Concept Implications

The proliferation of unmanned systems requires a new approach to C2 of RAS enabled formations. Maneuver battalions will employ hundreds of unmanned ground and air systems at the section, platoon, company, and battalion levels challenging a staff's ability to employ the systems. Controlling these systems in a manner similar to the RAS of today (remote control) could rapidly overwhelm staff and operators. The Army must determine and designate new or modified staff tasks required to facilitate the mission command. It must adapt current planning procedures (the military decision-making process and troop leading procedures) to account for unmanned and autonomous systems. It must determine control measures needed to manage autonomous systems, unmanned systems swarms, mesh sensors, and to clear airspace and fires for manned and unmanned systems. Artificial intelligence decision support technologies must be able to explain recommendations and in the case of autonomous systems provide data that explains decisions. [46]

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[44] United States. Department of the Army. *ADP 6-0 Mission Command, change 2. (*Washington, D.C.: Headquarters Department of the Army, March 12, 2014): iv.
[45] United States. Department of the Army. *ADP 6-0 Mission Command, change 2.*: iv.
[46] United States. GAO., "Artificial Intelligence.": 11.

The Joint Force must define standards for architecture, language, and protocols between RAS platforms and payloads.[47] The JCRAS states, “RAS components must be easily interchangeable to adapt rapidly to changing operational needs. Modular software and hardware design will enable RAS to be reconfigured based on mission need and rapidly upgraded with new functionality and payloads as these become available.”[48] Developing standard message formats and data protocols is necessary to enhance interoperability across formations, within the Joint Force, and with inter-organizational and multinational partners.[49]

The Army must develop and refine policies such as rules of engagement (RoE) as well as tactics, techniques, and procedures regarding the employment of RAS and artificial intelligence. Leaders will have to consider the impact of RAS amongst indigenous populations, particularly when local nationals have little or no exposure it. Future RoE must address the use of RAS employed via artillery and rockets particularly during competition and return to competition. Individual RAS and AI concepts of employment must take into consideration host nation legal restrictions (particularly during competition and return to competition), operational security requirements, and escalation regimes controlled by existing alliance structures.

Mission Command Capability Implications

The future force requires the capability to execute tactical, operational, and strategic communications and data sharing beyond-line-of-sight (BLOS) through a secure, autonomous, self-healing, and intelligent network. The network must be able to operate in and under spectrum interference. The Defense Advanced Research Projects Agency’s (DARPA) Collaborative Operations in Denied Environment (CODE) project attempts to address connectivity issues in a communications degraded environment.[50] This program uses a low-bandwidth network that functions in a communications degraded environment. This type of network is essential for the future force to be capable of employing RAS.

The future force at the tactical through strategic level requires the ability to maintain a COP that captures all systems in real time and systems that allow for mission command of multiple manned and unmanned systems. Staffs at all levels need the ability to create a meaningful representation of the electromagnetic and cyber environment. However, situational awareness is not enough. The proliferation of unmanned and autonomous systems demands an AI solution for unmanned systems across domains. The development of AI that enables unmanned platforms and networks within formations, particularly at the tactical level, is essential.

[47] Current efforts to standardize the operating systems for RAS include the Robot Operating System – Military (ROS-M). See Jonathan Chu, "Army Robotics in the Military," *SEI Insights*, June 12, 2017, https://insights.sei.cmu.edu/sei_blog/2017/06/army-robotics-in-the-military.html. The USMC Manned Unmanned Teaming Wargame produced a similar insight. See: United States. Department of the Navy. USMC. MCWL. Wargaming Division., "Manned Unmanned Teaming.": 14.
[48] United States. Joint Chiefs of Staff., "JCRAS.": 15.
[49] United States. Department of the Army. TRADOC. ARCIC. and AMC. TARDEC. Engineering Center Robotics Initiative. “Robotics Strategy White Paper.”: 20.
[50] Paul Scharre, *Army of None Autonomous Weapons and the Future of War* (New York: W.W. Norton and Company, 2018): 327-328.

The future force requires the capability to maintain assured PNT for unmanned systems and munitions to operate and navigate in a GPS-satellite denied environment. Work on munition PNT is well underway with the U.S. Air Force's Small Diameter Bomb that operates in GPS-denied environments.

The future force requires the capability to collect, assess, analyze, and fuse data through the employment of AI, and disseminate the information autonomously to the appropriate commands or systems at the speed of the battle. Decision support and intelligence system AI needs to have the ability to explain or account for recommendations and, in the case of autonomous systems, decisions.

The future force requires the capability to plan, emplace, and manage multiple RAS and autonomous systems in support of the intelligence collection effort and the conduct of operations.

The future force requires the capability to rapidly identify friend or foe unmanned and manned systems across domains as well as the ability for systems, particularly those that are employed in a MUM-T role to minimize or mask their EM signature.

The following vignette operationalizes many of the above capabilities (Figure 3).

> "After months of preparation, a military cyber team successfully located a critical system the enemy was masking. This cued a satellite to observe the area, using onboard processing to confirm it as a launcher and provide a targetable location. Another system received the processed satellite data, identified an Army long range precision fires unit as the best joint capability to engage the target, and tasked it. Additional systems cleared a path through the cluttered airspace between the shooter and the target, adjusting the course for about twenty percent of a swarm and some loitering munitions, while warning two F35s to change direction. Soon after, rounds slammed into the ground near the displacing launcher. A high-altitude balloon, previously tipped to observe the target while the rounds were still in the air, identified a need to reengage. A nearby loitering munition, already moving toward the target in anticipation of this possibility, went terminal and disabled the enemy launcher. Soon after, tripped thresholds caused drones carrying additional munitions to lift off from small, distributed supply nodes, enroute to the fires unit's next planned location. This process of converging capabilities across multiple domains would begin again in minutes at multiple locations across the battlefield, but with improved effects based on this engagement's learning."[51]

[51] David K. Spencer and Stephen C. Duncan, "Operationalizing Multi-Domain Operations through Artificial Intelligence," *Unpublished* (November 19, 2019), 4.

