Future Study Plan 2019

Operationalizing Artificial Intelligence for Multi-Domain Operations

Prepared by:

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14. ABSTRACT

AI is fundamental to the future Joint Force realizing the full potential of MDO. AI-enabled systems offer the ability to outmaneuver adversaries across domains, the EMS, 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 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, AI-enabled 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 networks provides U.S. Forces the ability to seize positions of operational, strategic, and tactical advantage. Increased understanding through an AI-enabled joint Multi-Domain Common Operating Picture (MDCOP) allows U.S. Forces the ability to orchestrate multi-domain effects to create windows of advantage.

15. SUBJECT TERMS

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Foreword

From the Chief, Future Warfare Division
United States Army Futures and Concepts Center

Warfare throughout history contains abundant examples of tools and technologies that changed the character of warfare. Since the initial study of multi-domain operations (MDO), the U.S. Army identified artificial intelligence as an emerging technology with the potential to change the character of warfare, and perhaps the nature of warfare as well. Using artificial intelligence (AI) solutions to mitigate military problems is a recurring theme over the past two years of future warfare study, examination, and learning. As part of the 2019 Future Study Program, we collaborated with Army, Joint, multinational, academic, and science and technology organizations to explore and understand the impact of AI on MDO and develop an operational framework for future research and development.

The *Operationalizing Artificial Intelligence for Multi-Domain Operations* Final Report provides organizing frameworks for employing AI to help the Army and Joint Force better define required capabilities and the associated data and network architecture to enable multi-domain capable forces. Describing how the Joint Force may employ AI solutions provides an operational description to understand the impact of AI on multi-domain operations in time and space. This report identifies and addresses the benefits, opportunities, and challenges associated with AI to provide a foundation for further analysis. Emerging technologies such as AI allow the Army to not only improve current tactics, techniques, and procedures, but also create new methods of employing and converging capabilities.

The report supports the Army Artificial Intelligence Task Force, the organization charged with developing the Army's AI strategies and policies. This paper initiates the Army's effort to operationalize AI by describing how the force employs AI solutions and related technologies across the MDO framework. This report enables the concept development community to revise Army functional concepts and battlefield development plans. It provides the capability development community with operational perspective and the technological implications the force must consider when identifying required capabilities. Additionally, the report provides a basis to develop scenarios or vignettes for concepts of operation documents or capability based assessments. The paper provides the science and technology community operational context to inform and shape AI research, development, modeling, and simulation. Lastly, it supports the development of a comprehensive vision for employing AI in the future to inform Army modernization efforts that will create the MDO capable forces ready to fight and win against any adversary.

Chris Rogers
Colonel, U.S. Army
Chief, Future Warfare Division,
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Executive Summary

Artificial intelligence (AI) is fundamental to the future Joint Force realizing the full potential of Multi-Domain Operations (MDO). Artificial Intelligence-enabled systems offer the ability to outmaneuver adversaries across domains, the electromagnetic spectrum, and the information environment. The employment of these systems during competition allows the Joint Force to understand the operational environment in near-real time, and thus better employ 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, AI-enabled maneuver, fires, and intelligence, surveillance, and reconnaissance 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 Multi-Domain Common Operating Picture (MDCOP) allows U.S. forces the ability to orchestrate multi-domain effects to create windows of advantage.

Developing an operational concept for AI allows the Army to understand better the potential impact of those technologies on the nature and character of war. Describing how the Army may employ AI 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 paper provides vignettes (Appendix A) that illustrate the organizational employment of AI 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.

Operationalizing AI 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. During the 2019 Future Study Plan (FSP19) the AI line of effort (LoE) identified the following issues associated with implementing AI-enabled multi-domain solutions:

- **Data management** – AI/ML applications depend upon access to curated data in order to function. The Army must foster a data-centric culture that ably generates, stores, and accesses data with standardized formats and protocols. Talent management efforts must focus on developing, training, and retaining a data savvy workforce. This can be achieved by:
    - fostering a data-centric culture across the Department
    - investing in data science training across the workforce
    - streamlining data access
    - designing and implementing protocols to ensure that data is discoverable, accessible, sharable, and interoperable

- **Functional decomposition** – Narrow AI is inherently limited and the data scientists who build algorithms require precise problem definitions that identify exactly what the joint force requires.
- **Explainable AI** – Artificial intelligence enabled systems require the ability to explain the logic behind decision making/recommendation and actions taken. This ability to explain the "why" underpins the trust that a human will place in an AI-enabled agent.
- **Edge computing / AI** – The future operating environment with a contested electromagnetic spectrum expected demands the ability to process extremely large data sets forward as well as AI-enabled platforms capable of acting autonomously.
- **Leverage the commercial sector** –Department of Defense labs continue to make significant strides in AI/ML development particularly in partnership with Federal Funded Research and Development Centers. The commercial sector continues to explore and expand on work that may be adaptable for military application.

As a part of the FSP19, the AI LoE developed five vignettes and one concept sketch (depicted in Appendix A) to assist in operationalizing artificial intelligence and machine learning. These vignettes illustrate how the Joint Force could employ AI/ML to address critical capabilities required by multi-domain operations. The MDCOP concept will rely on several *limited-memory AI* to build and maintain a picture depicting Blue, Red, and Green activities across the battlefield. A *reactive machine AI* will tailor the MDCOP to specific commanders and headquarters. The cooperative sensing, sustainment, attack, and targeting vignettes rely on a *reactive machine AI* to optimize sensor coverage, sustainment throughput, attack sequencing, and shooter selection.

The future force requires AI to realize fully the potential of multi-domain operations. Artificial intelligence-enabled systems allow the future force to conduct information collection and analysis to increase situational understanding in time constrained and information competitive environments. This capability enables rapid, informed, and sound decision-making. Artificial intelligence-enabled decision support agents will lighten the warfighter's cognitive workload and increase overall effectiveness. 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. Artificial intelligence enables the operational speed MDO demands at the scale of conflict with a near-peer adversary.

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Introduction

In January 2018, the Chief of Staff of the Army, General Mark Milley, warned, "Whether we like it or not, artificial intelligence is coming."[1] He echoed this comment during a June 2018 National Security Forum by describing artificial intelligence (AI) as "… a technology our opponents will use against us, and it will be to our benefit to get there first."[2] Artificial intelligence and the related concepts of machine learning (ML) and neural networks could transform how the military makes decisions, acquires and engages targets, conducts operations, protects, and sustains itself. Both China and Russia have indicated a desire to become world leaders in AI, with the widely reported warning from Russian President Vladimir Putin that, whoever becomes the leader in AI will become the ruler of the world. The challenge the Army currently faces is the need to exploit the potential of this emerging technology before our adversaries while minimizing associated risk.

The Commanding General of Army Futures Command's (AFC), General John Murray shared the CSA's concern "AI is coming to the battlefield, it's not a question of if, it's when and who."[3] The Futures and Concepts Center (FCC) Director, Lieutenant General Eric Wesley, is taking steps to ensure that the US military is the first to employ AI on the battlefield. He has emphasized the need to develop AI capabilities related to decision-making and data management. In a *Breaking Defense* interview with Sydney Freedberg Jr., Lieutenant General Wesley remarked, "All of the ubiquitous data that's available to us will only be sufficiently integrated by artificial intelligence." He followed this remark by saying "We will need AI, artificial intelligence, to do multi-domain command and control."[4]

Department of Defense AI Strategy

The *Summary of the 2018 Department of Defense Artificial Intelligence Strategy* describes an approach "to strengthen our national security and transform the speed and agility of our operations" consisting of five tenets[5]:

- Delivering AI-enabled capabilities that address key missions
- Scaling AI's impact across the Department of Defense (DoD) through a common foundation that enables decentralized development and experimentation

[1] Sharkov Damien, "U.S. Army Chief Says Embracing Robotics and AI is Vital for Future Combat," Newsweek, last modified January 18, 2018, https://www.newsweek.com/us-army-chief-wants-robots-and-artificial-intelligence-forces-battlefield-784309.
[2] Association of the United States Army, "Milley: Artificial Intelligence Could Change Warfare," Association of the United States Army, last modified June 27, 2018, https://www.ausa.org/news/milley-artificial-intelligence-could-change-warfare.
[3] Todd South, "Four Takeaways from the 4-star General at Army Futures Command," Army Times, last modified May 7, 2019, https://www.armytimes.com/news/your-army/2019/05/07/four-takeaways-from-the-4-star-general-at-army-futures-command/.
[4] Sydney J. Freedberg, "Forget the Terminator for Future Army AI: LTG Wesley," Breaking Defense, last modified November 30, 2018, https://breakingdefense.com/2018/11/artificial-intelligence-key-to-commanding-future-army-ltg-wesley/.
[5] United States. Department of Defense (DoD). *Summary of the 2018 Department of Defense Artificial Intelligence Strategy: Harnessing AI to Advance Our Security and Prosperity*, (Washington, D.C.: DoD, 2019), 17.

- Cultivating a leading AI workforce
- Engaging with commercial, academic, and international allies and partners
- Leading in military ethics and AI safety

The Summary notes that failure to adopt AI will result in military irrelevance, loss of cohesion amongst our allies and partners, economic decline, and challenges to societies built on individual freedom.[6]

The U.S. Army AI Strategy

In May of 2019, the Army AI Task Force (A-AITF) published *The United States Army's Artificial Intelligence (AI) Strategy* as an annex to the DoD AI Strategy described above. This document establishes the ends, ways, and means that the Army will employ AI to "enable the warfighter across domains."[7]

Ends	Ways	Means
• Develop Multi-Domain Operations solutions (compete, penetrate, disintegrate, exploit) • Reduce Solider and Leader cognitive load • Make the Army enterprise more efficient • Protect the force	• Develop AI capabilities to address Army and Joint force needs • Use the Joint Planning Areas to organize future Army and Joint capabilities • Ensure other accommodations are made to enable and exploit AI • Assess and mitigate risk	• Establish the AI framework and foundation • Set the conditions for Army AI success[8] • Establish an enterprise AI infrastructure • Synchronize, transform, and grow AI efforts

Table 1: Army AI Strategy Summarized

Key Definitions and Terms

The following terms and concepts related to AI are critical to understanding the rest of this paper. The DoD defines AI as "the ability of machines to perform tasks that normally require human intelligence."[9] Researchers divide AI into two distinct categories – general and narrow. General AI (also known as Artificial General Intelligence) is a "system that exhibits intelligence comparable to that of a human or beyond, across the range of contexts in which a human might

[6] United States. DoD., "DoD AI Strategy", 5.
[7] United States. DoD. Department of the Army (DA). AFC. A-AITF, *The United States Army's Artificial Intelligence (AI) Strategy*, (Washington, DC: DoD, 2019), 1.
[8] Key steps to this include: "…advising Army leadership on AI investments; developing AI software certification and accreditation / risk management framework (RMF) policies; identifying code development authorities; ensuring governance; streamlining acquisitions and contracts processes; identifying credential and access management (ICAM) for end points, data streams, and access to data; and building policies for data acquisition, retention, and creation for AI training." United States. DoD. DA. AFC. A-AITF., *Army AI Strategy*. 10.
[9] United States. DoD., "DoD AI Strategy." 5.

interact."[10] General AI does not exist today and the timeframe (ranging from several years to never) of it emergence and operational application is an unsettled controversy among leading researchers and scientists.[11] Narrow AI, the only type that exists today, are "applications that provide domain-specific expertise or task completion."[12] Machine Learning is a subset of AI that uses "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."[13] Machine Learning employs two types of learning models: feedback-based and knowledge-based.[14]

Why Must the Army Operationalize Artificial Intelligence?[15]

Operationalizing, or stated another way, developing an operational description for AI 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 AI 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.[16] Operationalization serves as the next logical extension of the DoD and Army AI Strategy by providing additional context to required capabilities identified in concepts, and capability objectives. This paper uses vignettes to visualize and describe the organizational employment of AI in time, space and purposeful tasks according to five employment variables and one developmental variable:

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

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[10] United States. Government Accountability Office (GAO)., *Artificial Intelligence - Emerging Opportunities, Challenges, and Implications*, (Washington, D.C.: United States GAO, 2018), https://www.gao.gov/assets/700/690910.pdf, 10.

[11] Michael C. Horowitz, "The Promise and Peril of Military Applications of Artificial Intelligence," Bulletin of the Atomic Scientists, last modified December 5, 2018, https://thebulletin.org/2018/04/the-promise-and-peril-of-military-applications-of-artificial-intelligence/.

[12] United States. GAO., "Artificial Intelligence." 10.

[13] Kimberly Nevala, "The Machine Learning Primer," Analytics, Business Intelligence and Data Management | SAS, accessed June 5, 2019, https://www.sas.com/content/dam/SAS/en_us/doc/whitepaper1/machine-learning-primer-108796.pdf, 10.

[14] Andrew Ladas, "AI & ML ERA Deep Dive" (lecture, Army Research Laboratory, May 12, 2017). Feedback-based learning consists of supervised, unsupervised, and reinforcement learning. Knowledge-based learning consists of inductive and deductive techniques. See Appendix C for definitions.

[15] Adapted from: United States. DoD. DA. AFC. Futures and Concepts Center (FCC). Future Warfare Division (FWD)., *Operationalizing Robotic and Autonomous Systems in Support of Multi-Domain Operations*, (Fort Eustis, VA: Futures and Concepts Center, 2018), http://arcic-sem.azurewebsites.us/App_Documents/UQ/RAS-In-Support-of-Multi-Domain-Operations-White-Paper_Signed_131500Dec18....pdf, 2-3.

[16] In *The Operational Environment and the Changing Character of Future Warfare*, the Training and Doctrine Command (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.