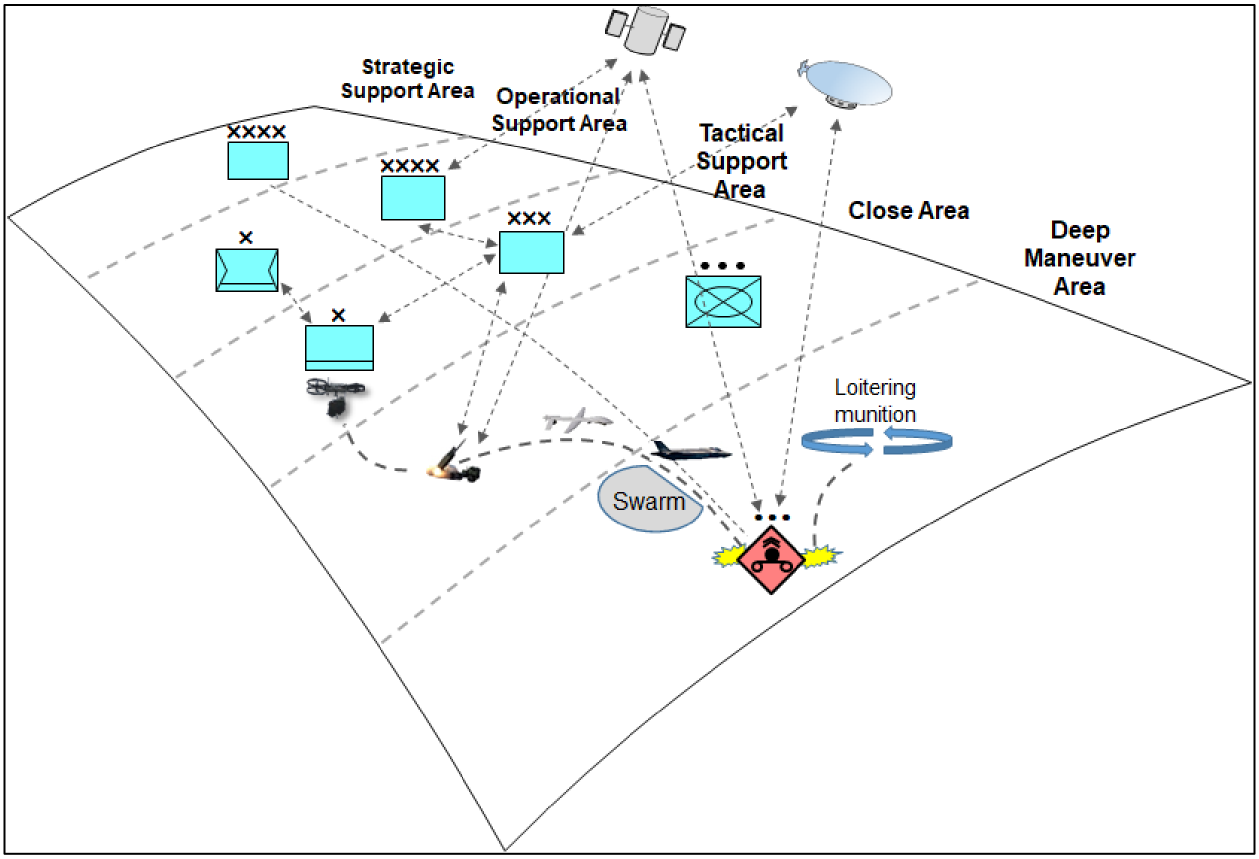

Figure 3: Artificial Intelligence Enabled Targeting Vignette[52]

Figure 4 depicts a possible AI framework for the C2, fires, and ISR functions the vignette described. The top half of the figure illustrates AI processing at platform or single system level. While on-board AI-enabled processing of sensor data may be sufficient to execute platform or small, closed system tasks, it may be insufficient to facilitate convergence of MDO capabilities. Commanders and staffs responsible for converging multi-domain capabilities during high-tempo operations may require additional AI-enabled fusion of data from platforms or systems responsible for tasking, collecting, and exploiting data and information within the ISR function. As depicted in the bottom half of the figure, this data does not, however, serve a single purpose during MDO capabilities convergence, thus is must enable cross-functional data sharing with C2 and fires platforms and systems-of-systems. The Army therefore requires AI to enable timely and efficient data and information sharing amongst these three functions, particularly over a complex, limited bandwidth, and potentially disrupted web of joint, interorganizational, and multinational networks. Finally, the figure's left side depicts the need for a powerful general-intelligent agent to enable control and optimization of multi-functional systems-of-systems tasks as JIM partners collect, process, and store massive amounts of data and information.

[52] The AI cell at the 5–8 November 2018 Unified Quest ISR-Strike Table Top Exercise developed Figure 3 based on a version of the text vignette.

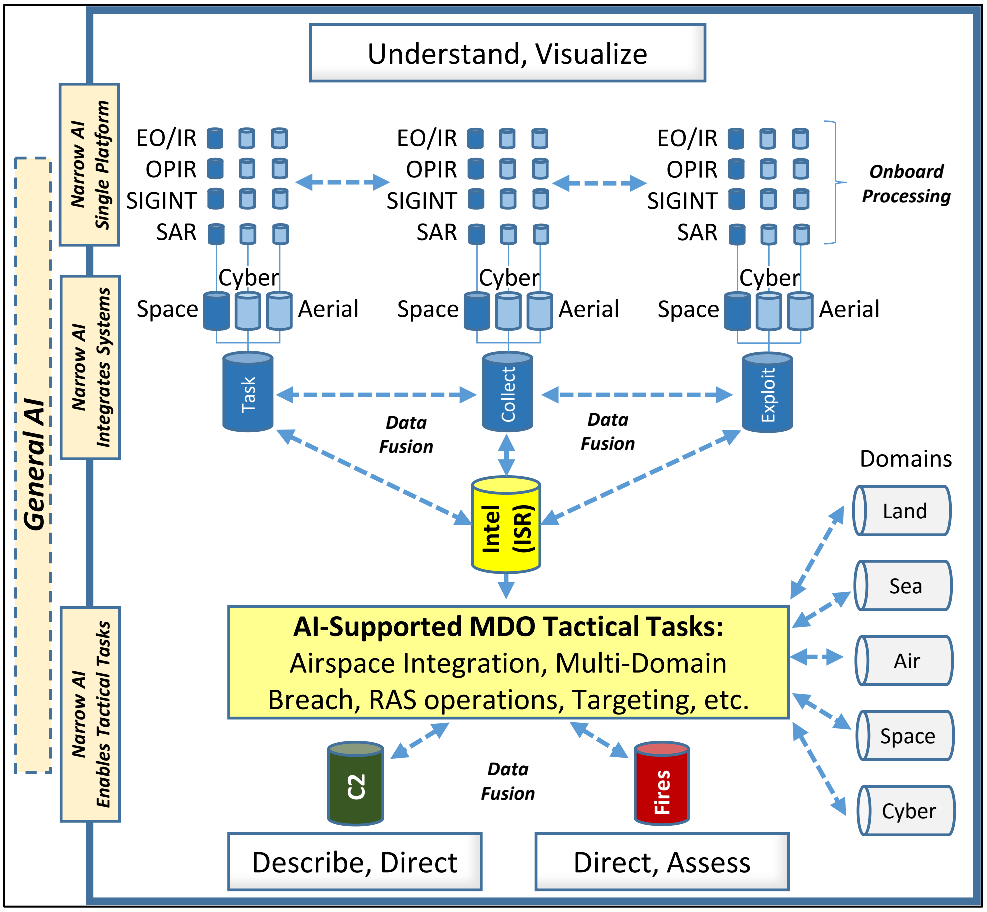

Figure 4: Networked AI for ISR, C2 and Fires[53]

The increased number of sensors and platforms, all processing and transmitting high volumes of diverse data at tactical speeds, exceeds human cognitive capabilities in time-sensitive environments. U.S. forces require a trusted, secure, integrated network (or system of networks), enabled by interoperable AI to converge joint capabilities across domains from a variety of manned and unmanned platforms at extended distances.

Mission Command Organizational Implications

Continued fielding of RAS into a formation increases the complexity of its command and control. A number of technologies can mitigate this complexity and possibly lead to the point where fundamental change to manned-unmanned organizational structure is possible. Future formations will increasingly rely on autonomous platforms, enabled by AI, to operate with minimal human intervention. Assured communications and sufficient network bandwidth are critical to sustaining a RAS-enabled formation's operational speed and tempo as the number of unmanned platforms operating within its system-of-manned/unmanned systems increases. The physical distance between headquarters and formations increases at echelons above brigade as maneuver forces advance and RAS traverses the battlefield. Assured communications and

[53] David K. Spencer and Stephen C. Duncan, "Operationalizing Multi-Domain Operations through Artificial Intelligence," *Unpublished* (November 19, 2019), 4.

network access will depend on effective electromagnetic spectrum management and availability. Enemies will attempt to exploit vulnerabilities arising from the constant software and protocol standard updates U.S. forces make to their systems. A compromised communication network poses catastrophic risk to any operation. U.S. future force requirements to transition from a RAS-enabled force to a RAS-centric force can occur after developments for assured communications and greater levels of autonomy are sufficiently complete. Coincidentally developing AI-enabled platforms and networks is necessary to effectively manage RAS proliferation in formations and must precede or occur simultaneously with the fielding of RAS in those formations.

Signature reduction and platform protection technologies for manned RAS command and control vehicles are instrumental to controlling the formation's RAS and its organizational resilience. The need for the control vehicles and the number of personnel on them can decrease as platform and system-of-systems AI and autonomy mature.

Artificial intelligence and platform autonomy must enable a future formation's support structure to sustain subordinate formations with minimally manned or autonomous support vehicles; otherwise, growth of the formation's "tail" occurs commensurate with the increased fielding of RAS into the formation. The future force will require RAS-enabling technologies that support reduction of formations' size while enhancing their effectiveness. The Army should therefore focus investments in AI, assured communications, and reliable and durable sensors that enable autonomous platforms to operate in all weather conditions; it should also invest in active and passive protection (i.e., electronic and visual signature reduction) of manned control vehicles. The Army should also operationalize sustainment of RAS-enabled formations to support experimentation and analysis of potential formation-manpower reductions and concomitant cost-benefit analyses.

Sustainment

The Army defines sustainment as "the provision of logistics, personnel services, and health service support necessary to maintain operations until successful mission completion."[54] Robotic and autonomous systems and AI introduce a number of sustainment related issues. First, the Army must determine how it will sustain a RAS-enabled force across the operational framework. Second, the Army must determine how RAS and AI will contribute to the overall sustainment effort.