- system interdependencies
- system vulnerabilities
- implementation / developmental challenges

Describing AI employment in this enables identification of system concept, capability, and force design considerations and issues requiring further assessment.

Why MDO Demands an AI Solution

The Army's MDO concept describes a different way of conducting operations than visualized in the past. First, the concept envisions the requirement to compete with near peers that will contest the Joint Force in all domains.[17] Second, the concept identifies that near peers, such as China and Russia, will employ advanced anti-access and area denial (A2/AD) systems in conflict to create standoff with U.S. and partner forces. The ability to penetrate and dis-integrate threat A2/AD systems figures prominently in the MDO central idea and MDO operational problems.[18]

The MDO concept requires the Joint Force to conduct operations in all domains, the electromagnetic spectrum, and the information environment that geographically span the broad MDO framework (Figure 1). The MDO framework encompasses areas from the "strategic support area" (including the continental United States) to an adversary's "deep fire areas" anywhere on the globe. Penetrating and dis-integrating A2/AD systems enables the Joint Force to deploy contested from the homeland and maneuver in forward areas to close with and defeat an adversary.

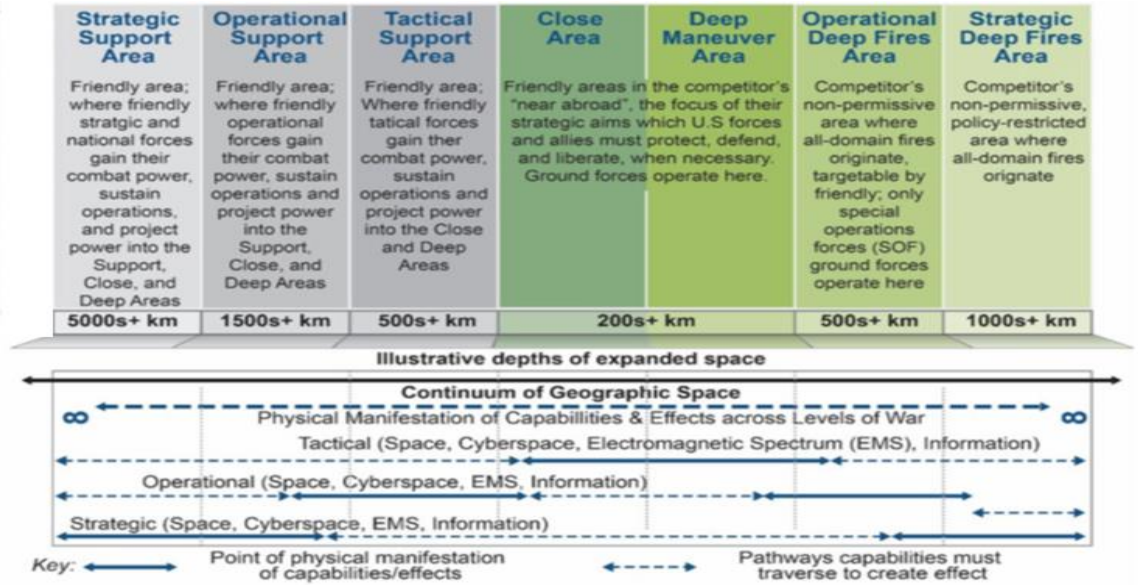

Figure 1: MDO Framework[19]

[17] United States. DoD. DA. TRADOC., *The U.S. Army in Multi-domain Operations 2028*, (Fort Eustis, VA: TRADOC, 2018), viii,x.
[18] Ibid. 2, 4–5.
[19] Ibid. 8.

The speed of MDO combined with the scale of competing with and fighting a near-peer adversary requires decision-making and action taking beyond human cognitive ability. Multi-Domain Operations demand AI solutions to enable:

- ***Convergence*** – the ability at echelon to integrate rapidly, continuously, and accurately organic and external capabilities from across all domains, the electromagnetic spectrum (EMS), and the information environment across the MDO framework.[20] Convergence not only concerns effects but also processes such as intelligence development, surveillance, and reconnaissance. The joint force must be able to converge capabilities and processes across the MDO framework against a near peer competitor/adversary who is capable of disrupting the electro-magnetic spectrum. [21]
- ***Optimization*** – multi-domain operations require the ability to deliver effects to the right target, at the right time, and in the most effective and efficient manner possible. [22] This ability to optimize must include employing the most effective and efficient means to strike a target using the best method to find, track, and assess the delivery of effects.[23]
- ***Synchronization*** – the ability to combine situational awareness, fires (lethal and non-lethal), and maneuver to penetrate and exploit. [24] Also the ability to orchestrate rapidly sustainment, communications, maneuver support, and protection capabilities to enable power projection in competition and semi-independent maneuver in conflict. [25]
- ***Speed of awareness and action*** – the ability to recognize and visualize conditions leading to windows of domain superiority and/or challenges and to act on those during all phases of the conflict continuum. [26] Echelons-above-brigade headquarters must rapidly process, exploit, and disseminate (PED) high volumes of data to create awareness, understanding, and targeting data. [27] These echelons must possess the ability to change rapidly the task organization of forces to converge effects at the point of need.

Table 2 identifies where AI-enabled capabilities can enable the Joint Force to realize the tenets of multi-domain operations.

[20] United States. DoD. DA. TRADOC., "*MDO 2028."* 20, 22-23, 29, and 43.
[21] Ibid. 21. See also: United States. DoD. DA. TRADOC., *TRADOC Pamphlet 525-3-8. US Army Concept for Multi-Domain Operations at Echelons Above Brigade 2025-2040*, (Fort Eustis, VA: TRADOC, 2018).
[22] Ibid. 20.
[23] Ibid, 40. See also: United States. DoD. DA. TRADOC., "TRADOC PAM 525-3-8." 25.
[24] Ibid, 19
[25] Ibid, 19 and 47.
[26] Ibid, 1, 28, 43, and 47.
[27] Ibid. 22, 34, 38-39, 41 and 43. See also: Horowitz, "The Promise and Peril." and Andrew Feickert et al., U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress, (Washington, DC: Congressional Research Service, 2018).

AI Enabled Tenets of Multi-Domain Operations		
Calibrated Force Posture	***Multi-Domain Formations***	***Convergence***
Forward presence forces – *provides mission command, intelligence, sustainment, security force assistance, civil affairs, psychological operations, and Special Operations Forces during competition and transition to armed conflict; provide enhanced interoperability to partners*	**Conduct independent maneuver** – *formations enabled by capabilities such as reduced visual and electromagnetic signatures, redundant channels for communications hardened against enemy interference, reduced logistics demand, enhanced medical support, multiple sustainment networks, robust maneuver support capability and capacity, and multi-domain obscuration capabilities*	**Cross-domain synergy** – *optimizes capabilities from across all domains, the electromagnetic spectrum, and the information environment to achieve the maximum effect from the available resources*
Expeditionary forces – *quickly and effectively deploy along contested lines of communication*	**Employ cross-domain fires** – *combine with necessary advances in mobility and lethality in future air and ground platforms, communications networks, and data processing (speed and volume) to provide the capabilities for cross-domain maneuver*	**Layered options** – *the layering of multiple forms of convergence provides friendly commanders with options and imposes complexity upon the enemy*
National-level capabilities – *the ability to leverage national cyber, space, and niche strike capabilities at the operational and tactical level for strategic effect*	**Maximize human potential** – *sensors monitoring status of human performance augment commander' understanding of their units, inform decisions about the tempo and intensity of operations, and assist units in sustaining and regenerating physical and psychological strength. Man-machine interfaces, enabled by AI, improve decision making in both speed and accuracy*	**Mission command** – *allows the Joint Force to preserve the ability to continuously and rapidly integrate multi-domain capabilities despite disrupted communications.*
Authorities – *coordinate and identify tailored authorities in three broad areas: access, surveillance, and employment*		**Convergence at echelon** – *multi-domain formations and calibrated force posture enable convergence*

Table 2: AI-Enabled Tenets of Multi-Domain Operations

What Does Operationalize AI Mean?[28]

Operationalize is a description of the way an organization employs 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.[29] During the FSP19 AI LoE, AI subject matter experts and representatives from the operational force, and concept/capability designers described a formation's application of AI (phenomenon) using these specific operational variables: benefits, interdependencies, and vulnerabilities. The MDO operational framework and temporal model provided context for this process. The combination of an operational definition with the MDO operational framework operationalizes AI.

This paper provides a narrow examination of the application of AI within the MDO concept. It builds upon the MDO concept by indicating how the force applies AI technologies in specific instances. It provides the capability development community with operational perspective on when, how, and where AI enabled technologies are required to fully implement concepts described in the Multi-Domain Operations Concept. It also provides capability developers a basis from which to further develop scenarios or vignettes for capability based assessments or cost-benefit analyses. The paper provides the science and technology community with operational context for AI developmental research and prototyping. Lastly, this paper provides the Army a vision for employing emerging AI applications in the future operating environment to inform formation equipping. This paper is not an effort to operationalize fully AI; it is a first step in an A-AITF led effort. The A-AITF will produce a more holistic and encompassing concept that describes more fully how the Army will realize the full benefit of AI enabled technologies.

Key Findings from the FSP19 Artificial Intelligence Line of Effort

The FCC established the AI LoE as a part of FSP19 effort to operationalize AI/ML for multi-domain operations and activities. The FSP set out to validate the MDO concept through an iterative series of tabletop exercises (TTX). The first event of the FY19 study – the Intelligence, Surveillance, and Reconnaissance (ISR) Strike TTX – identified requirements for complementary, reinforcing, and redundant *see*, *stimulate*, and *strike* solutions to contest, penetrate, and dis-integrate layered A2/AD systems.[30] The second event, the Command and Control (C2) TTX, determined how to best organize, command, and control multi-domain organizations and capabilities to defeat an adversary's integrated fires and air defense systems.[31] The C2 TTX also explored the technical and network architecture, control measures, and procedures to make current and future capabilities responsive to commanders' requirements. Lastly, the Sustainment and Protection TTX examined how Army forces sustain and protect

[28] Adapted from: United States. DoD. DA. AFC. FCC. FWD., "Operationalizing RAS."
[29] United States. DoD. DA. *ADP 1-01 Doctrine Primer*. (Washington, D.C.: Headquarters DA, 2014): 4-8.
[30] The ISR-Strike TTX occurred 5-8 November 2018 at Carlisle Barracks, PA.
[31] The C2 TTX occurred 9-12 January 2019 at Carlisle Barracks, PA.

forward postured and expeditionary forces against a near-peer threat.[32] The AI LoE focused on how AI/ML could enable, improve, or completely revise the execution of tasks associated with ISR-Strike, C2, sustainment, and protection.

The AI study culminated with a seminar from 6–10 May 2019 at the U.S. Army War College, Carlisle Barracks, PA. Subject matter experts (SME) studied how the Army, as part of the Joint Force, might employ AI-enabled capabilities in support of multi-domain operations.[33] The seminar examined several tactical vignettes that conceptualized AI-enabled MDO. The seminar dialogue enabled participants to identify required MDO capabilities and associated AI solutions. The event reaffirmed the need for robust, interoperable AI to enable multi-domain operations. Additionally, the seminar SMEs drafted organizing frameworks for AI that, when developed, will allow the A-AITF and other stakeholders to define key required capabilities, articulate necessary changes to existing information technology policies (or inform new ones), and create the data infrastructure that enables the 2028 MDO capable force.

The AI LoE developed the following insights:

Layered AI Framework. The FSP19 and other learning events identified the need for a framework to link narrow AI solutions together to enable complicated tasks.[34] AI solutions must operate as a system of multiple layers to enable these tasks – allowing the Joint Force to conduct complicated tactical tasks that span the joint functions.[35]

Today's narrow AI is capable of performing a single task, but the Joint Force requires AI applications that can connect a series of narrow AI in a way that can rapidly address complicated tasks.[36] Figure 2 conceptualizes how AI-enabled solutions must fuse data and applications to enable multi-domain operations. This framework depicts three joint functions in MDO: C2, fires, and intelligence.[37] The left side identifies layers of solutions for narrow AI—that designed for a specific activity—that span from left to right across the figure. The small cylinders in Layer 1 at the top represent various ISR sensor tasks in the space, cyber, and air domains. Narrow AI at this level might enable onboard platform exploitation of data. However, this is insufficient by itself to enable MDO. The concept demands another level of narrow AI (illustrated by the larger cylinders depicted in Layer 2) to fuse data *within* a joint function across all the systems responsible for tasking, collecting, and exploiting within the ISR activity to assist commanders

[32] The Sustainment and Protection TTX occurred 18-12 March at Carlisle Barracks, PA.
[33] See Annex E for a complete list of organizations that provided SMEs.
[34] David Spencer, Stephen Duncan, and Adam Taliaferro, "Operationalizing Artificial Intelligence for Multi-Domain Operations: A First Look" (Baltimore, MD: SPIE International Society for Optics and Photonics Defense and Commercial Sensing Conference, May 2019), 3-4.
[35] Joint Functions are C2, intelligence, fires, movement and maneuver, protection, sustainment, and information. See U.S. Joint Chiefs of Staff, "Joint Publication 5-0: Joint Planning" Joint Chiefs of Staff (16 June 2017), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp5_0_20171606.pdf (14 April 2019), V-25.
[36] Tannya D. Jajal, "Distinguishing Between Narrow AI, General AI and Super AI," Medium, last modified May 21, 2018, https://medium.com/@tjajal/distinguishing-between-narrow-ai-general-ai-and-super-ai-a4bc44172e22.
[37] The framework only expands the intelligence activity at the top of the framework into layers to illustrate the complexity of integrated AI solutions. See Spencer, et. al, Operationalizing Artificial Intelligence for Multi-Domain Operations: A First Look, 3-4.

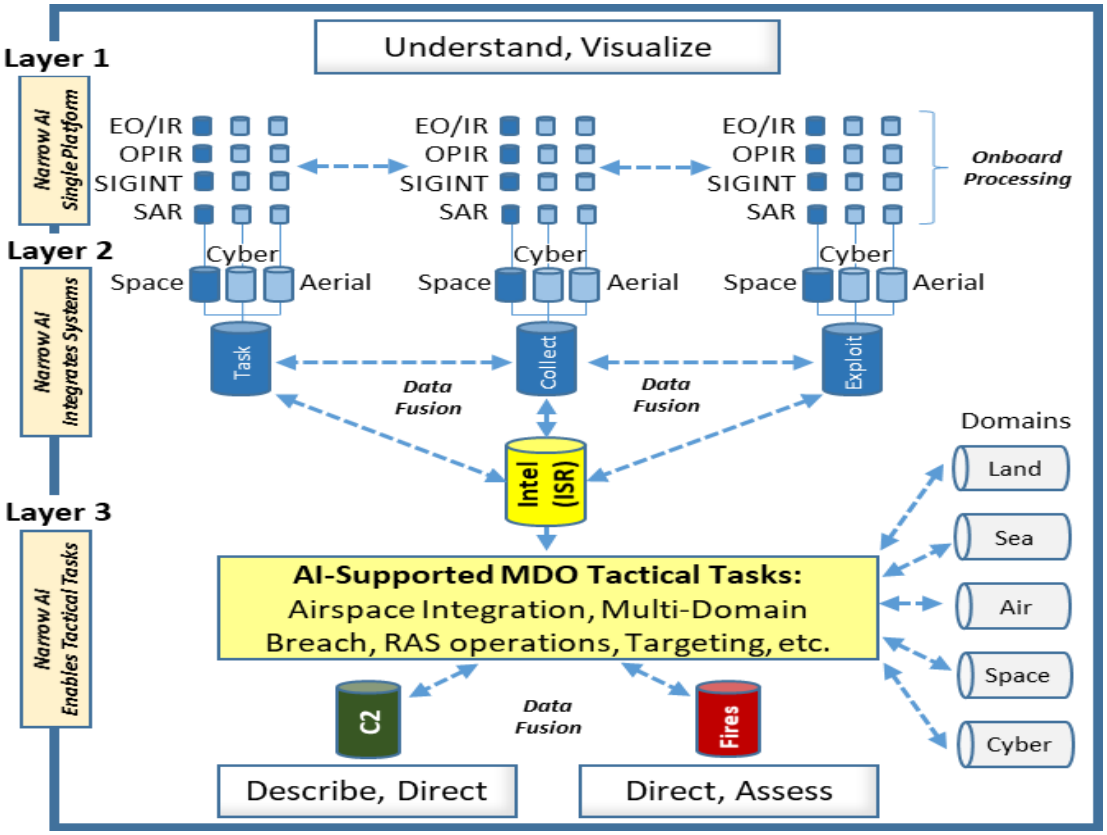

Figure 2: Layered AI Framework

and staffs in understanding and visualizing their operational environments. Finally, Layer 3 solutions integrate data outputs from Layers 1 and 2 *across* functions to enable the conduct of a complicated MDO task.

This example illustrates the challenge of developing associated AI solutions. Multi-domain tasks and activities require solutions and processes that synchronizes multiple AI solutions. A layered framework of narrow AI solutions that can integrate these activities is a conceptual model to drive development. To converge capabilities successfully in all domains at large scales and rapid speeds, these solutions must be fully interoperable across the Joint Force.

Data management. Competition and armed conflict against a near peer will require decision-making and action at machine speed. While AI applications can enable both of these, but most applications require access to curated data during training and application fielding.[38] Artificial intelligence-enabled MDO processes, such as automated target recognition, intelligence fusion,

[38] "Data curation is a means of managing data that makes it more useful for users engaging in data discovery and analysis." Michelle Knight, "Data Curation 101: The What, Why, and How," DATAVERSITY, last modified November 30, 2017, https://www.dataversity.net/data-curation-101/. There are emerging approaches to AI that are not data dependent. Carnegie Melon University's Noam Brown and Tuomas Sandholm have employed a "game-theoretic" approach to develop an AI application that developed strategies through self-play, modified them in-game, and consistently defeated elite-level Texas Hold 'Em players. See: Noam Brown and Tuomas Sandholm, "Superhuman AI for heads-up no-limit poker: Libratus beats top professionals," *Science* 359, no. 6374 (January 2018): xx, doi:10.1126/science.aao1733.

and predictive analytics, rely on large amounts of data from diverse sensors and platforms. Availability of large data sets allows AI algorithms to train and improve their ability to synthesize information for more accurate predictions and processes. The ability to rapidly exploit data through sophisticated AI applications will provide a marked advantage to the Joint Force.

Conversely, as MDO processes increasingly rely on AI-enabled solutions, poorly managed data—that which is inaccurate, inaccessible, or improperly labeled—increases the risk of mission failure.[39] This is because the operator may not realize that their data is dirty or compromised until it is too late, precluding a traditional analog solution. Additional data challenges include interoperability requirements, and access to the Joint Force's, interagency departments', and multi-national partners' data. The proliferation of publicly available information (i.e. social media, text messages, images, videos, and reports) combined with classified data presents opportunities to identify and reduce gaps in traditional ISR collection.[40] Facilitating rapid clearance approvals, disclosures, and data transfer across networks are implications associated with new opportunities to use AI solutions to fuse data for processing and exploitation.

The DoD digital modernization strategy outlines the Department's vision for agile, resilient, seamless, and secure infrastructure that transforms data into actionable information.[41] The Department will publish subsequent documents that support and enhance its digital modernization strategy.[42] During the AI Seminar, SMEs identified important data management considerations that can inform future Army and DoD data strategies.

AI enabled solutions require:

- ***Fostering a data-centric culture*** by informing the Joint Force on the importance of data to military operations
- ***Investing in data science training*** and education to ensure personnel have the requisite skills to build and manage AI solutions[43]
- ***Streamlining data access*** to enable academia and the science and technology community to develop and train AI solutions with relevant military data
- ***Designing and implementing protocols*** to ensure data is discoverable, accessible, sharable, and interoperable, across joint, inter-organizational, and multinational partners

[39] Also known as "dirty data". See Kristian Kalsing, "The 6 Common Ways Dirty Data is Created," Simplify SAP & Automate Business Processes | Winshuttle, last modified May 19, 2014, https://www.winshuttle.com/blog/6ways-dirty-data/.
[40] David R. Lands, "Publicly Available Information: The Secret to Unclassified Data, Part I," Over the Horizon: Multi-Domain Operations and Strategy, last modified April 8, 2019, https://othjournal.com/2019/04/08/publicly-available-information-the-secret-to-unclassified-data-part-i/
[41] U.S. Department of Defense, "DoD Digital Modernization Strategy" DoD Chief Information Officer, July 12, 2019, https://media.defense.gov/2019/Jul/12/2002156622/-1/-1/1/DOD-DIGITAL-MODERNIZATION-STRATEGY-2019.PDF, 11.
[42] Ibid, 9.
[43] See also Andrew Feickert et al., *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress*, (Washington, DC: Congressional Research Service, 2018). 27-28 for a discussion on the need for a more technically educated work force.

Functional decomposition of MDO tasks. The layered AI framework identified that multiple narrow AI solutions are required to enable complicated multi-domain operations and activities. The Army and capability developers must move beyond broad visions of how AI will enable MDO; they must functionally decompose operations and tasks such as breach, deception, and targeting to identify and prioritize subtasks that AI/ML solutions are able to address.[44] This decomposition will allow researchers to focus on narrow AI solutions and develop potential applications that integrate them.

Functional decomposition also determines where AI solutions can potentially improve current processes. For example, the military decision making process (MDMP) has great potential for integrating and including AI-enabled processes.[45] The SMEs determined where specifically AI solutions could increase the efficiency and situational awareness of commanders and staffs by decomposing the mission analysis portion of MDMP (Figure 3). This process identified specific mission analysis subtasks that lend themselves to narrow AI-enabled solutions.

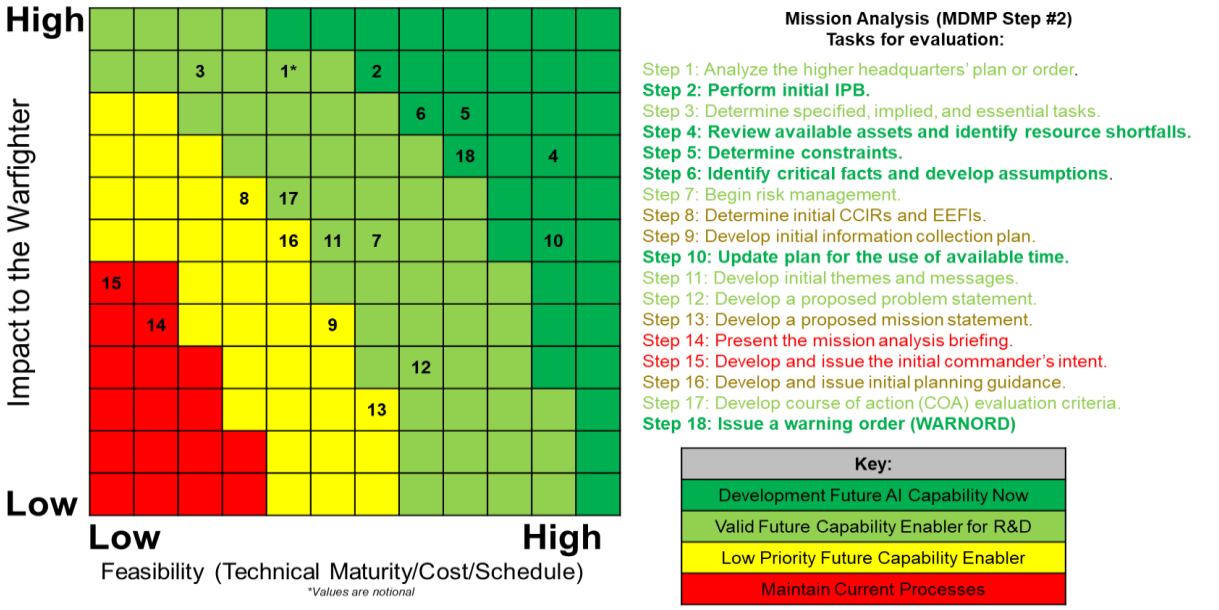

Figure 3: Functional Decomposition of Mission Analysis[46]

The SMEs assessed whether current AI, ML, data processing, and other related technologies could improve mission analysis. The SMEs evaluated the benefit to the warfighter (y- axis) and compared it to the technical feasibility of the task solution (x-axis) to prioritize research, development, and implementation. Furthermore, the assessment identifies where current processes are adequate to support MDO. Additionally, task decomposition can assist in

[44] Functional decomposition is an analytic method that dissects a complicated or lengthy process into discrete elements.
[45] United States. DoD. DA. Mission Command Artificial Intelligence Concept of Operations. (Washington, D.C.: Headquarters DA, 2019): 10.
[46] Mr. Greg Henderson, Army Futures Command, Combat Capabilities Development Command, C5ISR, led and developed the mission analysis functional decomposition the AI Seminar.

identifying data exchange requirements, informing potential network architecture developments that enable increased automation and AI-enabled tasks.

Edge computing and artificial intelligence. Edge computing refers to the practice of pushing computing power down to the source of data instead of relying on a centralized computing solution.[47] Edge computing allows AI-enabled processes to operate in degraded environments with limited connectivity. In competition and armed conflict, near-peer competitors will contest the EMS, degrading the ability of the Joint Force to use remote cloud-based servers. Situations where even latency in the seconds can risk task failure, edge computing is necessary when a commander or analyst requires real-time analysis on operational data.[48] Edge computing enables forces to receive, collect, and analyze data at forward locations, reducing the reliance on computers that are more powerful or large data clouds/lakes located in the Operational or Strategic Support Areas.