Sustainment Concepts Implications

Robotic and autonomous systems can improve the effectiveness of providing resupply to forces closest to the line of contact, and increase force protection by reducing the number of personnel delivering logistic packages (LOGPAC), particularly if the forward units are RAS-enabled. Delivering LOGPAC via RAS-enabled vehicles necessitates changes to tactics, techniques, or procedures and will require technical considerations for all RAS vehicles; RAS-enabled sustainment demands a concept-based, technically integrated system-of-systems solutions

[54] United States. Department of the Army. *ADP 4-0 Sustainment*. (Washington, D.C.: Headquarters Department of the Army, July, 2012): 1.

approach. Integrated concepts of operation (CONOPS) and concepts of employment (CONEMPS) must precede capabilities development and organizational design if the Army is to realize the full potential benefit of RAS, particularly when sustaining and recovering RAS on the battlefield. The Army should develop formation-based RAS CONOPS and system-of-systems CONEMPS at various echelons (e.g., company through theater army), or within multifunctional organizations (e.g., Brigade Combat Teams). The CONOPS or CONEMPS should describe the integrated purpose, tasks, and technical employment of RAS within an echelon or formation.

Concepts of employment for MEDEVAC and casualty treatment RAS need to address issues concerning remote patient care, patient abandonment, and expansion of clinical practice guidelines and medical-practice authorities for forward-located medics. Casualty evacuation doctrine will require modification to support unmanned evacuation and delay of first responder intervention. The Army will also need to address Army Health System and Army doctrine supporting extended duration of movement of casualties via autonomous systems.

Sustainment Capabilities Implications

Artificial intelligence and RAS will enable precision logistics within the sustainment enterprise.[55] Artificial intelligence agents, algorithms, and platform on-board sensors will provide predictive analysis tools permitting resupply with little or no human intervention. An AI-enabled system-of-systems will provide commanders with the ability to resupply without request, at the point of need, based on intent driven priorities. The future force will utilize RAS to resupply formations.

The future force requires RAS-enabled vehicles that can transfer, self-load and employ all relevant classes of supply (III/V) if humans are to remain out of a formation's resupply process. RAS must be maintainable (or self-maintaining) and employable by Soldiers; enabled to prevent enemy exploitation; and have the ability to generate, store, and distribute sufficient power across formations and RAS platforms.[56] Tactical operations will require autonomous platforms, enabled by AI, to operate with minimal human intervention. Both automated reloading and refueling are complicated procedures, however the operational benefits of using RAS to conduct these tasks will lead to enhanced Soldier safety, reduction in training requirements, and reduced re-arm time.[57] Assured communications and sufficient network bandwidth are critical to sustaining operational speed and tempo as unmanned platforms operate and conduct sustainment within a system of manned/unmanned systems.

Objectively, formations will store and transport supplies in standardized containers, similar to an ammunition magazine or fuel cells, to expedite rapid off load and pick up by robotic and autonomous systems. Development of technologically sophisticated sensors and handling

[55] United States. Department of the Army. TRADOC. ARCIC. "*The U.S. Army in Multi-Domain Operations, 2028*.": GL-8.
[56] The criticality of future RAS being maintainable at lower levels was also found during the Marine Corp's Manned Unmanned Teaming Wargame. See: United States. Department of the Navy. USMC. MCWL. Wargaming Division., "Manned Unmanned Teaming.": 14.
[57] United States. Department of the Army. TRADOC. ARCIC and AMC. TARDEC. Engineering Center Robotics Initiative. "Robotics Strategy White Paper.": 12.

systems (e.g., fuel transfer ports and couplings) is necessary to provide RAS-enabled unmanned vehicles the ability to transfer, self-load, and employ required classes of supply. Robotic-enabled rearming and refueling requires development of tactile force and geometrical vision load sensing, collision avoidance, force feedback, and position detection capabilities and systems. Some relatively simple tasks can become increasingly more difficult with RAS-enabled vehicles; tasks that require problem solving, such as vehicle recovery or on-site repair may be beyond technological abilities in 2035.

The future force requires medical RAS that is interoperable with JOMIS and Genesis medical systems for documentation and communication of patient care. The future force requires the capability for operators to adjust UGV and UAS payloads installed on teamed unmanned platforms. This includes UAS (Category 3+) and UGV that can adjust payload in a field environment to conduct CASEVAC missions.[58]

Organizational Design

Force developers design (or redesign) units based on the requirement to execute specific missions, and the associated functions and capabilities required to execute those missions. The following provides an analysis of potential impacts of RAS and AI on organizational design. These impacts fall into three broad categories – task overload, technical operation and maintenance, and personnel.

Task Overload

The proliferation of RAS and the use of AI significantly increase the complexity of a staff's C2 requirements. The Army will identify new staff tasks and modify old ones. This warrants an examination of staff compositions and their respective responsibilities. The volume, changing nature, and type of information generated by RAS and AI impacts the required skills and attributes the Army will need in future leaders and Soldiers.

Technical Operation and Maintenance

The near ubiquity of RAS and AI envisioned at events such as the UQ18 DFWG will require technically skilled maintenance personnel currently unforecasted in organizational design. Professional education and training will need to address the operation and maintenance of RAS and AI systems.

Future formations will require operators and maintainers to support RAS. The numbers of machines, processors, and computing systems in emerging RAS-heavy formations, such as the Next-Generation BCT, will require technically skilled maintenance personnel currently un-forecasted in these organizations' designs. Sustainment organizations will need additional military occupational specialties (MOS) to conduct field and sustainment level maintenance on

[58] Beginning in 2019, The U.S. Army Medical Research and Material Command will begin research on robotic en route care; currently there is no plan to employ unmanned systems in a dedicated MEDEVAC role. See: Nathan T. Fisher and Gary R. Gilbert, "Medical Robotic and Autonomous System Technology Enablers for the Multi-Domain Battle 2030-2050," *Small Wars Journal* (n.d.).

RAS platforms. Artificial intelligence and platform autonomy must enable a future formation's support structure to sustain subordinate formations with minimally manned or autonomous support vehicles; otherwise, growth of the formation's "tail" occurs commensurate with the increased fielding of RAS into the formation.