Figure 4 illustrates data processing requirements and potential solutions using the MDO operational framework. The assumption that data is readily available and accessible in the cloud in contested environments against near-peer competitors is not valid. Operations in contested

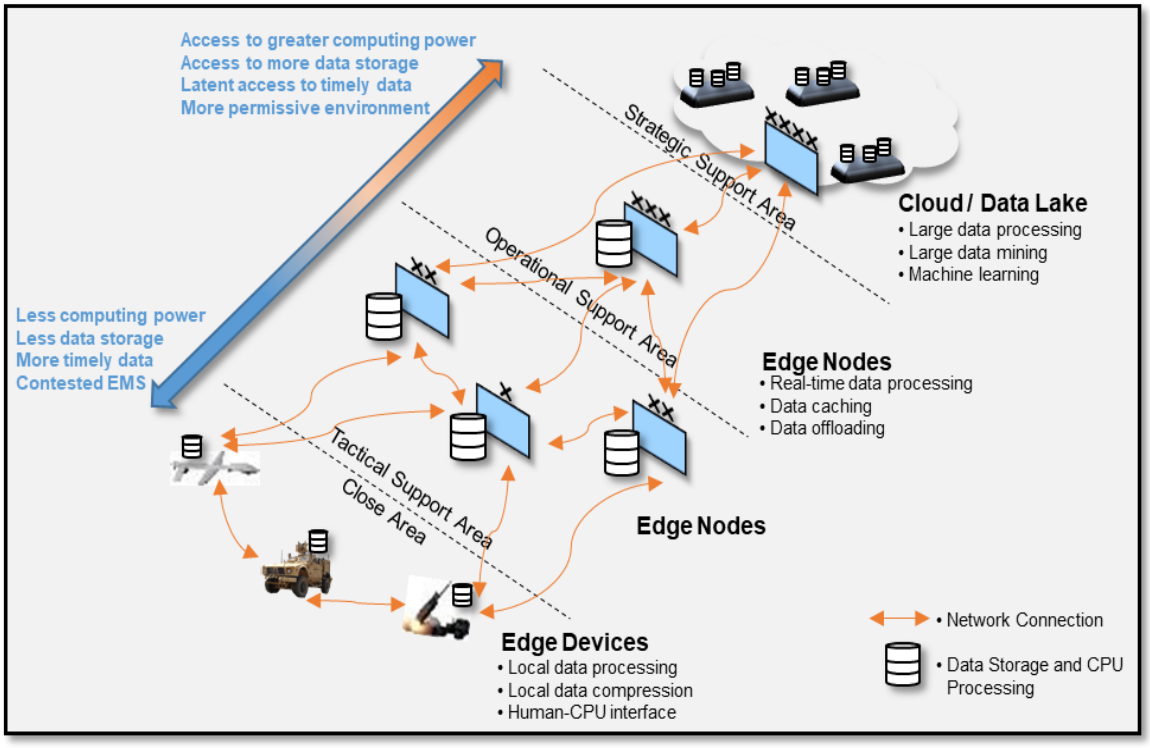

Figure 4: Edge Processing and Data Transfers in the MDO Framework

[47] Paul Miller, "What is Edge Computing?," The Verge, last modified May 7, 2018, https://www.theverge.com/circuitbreaker/2018/5/7/17327584/edge-computing-cloud-google-microsoft-apple-amazon.

[48] Brandon Butler, "What is edge computing and how it's changing the network," Network World, last modified September 21, 2017, https://www.networkworld.com/article/3224893/what-is-edge-computing-and-how-it-s-changing-the-network.html.

domains and non-permissive environments require data processing to occur at multiple levels and echelons. In the Strategic Support Area, a relatively permissive environment and increased physical protection enable large data centers and cloud computing storage facilities to conduct data processing, machine learning, and analysis. Forces operating in the Operational and Tactical Support areas require edge nodes such as routers, switches, and base stations to direct network traffic, and process limited data. Forces at the forward edge in the Close Area and beyond – process and store critical data locally – enabling real-time PED of data. Edge devices transfer data back to centralized data centers when the EMS and network bandwidth capacity is available.

Seminar SMEs identified a number of benefits when using edge computing, most notably, that it could increase the speed of targeting and decision making. AI-enabled sensors with sufficient forward data access could identify targets autonomously, using minimal bandwidth, by conducting onboard PED of data. Additionally, edge computing could enable a MDCOP—a requirement for C2 and decision making in MDO. When operating independently or dispersed over great distances, forces with AI-enabled MDCOPs can access a "tactical cloud" when the network is functional or generate their own local MDCOP.

Explainable AI solutions. The AI LoE study and learning events indicate that trust in AI-enabled systems is essential. Trust increases through familiarity, increased exposure, and reliable performance. However, until users realize trust in AI systems there is a need for explainable AI (i.e., the ability to explain the logic behind a recommendation or action). The challenge for AI developers is to produce explainable models that maintain optimal performance.[49]

Figure 5 depicts the flow of AI-related processes that lead to a recommended action for commander's decision.[50] In this example, data sets support the training of the neural net model and resulting algorithms that recommend an action. In many instances, decision support agents conceptualize confidence as percentages (e.g. 81% confidence value on confirmation of target identification). This model identifies the need for an explainable interface that provides sufficient detail based on the training, knowledge, and expertise of commanders and staffs. An explainable interface allows decision makers to combine human-based contextual understanding and logic with AI solutions.

Current AI decision support systems demonstrate the ability for AI to model countless options that can result in effective but unorthodox recommendations.[51] The ability to understand the logic behind recommendations, at least in the near term, is critical to developing trust in AI solutions. However, this desire for explainable recommendations/actions may inherently limit an AI-enabled decision support agent to conventional solutions.[52]

[49] Ladas, "AI & ML ERA."
[50] Adapted from Tien Pham, "AI & ML Essential Research Area" (presentation, Discussion with ARCIC, Army Research Laboratory, Adelphi, MD, January 17, 2018).
[51] See Brown and Sandholm, "Superhuman Computing,".
[52] For more on the potential limitations of "explainable AI" see: Michael C. Horowitz, "The Promise and Peril of Military Applications of Artificial Intelligence," Bulletin of the Atomic Scientists, last modified December 5, 2018, https://thebulletin.org/2018/04/the-promise-and-peril-of-military-applications-of-artificial-intelligence/.

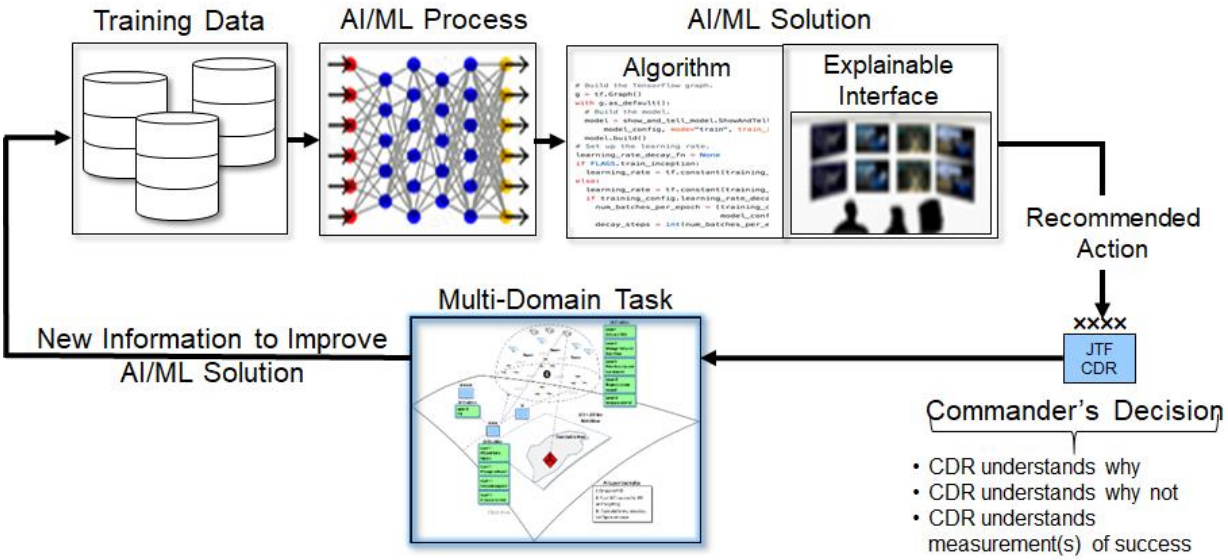

Figure 5: Explainable AI: Commander's Decision Support Tool

Leveraging the commercial sector. Leveraging commercial AI solutions for military problems is possible, but challenging. Data management is critical. Capability developers must account for the availability of curated data. Additional challenges include classification issues. Furthermore, most commercial AI applications operate in a permissive EMS environment. The use of commercial off-the-shelf solutions for military application must accommodate a more challenging environment while maintaining optimal performance.

The commercial sector is conducting innovative research on AI, and the military should capitalize on these opportunities. The SMEs identified concerns when capitalizing on commercial sector AI development. Military users must ensure commercial technologies support military application. Key questions related to commercial sector AI feasibility and scalability for MDO include:

- ***What are the underlying assumptions*** associated with the model to determine if the model accounted for operations in contested environments and the scale of MDO?
- ***How was the model tested*** and what training data was used to determine if the data is statistically significant and relevant to military operations?
- ***How much computing power is required*** to determine how and where the AI solutions process data and the logistical support required?
- ***How does the model make decisions*** to determine the human-AI user interface?[53]

[53] Jenny Stacy, "For the Army successfully develop AI, it needs to ask the right questions," DVIDS, last modified June 6, 2019, https://www.dvidshub.net/news/328529/army-successfully-develop-artificial-intelligence-needs-ask-right-questions.

The military and commercial sectors face many similar problems but in different contexts (e.g. exploiting data to produce "actionable" intelligence). Increased cooperation and collaboration among academia, the concepts community, the operational force, and the S&T community creates opportunities to apply commercial AI solutions to solve MDO problems.

As a part of the FSP19, SMEs participating in the AI LoE developed a series of vignettes illustrating the application of AI-enabled capabilities (Appendix A), thereby operationalizing these technologies. These vignettes serve as a start point for the A-AITF to depict and describe the operational employment of these systems.

Implementation Challenges and Vulnerabilities

The FY19 FSP AI LoE discovered multiple implementation challenges and potential vulnerabilities during the TTXs, AI Seminar, and in independent research and external learning events.

Implementation and Development Challenges

Current AI algorithms rely on large samples of data that is clean and curated. Once developers train these algorithms, they work well in controlled environments with access to labeled data. multi-domain operations require AI/ML applications that are capable of learning in complex data environments. These algorithms must work with small sets of heterogeneous data in a contested environment.[54] Additionally, future AI-enabled platforms (and retrofitted legacy systems) must be compatible with data networks.[55] This compatibility is particularly important for the *MDCOP* and *Cooperative Sensing* vignettes previously discussed due to data heterogeneity and potentially inconsistent sensor output. The DoD is taking a step in the right direction towards better data management with the promulgation of the Global Force Management Data Initiative that establishes a common data standard for force structure data.[56] The Joint Force requires similar initiatives for operational data to reduce the burden of curation and better enable AI at the battlefield's edge.

Current AI applications in both the commercial sector and in military applications consume large amounts of computing power and operate in relatively permissive networks that rely on centralized computing power with access to the "cloud".[57] Multi-Domain operations require AI applications that can perform at the point of need with low size, weight, and power, time available.[58] These applications, particularly ones employed on platforms, must account for network instability, time variation, bandwidth constraints, and adversary disruption.[59]

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[54] Tien Pham and Brian Henz, "AI-Enabled Real-Time Situational Understanding at the Tactical Edge" (presentation, Army ATR Workshop, Army Research Laboratory, July 18, 2017).
[55] Coffman, "CFT Kill Web."
[56] United States. DoD. DA. G-3/5/7. DAMO-FME, "Global Force Management Data Initiative Overview (Unclassified/FOUO)" (presentation, Department of the Army, Washington, DC, February 11, 2109). The Army plans to be GFM-DI compliant by 4th quarter 2020.
[57] See Annex C
[58] Pham and Henz, "AI-Enable Situational Understanding."
[59] Brett Piekarski et al., *Distributed and Collaborative Intelligent Systems and Technology (DCIST) Collaborative Research Alliance - Biennial Program Plan*, (Adelphi, MD: Army Research Lab, 2018). 5.

Currently, there is no framework for designing AI enabled systems that can interact with humans.[60] Today's state-of-the-art today AI-enabled systems focus narrowly on well-defined problems.

Current geospatial intelligence and signals intelligence lack the range, resolution, and precision to support targeting.[61] These limitations will also affect the fidelity of an AI-enabled multi-domain common operating picture.

While both the AI Seminar and the preceding TTXs confirmed the need for a joint approach to managing, processing, and curating data, each individual service continues to struggle with interoperability between C2 software and stove-piped surveillance and weapon system development. The joint community must develop, and the Services must implement a synchronized approach that allows the Joint Force to realize fully the advantages of AI-enabled systems.

The security classification of partner data will present significant challenges when developing and implementing multi-national approaches to AI-enabled material solutions.[62] Additionally, data classification will have a deleterious impact on efforts to work with "non-traditional" capability development partners (small business and academia) to realize AI across the force.[63]

Artificial intelligence/machine learning may not always be an appropriate fit as a material solution to a capability requirement.[64] Today's narrow AI is brittle and resource intensive (in terms of data and/or training requirements). The "brittleness" of AI refers to its inability to adapt to changing circumstances. For example, an AI application that optimizes a route based on traffic and overall speed could not necessarily recommend routes based on likelihood of detection. AI-enabled solutions may carry a large "collection burden" i.e. the amount of resources consumed gathering and curating the data may exceed the value of the system's output. Capability developers should exhaust non-AI solutions before pursuing an AI-enabled capability. As one AI Seminar SME observed, "If you have the choice between AI and automation, always go with automation."

Vulnerabilities

A near-peer threat will be capable of creating a degraded, intermittent, and limited environment (DIL) that impairs and, at times, denies communications and data transport.[65] This environment will challenge AI-enabled systems, such as those in the aforementioned vignettes, due to the reliance upon a near-continuous stream of data. On-board AI and autonomous systems will partially mitigate the impact of a DIL environment. Peer threats will likely employ global

[60] Piekarski, "DCIST CRA." 8.
[61] United States. DoD. DA. TRADOC. TCM - Aerial., "MDSS." 7.
[62] Ross Coffman, "CFT Kill Web Effort Synch. Version 3.0" (presentation, Next Generation Cross Functional Team, Warren, MI, June 4, 2019).
[63] Coffman, "CFT Kill Web."
[64] United States. DoD. Joint Artificial Intelligence Center (JAIC)., Joint AI Project - 'Getting Started' Checklist, (Washington, DC: JAIC, n.d).
[65] United States. DoD. DA. TRADOC. TCM - Aerial., "MDSS." 4.

positioning system jammers that could potentially contaminate sensor data, confounding actions and recommendations made by AI-enabled systems.

Insider threat malware and potentially compromised supply chains make AI-enabled systems vulnerable, particularly during the "training phase" of an AI/ML algorithm and during the fielding of an AI-enabled system. The ability to secure networks and algorithms, training data, and training approaches will prove critical when protecting AI-enabled systems from compromise or corruption.