<u>*Personnel*</u>

Initially, and counter intuitively, the number of personnel in the operational area will increase because of robotic and autonomous systems.[59] Continued fielding of RAS into a formation increases the complexity of its mission command and sustainment. The need for control vehicles and the number of personnel on them can decrease as platform and system-of-systems AI and autonomy mature. Further study is required to determine the effect of RAS and AI on formation manning. These technologies may support the reduction of a formation's total personnel while enhancing effectiveness.

Robotic and autonomous systems and AI will give rise to new training requirements. The Army must establish a set of live, virtual, and constructive training means that adequately prepare leaders and Soldiers to employ these systems effectively.[60] The cumulative effect of RAS and AI may demand new MOS to conduct mechanical, electronic, and software maintenance. The need to increase the number of higher paid, technically trained maintenance personnel required to conduct repairs and services on a RAS heavy fleet may offset the force related benefit of unmanned systems.[61] Put simply, RAS employed to conduct the "dull, difficult, and dangerous" tasks may levy a higher personnel cost in terms of both quality and quantity than having Soldiers perform these tasks.

Other Concept, Capability and Organizational Design Impacts

The Army should incorporate RAS and AI into its operating and functional concepts. Tactics, techniques, and procedures for employment will emerge through continuous experimentation and wargaming. This articulation should identify the degree of autonomy required by RAS to accomplish tasks based on the OE and expected future system capabilities.[62]

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[59] Robert J. Bunker, "Colloquium Brief: Robotics and Military Operations - Kingston Conference on International Security," Strategic Studies Institute, last modified August 14, 2015, http://ssi.armywarcollege.edu/index.cfm/articles/Robotics-and-Military-Operations-KCIS/2015/08/14.
[60] United States. Department of the Army. TRADOC. ARCIC and AMC. TARDEC. Engineering Center Robotics Initiative. "Robotics Strategy White Paper.": 22.
[61] Hope, "Robotics Technology.": R-1.
[62]United States. Department of the Army. TRADOC. ARCIC and AMC. TARDEC. Engineering Center Robotics Initiative. "Robotics Strategy White Paper.": 20.

Three additional capabilities fall outside of the sustainment or mission command categories:

- The Joint Force must establish a set of common core capabilities by RAS type (e.g., UAS, UGV, UMS) and class (e.g. UAS Class I-V)
- Autonomous cyber defenses that are capable of machine learning and have minimal impact on network bandwidth and latency
- Unmanned systems that can identify CBRN contamination, minimize spreading contaminates through own movement, and/or self-decontaminate

Conclusion

Robotic and autonomous systems and AI are fundamental to the Joint Force realizing the full potential of Multi-Domain Operations. Robotic and autonomous systems and, in particular, AI offer the ability to outmaneuver adversaries across domains. The employment of these systems during competition allows the Joint Force to understand the OE in real time and thus better employ both manned and unmanned capabilities to defeat threat operations meant to destabilize the region, deter escalation of violence, and turn denied spaces into contested spaces. In the transition from competition to armed conflict, RAS and AI maneuver, fires, and ISR capabilities provide the Joint Force with the ability to deny the enemy's efforts to seize positions of advantage. Improved sustainment throughput combined with the ability to attack the enemy's A2/AD network provides U.S. forces with the ability to seize positions of operational, strategic, and tactical advantage. Increased understanding through an AI-enabled joint COP allows U.S. forces the ability to orchestrate multi-domain effects to create windows of advantage. Post-conflict RAS and AI offer increased capacity to produce sustainable outcomes and the combat power to set conditions for deterrence. To realize the full potential of RAS and AI in the future force, the U.S. Army must account for the mission command of multiple unmanned systems and challenges associated with AI, the sustainment of manned and unmanned systems, and the impacts on organizational design.

Artificial intelligence has emerged as a foundational capability for future unified land operations. Artificial intelligence agents and algorithms will enable future force operations by processing, exploiting, and disseminating intelligence and targeting data. Operating forces will use AI to cue sensors and integrate cross-domain fires; reduce a staff's cognitive load while simultaneously enabling a commander's decisions at the pace of battle; and manage airspace, networks, and robotic and autonomous systems. In 2019, the Future Warfare Division will utilize Unified Quest to examine and operationalize artificial intelligence. Similar to the Unified Quest 2018 RAS study, this focused study thread will determine AI required capabilities and tasks at echelon to support multi-domain operations within the MDO operational framework. The AI Study Team will publish a White Paper by June 2019 that will further inform the Multi-Domain Operational Concept, provide input to Army Operational and Organizational Concepts' required capabilities and organizational designs, and operationalize Army Modernization Strategy investments enabled by AI technologies.

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Appendix B - Acronyms

A2/AD – Anti-access/Area Denial
ACO – Autonomous Convoy Operations
AI – Artificial Intelligence
ARCIC – Army Capabilities Integration Center

BCT – Brigade Combat Team
BLOS – Beyond Line of Site

C4ISR – Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAB – Combat Aviation Brigade
CASEVAC – Casualty Evacuation
CBRN – Chemical, Biological, Radiological, and Nuclear
CBRNE – Chemical, Biological, Radiological, Nuclear, and high-yield Explosive
CODE – Collaborative Operations in a Denied Environment
CoE – Center of Excellence
COP – Common Operating Picture

DARPA – Defense Advanced Research Projects Agency
DFC – Division Fires Command
DIL – Disconnected, Intermittent, and Latent
DoD – Department of Defense

EAB – Echelons Above Brigade
EM – Electro-Magnetic
EO – Electro-Optical
EW – Electronic Warfare

FVL – Future Vertical Lift

GCS – Ground Control Station
GPS – Global Positioning System

IR – Infrared
ISR – Intelligence, Surveillance, and Reconnaissance
IT – Information Technology

JCRAS – Joint Concept for Robotic and Autonomous Systems
JOMIS – Joint Operational Medical Information System
JP – Joint Publication
JPADS – Joint Precision Airdrop System
JPST – Joint Precision Strike Team
LF – Leader-Follower

LRF/D – Laser Range Finder / Designator
LRPF – Long Range Precision Fires

MAS-D – Maneuver, Aviation, and Soldier Division
MDO – Multi-Domain Operations
MEB – Maneuver Enhancement Brigade
MEDEVAC – Medical Evacuation
MLRS – Multiple Launch Rocket System
MOS – Military Occupational Specialty
MUM-T – Manned-Unmanned Teaming

NAS – National Airspace System

OE – Operational Environment
OFC – Operational Fires Command

PED – Processing, Exploitation, and Dissemination
PNT – Position, Navigation, and Timing

RAS – Robotic and Autonomous Systems
RSTA – Reconnaissance, Surveillance, and Target Acquisition

SAR – Synthetic Aperture Radar
SATCOM – Satellite Communications
SEAD – Suppression of Enemy Air Defense
SIDRA – Sustain current systems, Improve existing systems, Develop new capabilities, Replace obsolete systems, Assess new technologies and systems
SIGINT – Signal Intelligence
SMET – Squad Multipurpose Equipment Transport
SOF – Special Operations Forces
SPAR – Strategic Portfolio Analysis Review
STO – Science and Technology Objectives

TARDEC – Tank-Automotive Research, Development, and Engineering Center
TRADOC – Training and Doctrine Command

U.S. – United States
UAS – Unmanned Aircraft System
UGV – Unmanned Ground Vehicle
UMS – Unmanned Maritime System

Appendix C - Lexicon

Appliqué kit – Add on kit that enables manned platforms to be operated with unmanned capabilities at the commander's discretion.[63]

Artificial intelligence (AI) – The capability of computer systems to perform tasks that normally require human intelligence such as perception, conversation, and decision-making. Advances in AI are making it possible to cede to machines many tasks long regarded as impossible. Artificial intelligence development can be described in waves:

- Wave 1 – expert or rules based systems
- Wave 2 – statistical learning, perceiving, and prediction systems
- Wave 3 – abstracting and reasoning capability[64]

See also Narrow AI and General AI.

Autonomy. The level of independence that humans award a system to execute a given task. It is the condition or quality of being self-governing in order to achieve an assigned task based on the system's own situational awareness (integrated sensing, perceiving, and analyzing), planning and decision-making. Autonomy is a spectrum of automation in which independent decision-making can be tailored for a specific mission, risk level, and degree of human-machine teaming. [65] There are three generally accepted levels of autonomy:

- Semiautonomous operation – the machine performs a task and then waits for a human user to take an action before continuing (also referred to as human in the loop).[66]
- Supervised autonomous operation – the machine can sense, decide, and act on its own, but a human user can observe the machine's behavior and intervene (also referred to as human on the loop).[67]
- Fully autonomous operation – systems that sense, decide, and act entirely without human intervention.[68]

Command and control (C2) – The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission.[69]

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[63] United States. Department of the Army. TRADOC. ARCIC. Maneuver, Aviation and Solider Division., "U.S. Army RAS.": 23.
[64] United States. GAO., "Artificial Intelligence.": 16.
[65] United States. JCS., "JCRAS.": 2.
[66] Paul Scharre, *Army of None Autonomous Weapons and the Future of War* (New York: W.W. Norton and Company, 2018), 29.
[67] Ibid.
[68] Ibid: 30.
[69] United States. DoD., *DOD Dictionary of Military and Associated Terms*, (Washington, D.C.: DoD, 2018): 43.

Common operational picture (COP) – A single identical display of relevant information shared by more than one command that facilitates collaborative planning and assists all echelons to achieve situational awareness.[70]

Computer Vision – Algorithms and techniques to classify or understand the content of scenes.[71]

Concept of operations (CONOPS) – A verbal or graphic statement that clearly and concisely expresses what the Joint Force Commander intends to accomplish and how it will be done using available resources.[72]

Common Control – The ability for one common software package to control an array of systems.[73]

Cyberspace – A global domain within the information environment consisting of the interdependent network of information technology infrastructures and resident data, including the Internet, telecommunications networks, computer systems, and embedded processors and controllers.[74]

Electromagnetic spectrum – The range of frequencies of electromagnetic radiation from zero to infinity, divided into 26 alphabetically designated bands.[75]

General AI – An AI system that exhibits intelligence comparable to that of a human, or beyond, across the range of contexts in which a human might interact.[76]

Group 1 Unmanned Aircraft System (UAS) – Capabilities – typically hand-launched, portable systems employed at the small unit level or for base security. They are capable of providing "over the hill" or "around the corner type reconnaissance, surveillance, and target acquisition (RSTA). Payloads are modular such as Electro-Optical (EO), Infrared (IR), and Synthetic Aperture Rader (SAR). They have a small logistics footprint. Advantages – lightweight, man-potable, organic assets that provide timely and accurate situational awareness. Limitations – typically operate within the operator's Line of Sight at low altitudes, generally less than 1200 feet Above Ground Level (AGL) and have limited local endurance.[77]

Group 2 UAS – Capabilities – typically medium-sized, catapult launched, mobile systems that usually support brigade-level and lower intelligence, surveillance, and reconnaissance / RSTA requirements. These systems operate at altitudes less than 3500 AGL with a local to medium range. They usually operate from unimproved areas. Payloads may include a sensor ball with EO/IR and a Laser Range Finder / Designator (LRF/D) capability. They usually have a medium