Adversarial attacks through data poisoning and spoofing can degrade or disable an AI algorithm.[66] Attackers can employ generative adversarial networks (GAN) against specific AI algorithms. AI application designers can be mitigate these attacks through adversarial training or defensive distillation; however, the GAN can counterattack these mitigation measures.[67] Pixel-level poisoned data can deceive or defeat image recognition algorithms such as those employed in the cooperative sensing, targeting, and attack vignettes (Appendix A).[68] This attack makes small modifications to an image. Adversaries could launch this type of attack against training data or sensor data that an AI-agent employs.

Conclusion

Artificial intelligence and related technologies are foundational requirements for multi-domain operations. In the future operational environment, near peer competitors will blur the line between peace and war and expand the battlefield in all domains and geography. Additionally, adversaries are proliferating techniques and technologies to employ A2/AD systems and rapidly defeat friendly forces. These trends indicate that the Army and Joint force require AI-enabled solutions to operate at rapid speeds and at large scales to defeat near-peer competitors in large-scale ground combat operations. Artificial intelligence-enabled processes improve current procedures and reduce the time required to conduct tasks and activities, increasing speed of decision-making and operations. These solutions support targeting at large scales, enabling commands to simultaneously converge capabilities across the battlefield and optimize effects.

Realizing the benefits AI contributes to multi-domain operations requires organizing frameworks that define required capabilities, articulate policy changes, and create infrastructure to support AI development. Data management is critical to AI-related research and development. The Joint Force must implement procedures that data and digital modernization strategy documents describe. Researchers and developers must have access to previously collected training and simulation centers data. The Joint Force must develop deliberate procedures for future data collection and disbursement. Furthermore, AI development must move beyond broad visions and concepts, functional decomposition of multi-domain tasks supports the identification and prioritization of AI applications for research and development. Moreover, increased

[66] United States. DoD. Joint Artificial Intelligence Center (JAIC)., "Joint AI Project."
[67] Lydia Kostopoulos, "A New Class of Zero Days and Autonomous Weapons Systems," Medium, last modified December 6, 2018, https://medium.com/@lkcyber/a-new-class-of-zero-days-and-autonomous-weapons-systems-b7d135b727b3.
[68] Horowitz, "The Promise and Peril."

collaboration with the commercial sector enables the Joint Force to leverage innovative research and technologies, but capability developers must be cognizant of the challenges when applying commercial solutions for military applications. Artificial intelligence solutions must be robust and able to support operations in non-permissive environments against adversaries who will contest the electro-magnetic spectrum. Artificial intelligence solutions must also be interoperable with joint and multinational partners, and scalable at echelon. Lastly, commanders and staffs will learn to trust AI with use, but in the near term, AI solutions require the ability to explain the rationale behind recommended actions.

The representative vignettes participants developed in the AI LoE conceptualize how AI enables multi-domain operations and activities. The vignettes demonstrate how AI solutions enable the Joint Force to address key MDO problems to include the penetration and dis-integration of layered A2/AD threat systems. Additionally, convergence of these multi-domain capabilities requires layered and integrated AI solutions. The vignettes provide operational context to the science, technology, and capability development community. Increased operational context allows scientists and researchers to prioritize research, ensure operational relevance, and provide benchmarks to measure effectiveness of their developments.

The AI LoE provided the initial examination into how the Army and Joint Force will operationalize AI for MDO. This paper culminates learning conducted over an 18 month period. The LoE gained an understanding of the operational requirements, benefits, interdependencies, and vulnerabilities associated with AI to inform the MDO Concept and Army Modernization Strategy. The AI LoE supported the A-AITF, which is now developing an operational approach to determine how the Army will integrate and scale AI capabilities. In 2020, the A-AITF will lead the AI LoE for the FY20 Future Study Plan, continuing the work to operationalize AI for MDO and identifying the required AI capabilities and organizational designs of future formations.

Appendix A – Vignettes

This appendix outlines vignettes the AI line-of-effort developed as a part of 2019 Future Study Plan. Participants from across the Joint Force and S&T community conceptualized notional vignettes employing AI solutions to conduct tasks and activities that address key MDO problems. The vignettes depict actions across the MDO framework, to identify required AI solutions and AI-enabled actions in time and space. Each vignette incorporates multiple narrow AI applications that enable specific tasks. The vignettes examine a particular set of AI applications and establish a start point for full operationalization. These vignettes provide a basis for capability developers to construct additional scenarios or vignettes for capability based assessments or concepts of operation. The vignettes provide operational context to the S&T community, creating greater understanding on the required technological capabilities for MDO to inform and shape future research.

Command and Control (MDCOP)

The future force requires processes, enabled by AI/ML, to assist in fusing, disseminating, and visualizing data. Military headquarters and organizations require new command and control (C2) solutions because the scale and scope of combat operations against a near-pear adversary, combined with the overload of combat information and intelligence, will overwhelm staffs. This dynamic may result in commanders and staffs unable to identify fleeting opportunities and losing momentum.

Visual C2 displays must evolve from current methods of depicting forces in time and space to technologies that enable commanders to visualize current and future actions, effects, and functions across domains. MDO requires forces to converge capabilities across all domains, the electromagnetic spectrum, and the information environment. Commanders and staff must be able to visualize this convergence and understand the conditions required to realize this convergence and its effects.[69] AI/ML solutions will allow commanders and staff to visualize and understand across domains, opportunities and liabilities, and enable them to converge capabilities in time and space at rapid speeds and scale.

Figure 6 illustrates a concept for the multi-domain common operating picture (MDCOP). The MDCOP is an AI/ML-enabled tool that enables decision-making, C2, and assessment. The MDCOP employs predictive analytics to project future states such as enemy reactions, sustainment status, and combat power. AI/ML solutions conduct continuous course of action analysis to identify and visualize opportunities and liabilities.

[69] The Center for Army Lessons Learned (CALL) identified this requirement during the Rim of the Pacific (RIMPAC) Exercise 2018. See: United States. DoD. DA. TRADOC. CALL., Multi-Domain Operations: RIMPAC 2018 (UNCLASS//FOUO DIS D), (Fort Leavenworth, KS: CALL, 2018).

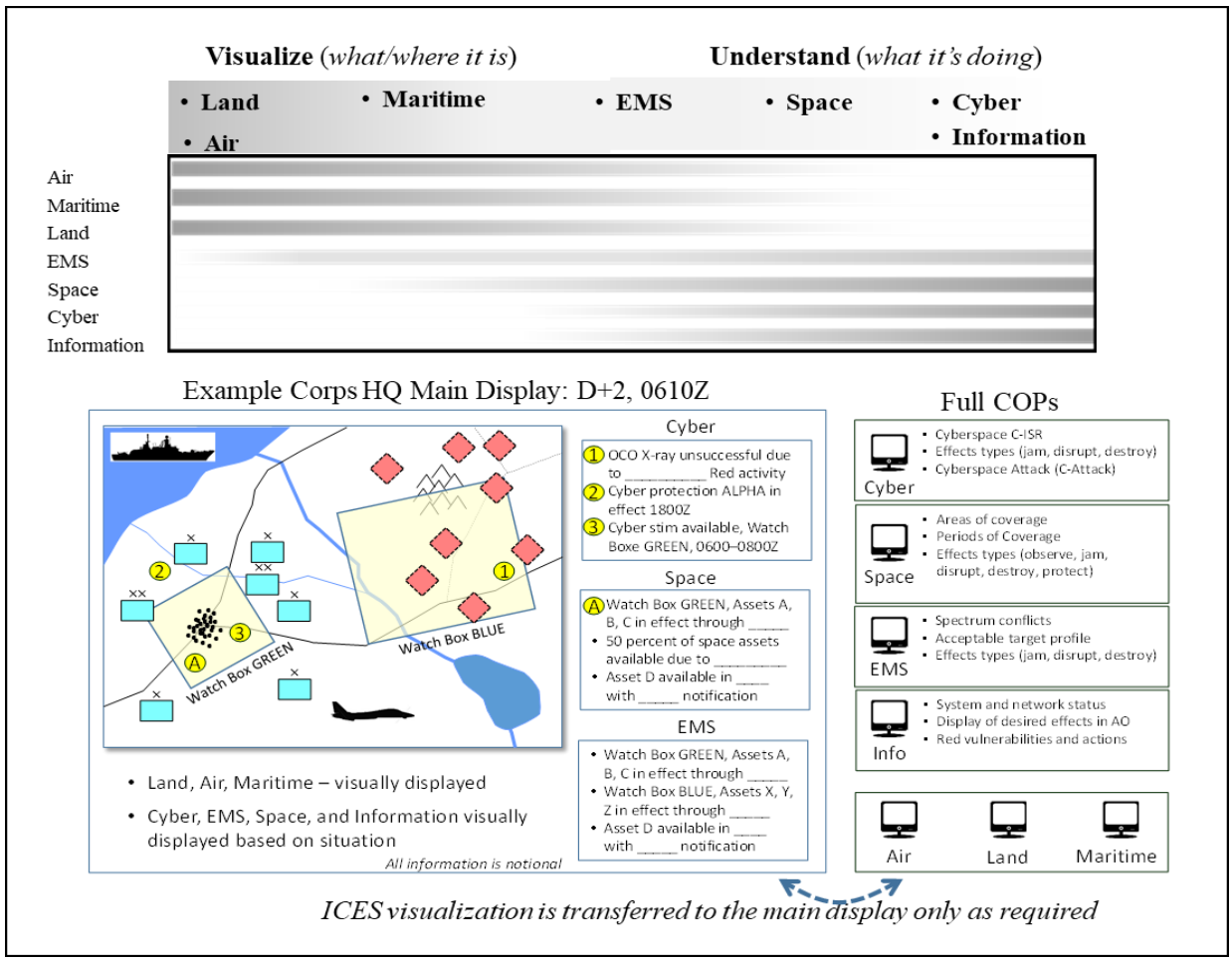

Figure 6: Proposed Multi-Domain COP

The MDCOP uses AI/ML solutions to aggregate data from multiple sources to display information to enable decision making.[70] For example, commanders and staffs require multi-domain information to determine enemy courses of action or to reallocate/redistribute critical supplies. The MDCOP moves beyond a graphic display of forces and instead enables improved understanding of current operations and potential future states.

The MDCOP integrates information and operations across all domains. The user or headquarters element can tailor the MDCOP to the echelon and mission requirements, displaying information relevant to their operations. For example, a sustainment commander's MDCOP may emphasize information related to logistics whereas a maneuver commander's display could highlight ground-based fires and cyber operations. Regardless of the organization, the MDCOP displays information that aids C2 and decision-making.

[70] For a discussion on the need for AI-enabled systems to identify and track friendly and enemy platforms across the battlefield see: Ross Coffman, "CFT Kill Web Effort Synch version 3.0" (presentation, Next Generation Cross Functional Team, Warren, MI, June 4, 2019).

Intelligence, Surveillance, and Reconnaissance (Cooperative Sensing)

The Joint Force is likely to operate in complex operational environments and interact with a diverse range of actors when facing near-peer competitors, requiring accessible, accurate, and timely data to create intelligence products. Intelligence operations ensure a shared understanding of the environment to include friendly forces, host nation partners, civilian populace, and adversarial state and non-state actors. A holistic understanding of the environment is critical to these groups' interaction and generation of coordinated outcomes. The challenge with intelligence operations is quickly processing, evaluating, and disseminating (PED) the intelligence created from the amount of data generated before, during, and after operations. The Army and Joint Force require tools and processes that aid intelligence gathering, filtering, and assessment.

Current Army and Joint intelligence tools, products, and platforms are not suitable for commanders and staffs operating against a near-peer competitor in a dynamic, high-intensity conflict. Existing intelligence databases are manpower-intensive and lack autonomous procedures to ensure continuous updates with current information.[71] Additionally, classification procedures restrict forces' ability to leverage all multi-source intelligence collection processes. Current processors that model and simulation enemy forces are special-purpose and time-intensive, requiring specialized personnel to operate. Furthermore, present-day intelligence, surveillance, and reconnaissance (ISR) platforms lack on-board processing, resulting in the need for humans to review and analyze countless hours of full motion video or imagery. These processes are insufficient for the scope and scale of operations against a near-peer competitor.

Artificial intelligence and machine learning solutions increase the effectiveness and efficiency of intelligence operations. AI/ML-enabled solutions will provide commanders and staffs the ability to create, maintain, and interact with intelligence models to provide relevant depictions of enemy behavior. Predictive analytic tools can create and assess enemy current and future activities, allowing commanders and staffs to focus on countering current enemy actions and anticipating future operations. AI/ML can assist in fusing and analyzing diverse streams of data from all intelligence sources, providing increased situational awareness at all echelons.[72] Lastly, AI/ML-enabled solutions, combined with edge processing, enables ISR platforms to perform onboard analysis and dissemination of data. This process creates faster ISR and targeting processes, reduces requirements for large, bandwidth-intensive network transfers of full motion video, and reallocates intelligent analysts to other tasks. AI/ML solutions improve intelligence operations, situational understanding of the enemy and environment.

[71] Joshua Elliot, "Causal Exploration of Complex Operational Environments," Defense Advanced Research Projects Agency, accessed July 25, 2019, https://www.darpa.mil/program/causal-exploration.
[72] United States. DoD. DA. AFC. FWD., *Operationalizing Artificial Intelligence in Support of Multi-Domain Operations: Findings from the Unified Quest 2019 ISR-Strike Tabletop Exercise*, (Fort Eustis, VA: Futures and Concepts Center, 2018) also Coffman, "CFT Kill Web".