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[70] United States. DoD., "DOD Dictionary.": 46.
[71] United States. GAO., "Artificial Intelligence.": 15.
[72] United States. Department of Defense (DoD)., "DOD Dictionary.": 48.
[73] United States. Department of the Army. TRADOC. ARCIC. MAS-D., "U.S. Army RAS.": 3.
[74] United States. DoD., "DOD Dictionary.": 59-60.
[75] Ibid: 75.
[76] United States. GAO., "Artificial Intelligence.": 10.
[77] United States. Department of the Army. TRADOC. UAS Center of Excellence (CoE)., *U.S. Army Roadmap for UAS 2010-2035*, (Fort Rucker, AL: TRADOC, 2010): 12.

logistical footprint. Advantages – benefit from an increase in power and endurance beyond that of Group 1. Due to increased power, they can carry sensors that have improved visual acuity and resolution. Limitations – may have limited range and endurance and require a medium size logistical package.[78]

Group 3 UAS – Capabilities – operate at medium altitudes and usually have medium to long range and endurance. Payloads may include a sensor ball with EO/IR, LRF/D, SAR, moving target indicator, and Chemical, Biological, Radiological, Nuclear, and high-yield Explosive (CBRNE) detection. Some Group 3 UAS carry weapons. They usually operate from unimproved areas. Advantages – wider array of sensors, as well as the capability of weaponization for precision guided munitions. Limitations – decrease endurance when carrying weapons. Logistics footprint typically includes ground support equipment.[79]

Group 4 UAS – Capabilities – operate at medium to high altitudes and have extended range and endurance. May include EO/IR, radars, lasers, communications relay, Signal Intelligence (SIGINT), Automated Identification System (AIS), and weapons. Must meet Department of Defense (DoD) airworthiness standards prior to operation in the National Airspace System (NAS). Advantages – the ability to carry larger or more numerous munitions payloads without sacrificing as much endurance as Group 3. Limitations – decreased endurance when carrying weapons. Normally require improved areas for launch and recovery. Logistics footprint is similar to a manned aircraft and has stringent airspace requirements. Lack of Satellite Communication (SATCOM) links could inhibit Beyond Line of Sight (BLOS) capability for some.[80]

Group 5 Unmanned Aircraft System – Largest UAS, operate in the medium to high altitude environment and typically have the greatest range/endurance and airspeed. Perform specialized missions including broad area surveillance and penetrating attacks. Payloads include EO/IR, radars, lasers, communications relay, SIGINT, AIS, weapons, and supplies. Must meet DoD airworthiness standards prior to operations in the NAS. Limitations – Require improved areas for launch and recovery. Logistics footprint may approach that of manned aircraft of similar size and has stringent airspace requirements.[81]

Intelligence – 1. The product resulting from the collection, processing, integration, evaluation, analysis, and interpretation of available information concerning foreign nations, hostile or potentially hostile forces or elements, or areas of actual or potential operations. 2. The activities that result in the product. 3. The organizations engaged in such activities.[82] That quality that enables an entity to function appropriately and with foresight in its environment.[83]

Intelligence, surveillance, and reconnaissance (ISR) – 1. An integrated operations and intelligence activity that synchronizes and integrates the planning and operation of sensors,

[78] United States. Department of the Army. TRADOC. UAS CoE., "UAS 2010-2035.": 12.
[79] Ibid: 13.
[80] Ibid 12.
[81] Ibid.
[82] United States. DoD., "DOD Dictionary.": 114.
[83] United States. GAO., "Artificial Intelligence.": 16.

assets, and processing, exploitation, and dissemination (PED) systems in direct support of current and future operations. 2. The organizations or assets conducting such activities.[84]

Intelligent Agent – A computer program that perceives its environment, reasons about it, then acts in it as would a human subject matter expert.[85]

Interoperability – 1. The ability to act together coherently, effectively, and efficiently to achieve tactical, operational, and strategic objectives. 2. The condition achieved among communications-electronics systems or items of communications electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users.[86]

Joint Force Commander (JFC) – A general term applied to a combatant commander, sub-unified commander, or joint task force commander authorized to exercise combatant command (command authority) or operational control over a Joint Force.[87]

Joint Precision Strike Team (JPST) – A forward positioned unit from the Operational Fires Command (OFC) Observation Battery that visually acquires targets for precision engagement by OFC rocket and missile fires. This unit is not a part of an approved Modified Table of Organization and Equipment at this time.

Leader-Follower (LF) function – An appliqué kit that provides a limited robotic-like capability to transportation and distribution units. A manned leader vehicle leads three to seven unmanned follower vehicles.[88]

Machine Cognition – The capability of a RAS to sense and perceive its environment, process inputs, render conclusions about the data that provides the machine with the ability to act appropriately in an uncertain environment using sophisticated inferential cognitive mechanisms such as learning and reasoning. *The U.S. Army Robotic and Autonomous Systems Strategy* refers to this as machine intelligence, perception, and reasoning[89].

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[84] United States. DoD., "DOD Dictionary.": 116.
[85] Antonio M. Lopez Jr., Jerome J. Comello, and William H. Cleckner, "Machines, the Military, and Strategic Thought," *Military Review* 84, no. 5 (September/October 2004): 71.
[86] United States. DoD., "DOD Dictionary.": 117-118.
[87] Ibid: 125.
[88] United States. Department of the Army. TRADOC. ARCIC. Maneuver, Aviation, and Soldier Division., "U.S. Army RAS.": 24.
[89] Ibid.