Figure 7 illustrates how the Joint Force could conduct intelligence operations to detect, identify, and determine the location of enemy targets through multi-sensor arrays that operate autonomously.[73]

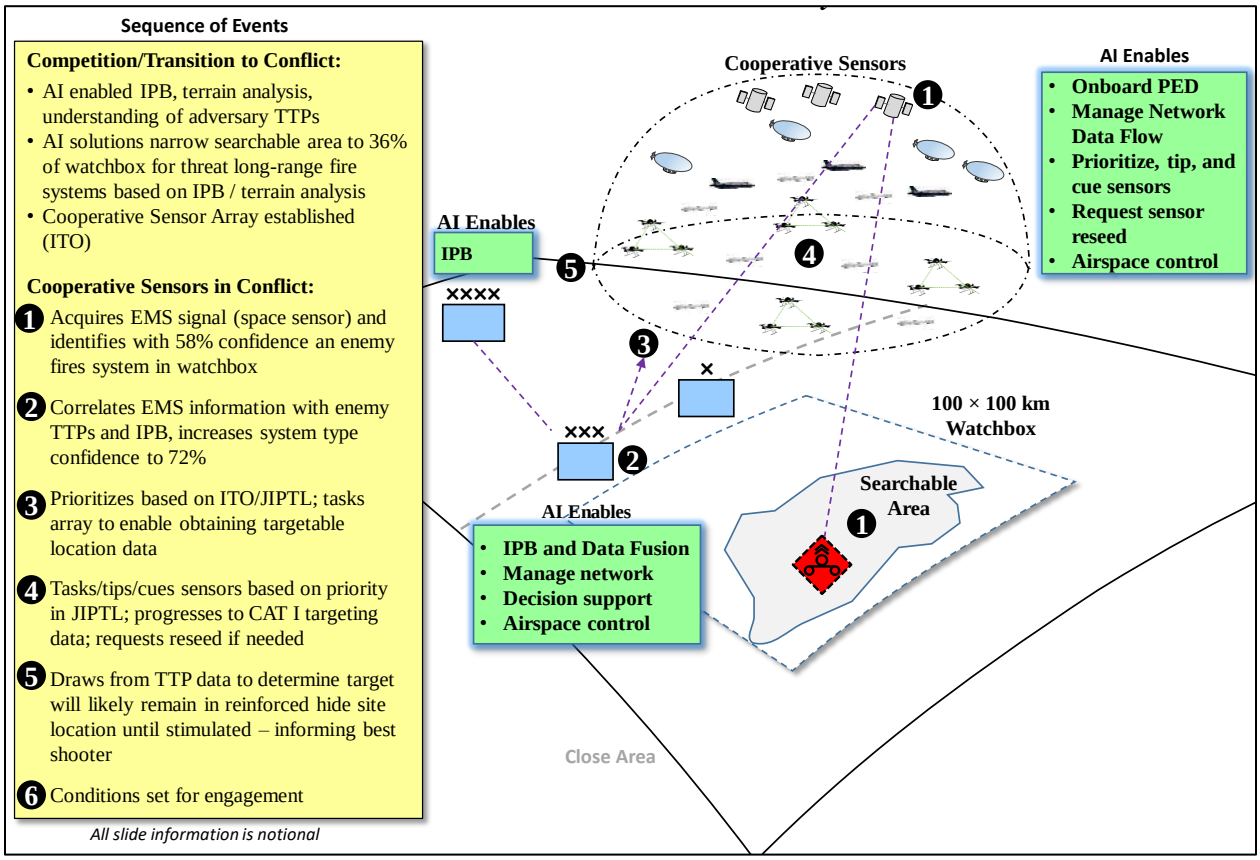

Figure 7: Cooperative-Sensing Vignette

In the vignette, AI-enabled intelligence processes narrow the searchable area for undetected enemy fires system based on terrain analysis, enemy characteristics, and other multi-sourced intelligence. The cooperative sensing process starts with the acquisition of an EMS signal from a space-based sensor. The onboard data processing from the sensor indicates a high probability of an enemy fires system. AI/ML solutions fuse data from multiple databases, collecting information in real time to increase the probability confidence of an enemy fires' system. AI solutions task sensors autonomously to select the best sensor to identify the target's location. Multiple sensors cross-cue each other, exchanging and fusing intelligence data in real time to confirm the target location.

[73] David Spencer, Stephen Duncan, and Adam Taliaferro, "Operationalizing artificial intelligence for multi-domain operations: a first look," Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications, no. 1100602 (May 2019): xx, doi:10.1117/12.2524227. The authors expand on the concept of the Multi-Domain Sensing Systems -1000 by increasing the scope of included sensors (Army and Joint) and relying on autonomous and semiautonomous systems. See: United States. Department of Defense. Department of the Army. Training and Doctrine Command. TRADOC Capability Manager (TCM) - Aerial., *Capability Development Document For Multi-Domain Sensing Systems (MDSS-1000) Increment 1 (Version 0.6)*, (Fort Huachuca, AZ: TRADOC, 2019).

This vignette reveals how AI/ML not only increases the effectiveness and efficiency of intelligence operations, but also transforms the way we gather, process, and disseminate intelligence in the future. The process is faster and increases capacity through a larger pool of sensors to conduct ISR. The process is also different from the way forces currently conduct ISR operations. This ISR operation did not require humans to analyze video feeds to confirm a target. Multiple sensors autonomously select the right sensor and platform to identify the target. Machine learning enables the sensors to improve autonomous ISR operations over time. This process transforms current staff-driven, time-intensive intelligence processes to one that supports operations at the required scales and speeds of MDO.

A cooperative sensing system will provide ISR to all echelons allowing those commands to gain, maintain, and exploit situational understanding.[74]

Sustainment

Future conflict against near-peer competitors in high-intensity conflict requires the Army and Joint Force to sustain its forces at unprecedented speed and scope. The future operating environment consists of a near-constant demand for commodities, fuel and ammunition in particular, and an enemy capable of targeting logistical nodes and routes across the MDO framework. The dynamic nature of future operations creates demands beyond the human cognitive ability to process, anticipate, and synchronize sustainment operations. Sustainment operations must be agile and responsive to support operations throughout the MDO framework.[75]

Current sustainment processes are neither responsive nor dynamic enough for MDO. Latent resupply requests and fulfillment procedures drive current resupply request processes. Command relationships determine what forces conduct sustainment operations, not the organization most readily available to support. Current sustainment operations use pre-planned sustainment consumption and usage rates, created by human-based, time-intensive logistics database programs based on historical data or professional experience. Current programs lack the ability to account for new sustainment information based on current operations, technological improvements, or dynamic changes in the environment.

Future sustainment operations require processes supported by AI solutions. Specifically, the MDO concept identifies the requirement for AI/ML-enabled sustainment operations employing predictive analytics to analyze historical and current data and anticipate future sustainment requirements. Sustainment forces require a real-time MDCOP enabled by AI/ML to account for and track commodities. AI/ML solutions enable sustainment forces to determine the right formation, assets, and route to optimize sustainment operations. Collectively, this process creates precision logistics.

The future force requires sustainment that can anticipate and deliver logistics to the point of need. Management systems, resource visibility, and situational awareness provide the flexibility

[74] United States. DoD. DA. TRADOC. TCM-Aerial., "MDSS-1000."
[75] United States. DoD. DA. AFC. FCC. FWD., *Operationalizing Artificial Intelligence in Support of Multi-Domain Operations: Findings from the Unified Quest 2019 Sustainment and Protection Tabletop Exercise*, (Fort Eustis, VA: FCC, 2019). 2.

to adjust concepts of sustainment in real time. Access to AI-enabled decision-making programs and the MDCOP allows the operational commander to adjust sustainment operations and the necessary support, such as convoy escorts, in real time.

The AI-enabled sustainment vignette (Figure 8) illustrates precision logistics across the sustainment enterprise from the Strategic Support Area (e.g., ships arriving from the continental United States) to forces in the Close Area engaging enemy forces.

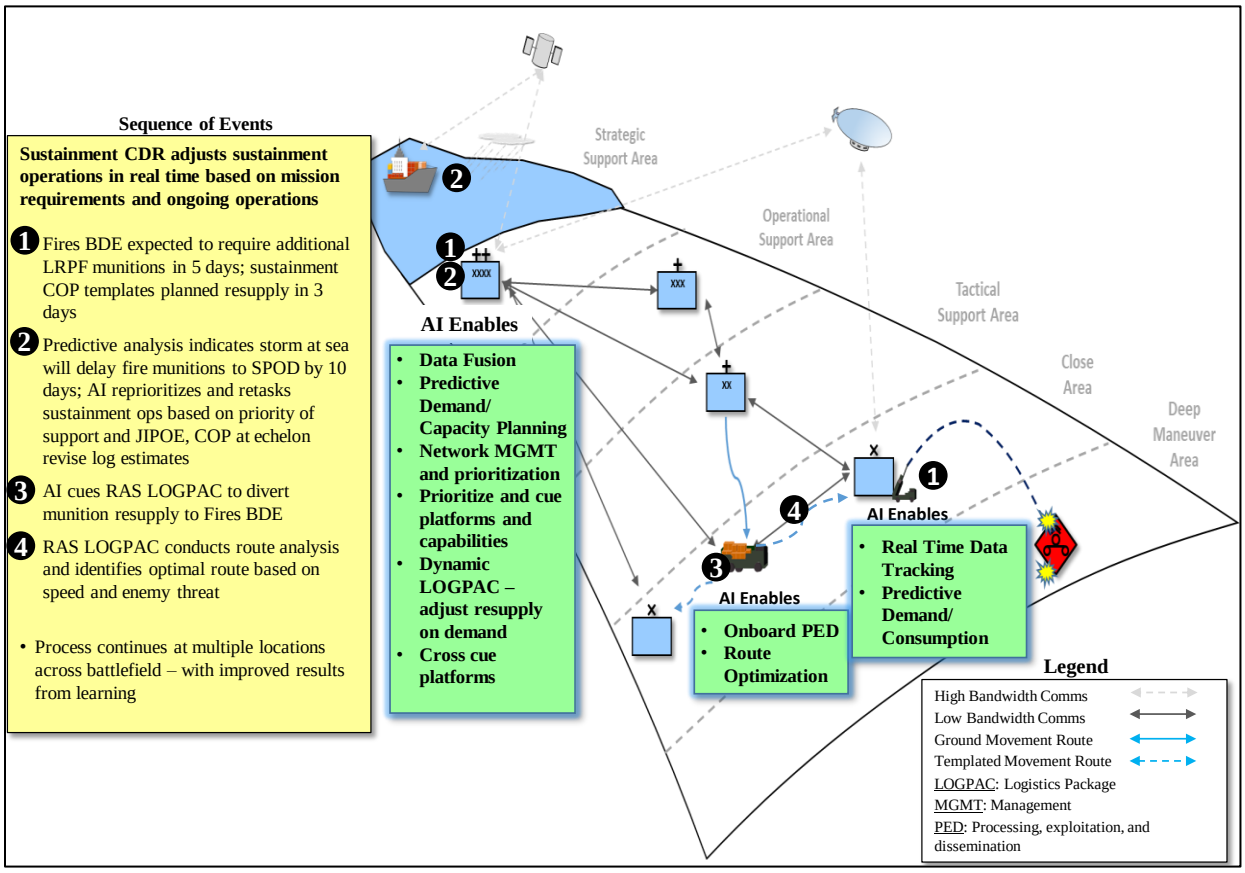

Figure 8: AI-Enabled Sustainment Vignette[76]

This vignette starts with friendly forces in the Close Area conducting fire missions against enemy forces using priority munitions tracked by the theater sustainment headquarters. AI/ML solutions process key munition inputs to include current on-hand supplies and rates of fire to create predictive consumption rates. This information generates an ahead-of-time resupply request based on an upcoming maritime munitions resupply.

However, storms at sea delay the arrival of additional priority munitions. To overcome this issue, AI/ML solutions recommend dynamic resupply of priority munitions by reprioritizing on hand

[76] Currently the Army is pursuing leader-follower technology, one of the first potential uses of this AI-enabled technology is resupply operations. See: Andrew Feickert et al., *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress*, (Washington, DC: Congressional Research Service, 2018). 23.

munitions. AI/ML solutions cue a current logistical resupply convoy to change its route to resupply the fires element. AI/ML solutions update the MDCOP so all sustainment organizations are aware of the AI system-directed actions.

The vignette demonstrates how AI/ML solutions increase the effectiveness and efficiency of sustainment operations.

Protection

Army doctrine states that protection is the preservation of the force so commanders can apply maximum combat power to accomplish missions.[77] However, preservation of the force is more than protecting troops. Friendly forces must protect critical infrastructure, digital networks, lines of communication, host nation partners, and civilians. Consequently, in high-intensity conflict against a near-peer competitor, threat forces will employ multi-domain attacks across the MDO framework at these targets to stress our protection capabilities.[78] Compounding the issue is the challenge of planning, integrating, and synchronizing diverse and dispersed forces with requirements to conduct protection operations.[79]

Current protection processes are insufficient for multi-domain operations. Currently, Joint Forces lack the ability to integrate joint and host-nation protection operations and capabilities.[80] Staff processes to identify, assess, and prioritize critical asset lists are manual and time-intensive. Protection assets are generally static, resulting in forces lacking the ability to adjust rapidly protection assets and capabilities on the battlefield, as required. These processes are inadequate to conduct protection operations at the scale and scope of high-intensity conflict against a near-peer competitor.

Artificial intelligence and machine learning increases the effectiveness and efficiency of protection operations. AI/ML solutions will prioritize protection of critical assets by conducting autonomous analysis, utilizing multiple evaluation criteria to determine the right protection capability when needed. Autonomous surveillance utilizing AI/ML multi-spectral recognition identifies and confirms targets beyond visual confirmation. AI/ML solutions can identify digital network anomalies and conduct autonomous cyber defensive measures to protect the network at a scale beyond human capacity.

Artificial intelligence already demonstrated its potential in the protection function as the Patriot Missile system was one of the first platforms to employ AI solutions. This semi-autonomous system can detect and engage targets without a human-in-the-loop as required. The following vignette identifies how AI/ML will increase the effectiveness of protection operations.

Figure 9 conceptualizes how AI/ML enables protection operations to provide the right protection asset and capability when required. In this vignette, Army forces provide protection support as the Air Force attempts to establish an “adaptive base”.

[77] United States. DoD. DA., ADP 3-37, *Protection*, (Washington, DC: DA, 2018). IV.
[78] United States. DoD. DA. AFC. FCC. FWD., "Sustainment and Protection TTX." 3.
[79] United States. DoD. DA., "Protection." IV.
[80] United States. DoD. DA. AFC. FCC. FWD., "Sustainment and Protection TTX." 5.

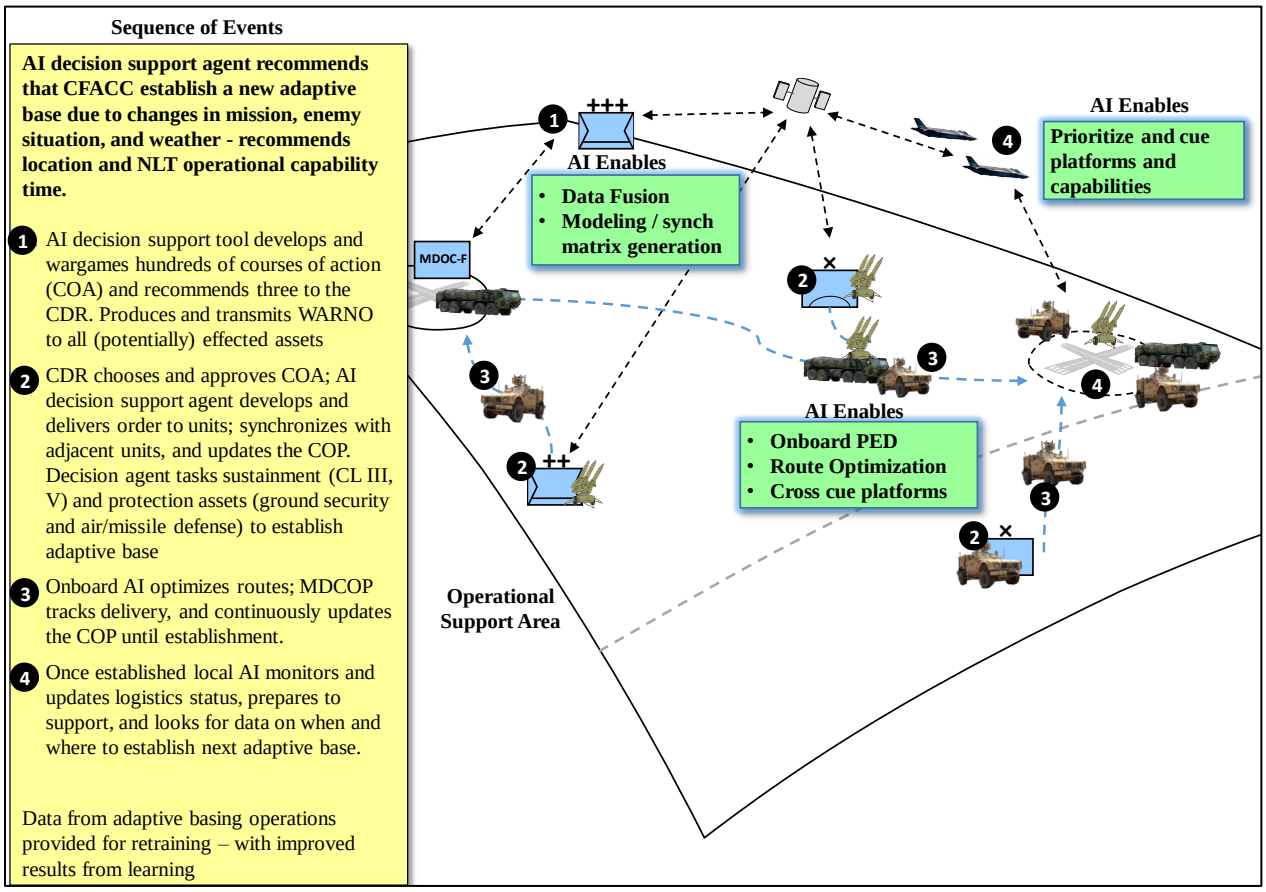

Figure 9: Army Support to Adaptive Basing

This vignettes starts with the Air Force decision to establish a new adaptive base and requires Army ground security escort, air and missile defense support. An AI/ML-enabled decision support tool conducts autonomous course of action (COA) analysis, analyzing current missions, available assets, enemy situation, and location of the new air base. Based on this analysis, the AI/ML-enabled decision support tool recommends three COAs to the Army commander for decision.

Following the commander's decision, the AI/ML solutions transmit the order to the effective units with a synchronization matrix to coordinate movement. On-board vehicular AI/ML solutions develop optimized routes to time and synchronize the arrival of security forces with air and missile defense assets. Once friendly forces establish the adaptive base, the MDCOP depicts the new air base and tracks logistic requirements to sustain it. The MDCOP captures data from the adaptive base operation for machine learning and AI algorithmic retraining to improve future results.

This vignette demonstrates how AI enables the planning, integrating, and synchronizing diverse and disaggregated forces to increase the effectiveness of protection operations.

Movement and Maneuver

The reemergence of near-peer threats signifies the need for formations at echelons above brigade (EAB) to maneuver so the joint force can prevail in large-scale combat.[81] These formations require the ability to maneuver to achieve positions of relative advantage at unprecedented speeds and across the breadth of the battlefield framework.[82] The future force requires the ability to orchestrate movement and maneuver of ground, aerial, manned, and unmanned platforms across time and space to create and exploit windows of superiority. Additionally, deception operations and obscuration have renewed importance given the need to achieve effects across domains. Multi-domain operations require Army forces to employ seamlessly organic and joint multi-domain capabilities to penetrate, dis-integrate, and exploit enemy systems and forces.

The MDO EAB Concept indicates that current EAB formations lack the agility and versatility required to conduct large-scale combat operations.[83] The inability of forces to conduct large-scale maneuver is partially due to the lack of sufficient MDC2 systems and solutions to orchestrate and synchronize complicated tasks. Commanders and staff risk cognitive overload in a coordinate the maneuver and fires of large formations. Additionally these organizations lack the capability to maintain situational awareness, particularly in EMS-contested environments. The future forces require solutions enabled by AI/ML to conduct movement and maneuver at the scale and speed required of MDO in high-intensity conflict. AI/ML solutions and edge processing enable the synchronization and coordination of EAB formations operating across the depth and breadth of the MDO framework in network-degraded environments. Ground and aerial platforms, enabled with edge processing, will have access to the MDCOP that can operate as part of a network, or locally. Access to the MDCOP enables commanders at all echelons to maintain situational awareness and converge capabilities. In addition, AI/ML-enabled systems will link sensors directly to shooters reducing coordination requirements and the cognitive load placed on commanders and staffs. Deception operations tailored to target enemy commanders across echelons will cause the enemy to prematurely unmask capabilities and misread friendly forces plans and intent. Moreover, the proliferation of robotic and autonomous systems demands AI-enabled C2 systems that can employ and control these systems during operations. Artificial intelligence/ML solutions provide the Army with the agility and versatility they require in the future operational environment.

Echelons above brigade formations in high-intensity conflicts against a near-peer competitor require the capabilities and capacities to:

- gain and maintain contact to reveal enemy dispositions
- posture for large-scale ground combat

[81] United States. DoD. DA. TRADOC., TRADOC Pamphlet 525-3-8. US Army Concept for Multi-Domain Operations at Echelons Above Brigade 2025-2040, (Fort Eustis, VA: TRADOC, 2018). i.
[82] The movement and maneuver warfighting function includes the following tasks: move, maneuver, employ direct fires, occupy an area, conduct mobility and counter mobility, conduct reconnaissance and surveillance, and employ battlefield obscuration. See: United States. DoD. DA., *Army Doctrine Reference Publication 3-0. Operations*, (Washington, DC: DA, 2016). 5-4.
[83] United States. DoD. DA. TRADOC., "MDO at EAB." 6.

- converge multi-domain capabilities to achieve desired effects
- exploit the initiative to defeat enemy formations.[84]

Artificial intelligence solutions will enable these required capabilities. The AI-enabled movement and maneuver vignette (Figure 10) conceptualizes the actions and required capabilities EAB formations use to conduct offensive operations.

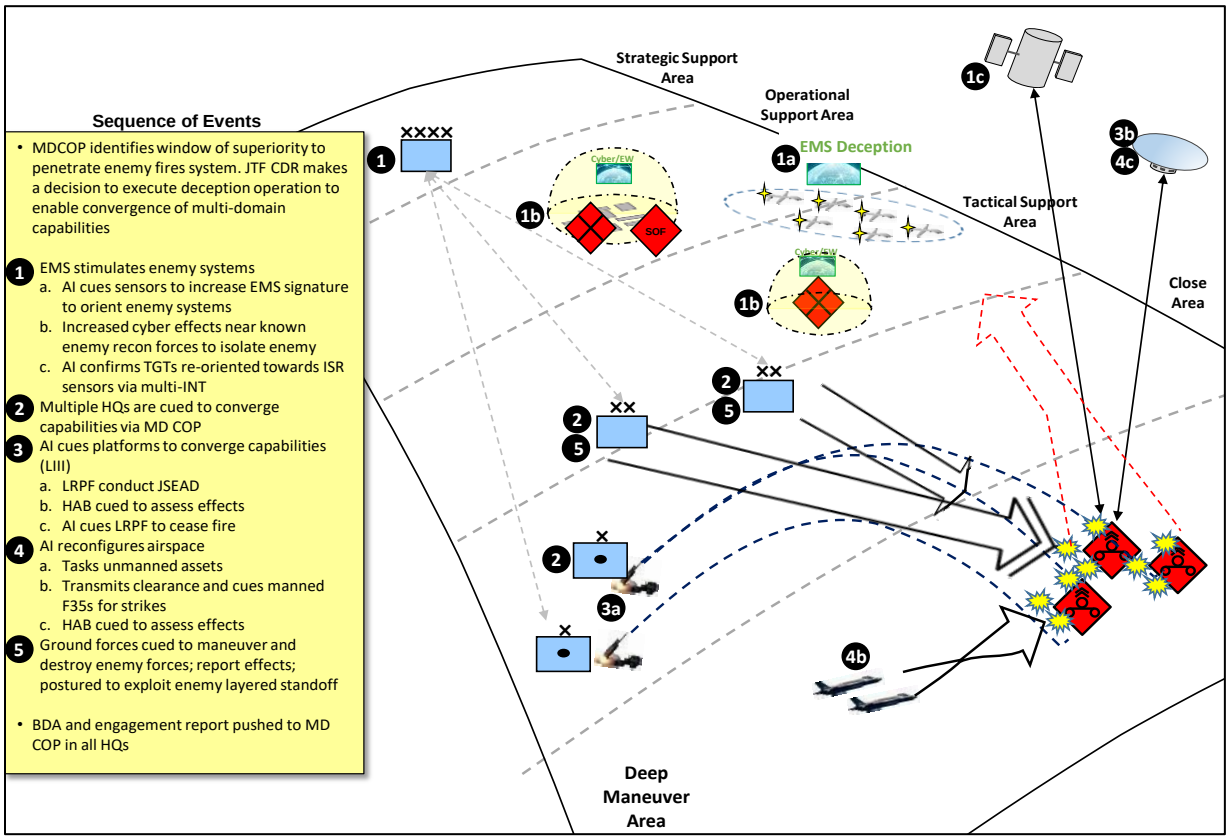

Figure 10: AI-Enabled Attack

This vignette starts with the field army commander's decision to deceive the enemy force as to the timing and direction of an attack. Autonomous unmanned aerial systems create false electro-magnetic signatures causing the enemy to react with detection and fires platforms. Machine learning enables the UAS to adjust their deception based on the enemy reaction. AI-enabled systems orchestrate cyber and electronic warfare operations to increase enemy confidence in the deception. Satellite and high-altitude sensors confirm the enemy's response. The actions provide the field army commander with a window of superiority to begin the attack.

Artificial intelligence/ML synchronization tools coordinate actions to enable the field army commander to focus on ground maneuver. Fires management systems, enabled by AI/ML, orchestrate the suppression of enemy forces and cues aerial and space-based sensors to assess the effects of converging fire and maneuver. Mission command AI/ML systems optimize airspace

[84] United States. DoD. DA. TRADOC., "MDO at EAB." iv.

allowing ground fires and joint aerial attack assets to converge effects, while aerial sensors continue to assess battlefield deconfliction and fires effects.

Artificial intelligence/ML enables commanders and staffs to analyze sensor data, assess the effectiveness of initial operations, and determine whether operations met the field army commander's intent. Based on that assessment, the field army commander orders the ground attack, employing forces equipped with the AI-enabled Next Generation Combat Vehicle and the Robotic Combat Vehicle.[85] Subordinate commands employ edge processing to maintain situational awareness and identify localized windows of domain superiority. Artificial intelligence/ML continuously adjusts the plan to ensure convergence at the decisive point.