Machine Learning – The use of algorithms to study data to detect patterns or by applying known rules to categorize, predict outcomes or actions, identify patterns and relationships, or detect anomalous or unexpected behaviors. [90]

- Supervised learning – a machine using an algorithm is presented data to which labels/ answers have been assigned. The algorithm then then identifies patterns that predict an answer.[91]
- Unsupervised learning – a machine using an algorithm is presented with unlabeled data and is tasked with identifying structure[92]
- Semi-supervised learning – a machine using an algorithm is presented with labeled and unlabeled data[93]
- Reinforcement learning – in reinforcement learning the machine is provided a set of allowed actions, rules and potential end states. In other words, the rules of the game are defined. By applying the rules, exploring different actions and observing resulting reactions the machine learns to exploit the rules to create a desired outcome.[94]

Manned-unmanned Teaming – The synchronized employment of Soldiers, manned and unmanned air and ground vehicles, robotics, and sensors to achieve enhanced situational understanding, greater lethality, and improved survivability. The concept of MUM-T is to combine the inherent strengths of manned and unmanned platforms to produce synergy and overmatch with asymmetric advantages.[95] Also referred to as Soldier-Machine Teaming.

Mission assurance – Actions taken to achieve mission resiliency and ensure the continuation of mission essential functions and assets allowed under all conditions and across the spectrum of threats and hazards.[96]

Narrow AI – Applications that provide domain-specific expertise or task completion[97]

Natural language – The kind of speech used in everyday conversation[98]

Optionally-Manned Platform – A RAS that is capable of offering operational employment as either a robotic platform or a traditional manned vehicle or system.[99]

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[90] Kimberly Nevala, *The Machine Learning Primer* (Cary, NC: SAS Institute Incorporated, 2017), PDF e-book, 5.
[91] United States. GAO., "Artificial Intelligence.": 20.
[92] Ibid.
[93] Ibid.
[94] Ibid: 18.
[95] United States. Department of the Army. TRADOC. ARCIC. Maneuver, Aviation, and Soldier Division. "U.S. Army RAS.": 24.
[96] Ibid: 4.
[97] United States. GAO., "Artificial Intelligence.": 10.
[98] Dan Jurafsky and James H. Martin, *Speech and Language Processing – An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition* (Upper Saddle River, NJ: Pearson Prentice Hall, 2007), 16, http://stp.lingfil.uu.se/~santinim/ml/2014/JurafskyMartinSpeechAndLanguageProcessing2ed_draft%202007.pdf.
[99] United States. Department of the Army. TRADOC. ARCIC. MAS-D., "U.S. Army RAS.": 24.

Perception – Consists of sensors (hardware) and sensing (software). A sensor modality refers to what constitutes the raw input to the sensor.[100]

Processing and Exploitation – In intelligence usage, is the conversion of collected information into forms suitable to the production of intelligence.[101]

Remotely Piloted/Controlled – A mode of operation wherein the human operator directly controls the actuators of a UMS on a continuous basis, from off the vehicle and via a tethered or radio linked control device using visual line of sight cues. In this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the user.[102]

Robot – A powered machine capable of executing a set of actions by direct human control, computer control, or a combination of both. It is comprised minimally of a platform, software, and a power source.[103]

Robotic and Autonomous Systems (RAS) – A framework to describe systems with a robotic element, an autonomous element, or more commonly, both.[104]

Robotic Wingman – A tactical RAS platform that augments manned, tactical, ground combat platforms. A robotic wingman may acquire and transmit data and combat information, lead columns of manned vehicles, augment manned platform movement and maneuver, or operate independently out of close proximity to manned systems. A robotic wingman will use variable degrees of direct human control and AI command and control technology.[105]

Sensor – A devise intended to detect and provide perceivable, measurable data.[106]

Sensor-to-Shooter Network – a closed loop, internal feedback system that links various suites of sensors deployed throughout a 3D battle space to a network of weapons platforms (shooters) using optimized communications pathways.[107]

Swarming – A tactic where large numbers of systems actively coordinate actions and self-organize to achieve operational outcomes.[108]

Tele-Operated – A mode of operation wherein the human operator, using video feedback and/or other sensory feedback, either directly controls the actuators or assigns incremental goals,

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[100] United States. Defense Science Board. Task Force on the Role of Autonomy in DoD Systems, "Autonomy.": 33.
[101] United States. DoD., "DOD Dictionary.": 187.
[102] United States. Department of the Army. TRADOC. ARCIC. MAS-D., "U.S. Army RAS.": 24.
[103] United States. JCS., "JCRAS.": A-4.
[104] Ibid: 2.
[105] United States. Department of the Army. TRADOC. ARCIC. MAS-D., "U.S. Army RAS.": 24.
[106] Ibid: 25
[107] Patrick Driscoll, "Modeling the Decision Quality in Sensor-to-Shooter (STS) Networks for Unattended Ground Sensor Clusters," in Proceedings of the Seventh International Conference on Information Quality (ICIQ-02) (Cambridge, MA: MIT ICIQ, 2002): 3, https://pdfs.semanticscholar.org/96f8/b385669fb32e9464144cc66cc995a37051a3.pdf .
[108] United States. JCS., "JCRAS": 8.

waypoints in mobility situations, on a continuous basis, from off the vehicle and via a tethered or radio linked control device. In this mode, the RAS may take limited initiative in reaching the assigned incremental goals.[109]

Unmanned Ground Vehicle (UGV) – An electro-mechanical unmanned ground platform. Can be operated via remote control, tele-operation, or may be equipped with some degree of autonomous behavior. Such a platform may also retain the ability to optionally-manned, where robotic capability is not necessary or desired.[110]

Unmanned system – An air, land, surface, subsurface, or space platform that does not have the human operator physically onboard the platform.[111]

[109] United States. Department of the Army. TRADOC. ARCIC. MAS-D., "U.S. Army RAS.": 25.
[110] Ibid.
[111] Ibid.

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Inside back cover

FUTURE WARFARE DIVISION