This vignette demonstrates the how AI/ML solutions provide army formations with the capabilities they require to conduct multi-domain operations in large-scale combat.

Fires

High-intensity conflict against a near-peer adversary demands the ability to synchronize fires and effects across echelons, domains, and amongst joint and multinational partners. As discussed in this report, near-peer adversaries will employ anti-access and area denial (A2/AD) systems to create layered standoff against U.S. forces.[86] The Multi-Domain Operations Concept describes an approach to defeat this layered standoff by penetrating and dis-integrating A2/AD systems. The ability to deliver multi-domain fires at speed and scale is critical to future force success. Army and Joint Forces must employ fires at precise times and locations, and at speeds and scales beyond human cognitive capacity. The current force lacks the ability to adjust control measures rapidly to optimize airspace use and converge effects ground fire assets deliver, fixed-wing systems, and unmanned aerial platforms. Assignment of fire missions is more a product of fires systems' availability than the ability to achieve the desired effect at the time and location of maximum effect.

Artificial intelligence and machine learning will enable the future force to deliver fires at the speed, scale, and precision demanded in future conflict.[87] Artificial intelligence/ML solutions will enable sensors to coordinate efforts to increase the reliability of target identification and battle damage assessments. AI algorithms processing inputs, such as priority target lists, weather, terrain, time, and distance, can recommend the best joint shooter in real time. Artificial intelligence/ML solutions adjust fire control measure dynamically to allow the convergence of capabilities at the point of need. As required, AI/ML solutions enable dynamic targeting processes, allowing forces to execute fully autonomous targeting processes from sensor to shooter.

[85] See Andrew Feickert et al., *U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress*, (Washington, DC: Congressional Research Service, 2018) for discussion on the NGCV and RCV.
[86] United States. DoD. DA. TRADOC., "Multi-Domain Operations." 11-12.
[87] United States. DoD. DA. AFC. FWD., "ISR-Strike TTX." 3. See also United States. DoD. DA. TRADOC., "TRADOC PAM 525-3-8." 24.

Multi-domain operations will occur at scales beyond the Army's recent experiences in Afghanistan and the Middle East. Future forces require the capability to deliver effects across the MDO framework to penetrate and dis-integrate enemy A2/AD systems. AI/ML-enabled solutions allow the Joint Force to converge capabilities to attain positions of advantage.

The AI-enabled fires vignette (Figure 11) illustrates a fully-automated targeting process, employing multiple organizations, assets, and capabilities to rapidly target, engage, and assess enemy A2/AD systems.

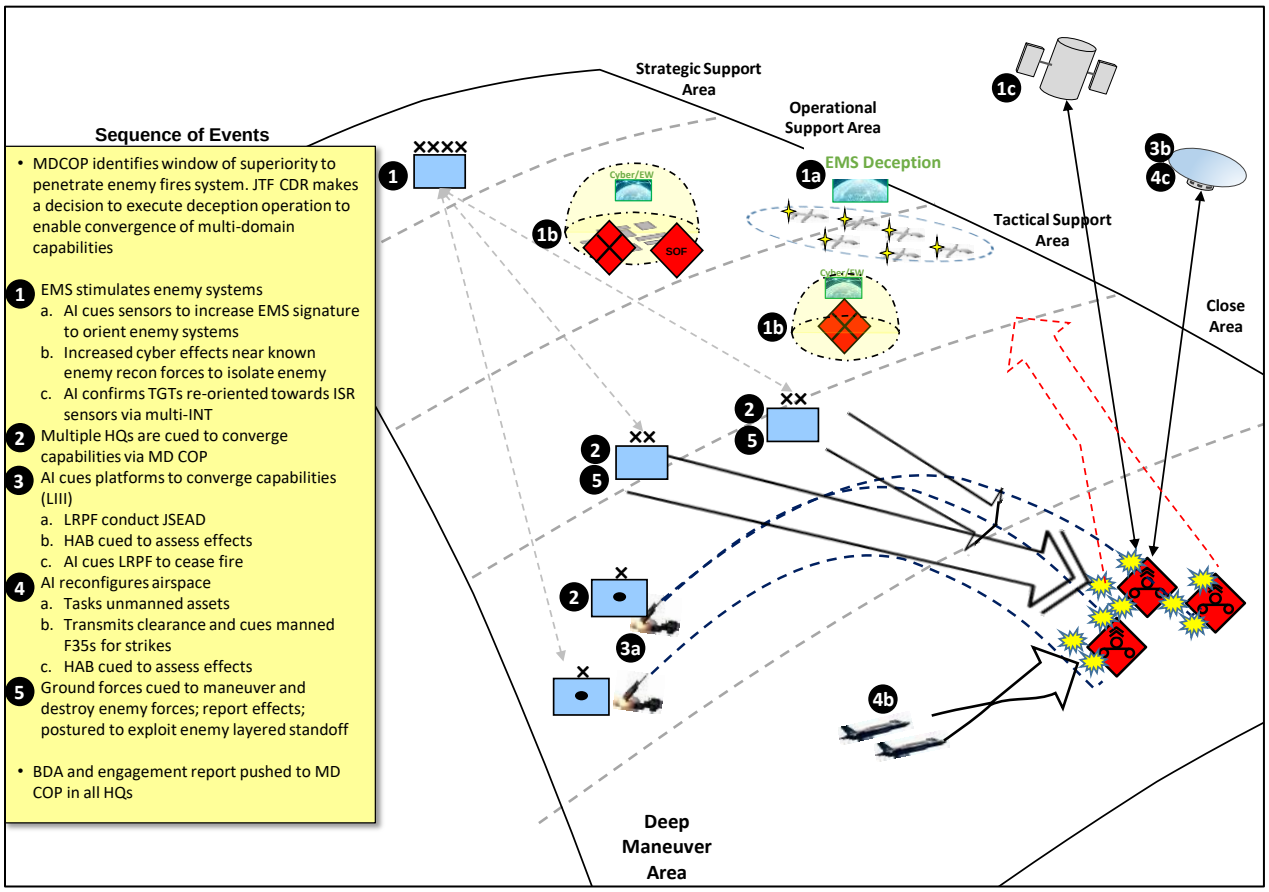

Figure 11: AI-Enabled Targeting

This vignette begins when the Joint Task Force commander decides to conduct an AI/ML-enabled fully autonomous targeting sequence. Upon initiation, autonomous cyber systems stimulate a target that is under the observation of a low-earth orbit satellite. The satellite's on-board AI fuses this data with other multi-intelligence data to develop a target location.

Upon target identification, AI/ML solutions continue to enable the targeting and engagement process. Based on current enemy information and environmental factors, AI/ML solutions select an Army long-range precision fire system as the best shooter. Next, AI/ML solutions cue a high-altitude balloon to observe and asses the strike. AI/ML solutions then task loitering munitions to move to the vicinity of the targeted system and re-engage as required. Simultaneously, an AI/ML-enabled fire control measure reconfigures the airspace and adjusts the maneuver of aerial

platforms. Following the fire missions, AI/ML-enabled logistic systems direct resupply operations of key munitions.[88]

Humans can conduct the tasks in the above vignette, but at limited scales. High-intensity conflict against a near-peer requires forces to rapidly and accurate converge capabilities at scale. This vignette conceptualizes how AI/ML solutions enable fires operations for multi-domain operations.

Artificial intelligence-enabled fires will depend upon intelligence, surveillance, and reconnaissance from an AI-enabled collective sensor system or similar system.[89] Additionally a network-enabled mission command system enables situational understanding of friendly and enemy at the tactical and operational level.[90] This network must link "sensors" to "shooters." The common operating picture will reduce the time the targeting process consumes to manually clear fires and manage air space.

[88] Spencer, Duncan, and Taliaferro, "AI for MDO, A First Look" 5. Resupply operations would likely employ AI-enabled leader follower technology and potentially a larger scale version of the Squad Multi-purpose Equipment Transport (SMET). See Feickert, "US Ground Forces." 22-24.
[89] United States. DoD. DA. TRADOC. TCM - Aerial., "MDSS." 1.
[90] United States. DoD. DA. TRADOC. TCM - Aerial., "MDSS." 1.

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Appendix C - Acronyms

A2/AD – Anti-Access and Area Denial
A-AITF – The (US) Army Artificial Intelligence Task Force
ADP – Army Doctrinal Publication
AFC – (The U.S.) Army Futures Command
AGI – Artificial General Intelligence
AI – Artificial Intelligence

CSA – Chief of Staff of the (US) Army

DIL – Degraded, Intermittent, and Limited
DoD – (The US) Department of Defense

EAB – Echelons Above Brigade
EMS – Electromagnetic Spectrum

FCC – (The US Army) Futures and Concepts Center

GAN – Generative Adversarial Networks

HAB – High Altitude Balloon
IADS – Integrated Air Defense System

LoE – Line of Effort
LTG – Lieutenant General

MDC2 – Multi-Domain Command and Control
MDCOP – Multi-Domain Common Operating Picture
MDMP – Military Decision Making Process
MDO – Multi-Domain Operations
ML – Machine Learning
MRL – Multiple Rocket Launcher

OE – Operational Environment

PED – Process, Exploit, and Disseminate

SAM – Surface-to-Air Missile
SRBM – Short Range Ballistic Missile
SWaPT – Size, Weight, and Power, Time available

TTX – Tabletop Exercise

UAS – Unmanned Aerial Systems

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Appendix D - Lexicon

Artificial intelligence (AI) – the ability of machines to perform tasks that normally require human intelligence.[91] *See also Narrow AI and General AI.*

Artificial Neural Networks (ANN, also referred to as Neural Networks) – software loosely model after the neuronal structure of the mammalian cerebral cortex. Nodes are organized into layers: input, hidden, and output. Input layers roughly correspond to photoreceptors in the retina. Hidden layers are like the neurons that process signals from the retina and pass those signals to the visual cortex. Output layers correspond to the visual cortex. Simple ANNs have a single hidden layer. ANNs with two or more hidden layers are capable of deep learning; such ANNs can process more complex data sets than ANNs having only one hidden layer. Deep learning currently provides the best solutions to problems in image and speech recognition, and natural language processing (NLP).[92]

Cloud – A network of remote servers that operate as a single ecosystem. Individual serves are designed to store and manage data, run applications, or deliver content or a service.[93]

Deductive Learning - knowledge-based machine learning techniques that starts with the series of rules and infers new rules that are more efficient in the context of a specific AI algorithm.[94]

General AI - system that exhibits intelligence comparable to that of a human or beyond, across the range of contexts in which a human might interact.[95]

Inductive Learning - knowledge-based machine learning techniques to infer an explainable model from any model as a black box.[96]

Machine Learning (ML) – uses 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.[97]

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[91] United States. Department of Defense (DoD)., *Summary of the 2018 Department of Defense Artificial Intelligence Strategy: Harnessing AI to Advance Our Security and Prosperity*, (Washington, D.C.: DoD, 2019), 5.
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Multi-Domain Command and Control (MDC2) – Command and control across all domains that protects, permits, and enhances the conduct of operations to create desired effects at the time, place, and method of choosing.[98]

Multi-Domain Operations (MDO) – Operations conducted across multiple domains and contested spaces to overcome an adversary's (or enemy's) strengths by presenting them with several operational and/or tactical dilemmas through the combined application of calibrated force posture; employment of multi-domain formations; and convergence of capabilities across domains, environments, and functions in time and spaces to achieve operational and tactical objectives.[99]

Narrow AI - applications that provide domain-specific expertise or task completion.[100]

Neural Networks – see Artificial Neural Networks

Reinforcement learning – a feedback-based machine learning technique that acts in an environment to maximize rewards.[101]

Supervised learning – a feedback-based machine learning technique that teaches desired behavior with label data.[102]

Unsupervised learning – a feedback-based machine learning technique that makes inferences without labeled data.[103]

[98] Aaron Sprecher and Sameek Parsa, "Gateway to Multi-Domain Command and Control: The E-3A Final Lifetime Extension Program, "*Transforming Joint Air Power - The Journal of the JAPCC* 25 (Winter 2018): https://www.japcc.org/wp-content/uploads/JAPCC_J25_screen.pdf. 13-15.
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[102] Ladas, "AI & ML ERA."
[103] Ladas, "AI & ML ERA."

Appendix E – Subject Matter Expert Contributing Organizations

Assistant Secretary of the Army (Acquisition, Logistics, and Technology) - ASA(ALT)	The MITRE Corporation
Forces Command	Special Operations Command
Concept and Capabilities Development Command • Army Research Lab • C5ISR	United States Air Force • A5 • A23 • Air Combat Command
TRADOC • G2 • G26 (Threat Emulation Force) • G27 • Centers of Excellence • Capability Manager – Mission Command Capability Manager – Maneuver Support	The Army Futures Command (AFC) • Army – Artificial Intelligence Task Force (A-AITF) • Cross Function Team (CFT)– Next Generation Combat Vehicle • CFT – Long Range Precision Fires Armaments Center
Futures and Concepts Center (FCC)	The USMC Warfighting Lab
The US Army Intelligence and Security Command	The RAND Corporation
The University of Southern California Institute for Creative Technologies	LMI
The United States Army War College	United States Army Special Operations Command
Department of the Army G4	Space and Missile Defense Command
Multinational Partners from: • Australia • Canada • Denmark • Germany • Italy • Netherlands • Singapore • The United Kingdom	Health Readiness Center of Excellence

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Find this and other Future Warfare Study reports supporting Multi-Domain Operations concept development at: https://dodtechspace.dtic.smil.mil/dodtechspace/groups/fwd-support-to-MDO-development

For additional information on the Unified Quest Future Study Plan
contact Future Warfare Division, Futures and Concepts Center,
U.S. Army Futures Command, Fort Eustis, Virginia 23604