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Discovering Leap-Ahead Technologies for Future Military Teaming

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14. ABSTRACT
A novel business model was developed to discover and deliver leap-ahead technologies that will enable mixed teams of Soldiers and artificial intelligence to perform effectively in complex Multi-Domain Operation environments. This business model re-envisions strategy development, research partnerships, and transition plans to create a new Science and Technology ecosystem within the framework of a new collaborative research program, Strengthening Teamwork for Robust Operations in Novel Groups (STRONG). This report describes the scientific background, development of strategy, approaches to partnerships, and transition to address the current challenge as well as position the Army for the future.

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1. Introduction

The recent emergence and widespread application of artificial intelligence and machine learning (AI/ML) is leading to a fundamental revolution in the way that society functions on all levels across the globe. Digital assistants; "smart" homes, workplaces, and cities; manned and unmanned vehicles; decision-making tools; and intelligent networks rely heavily on AI. As such, AI-enabled technologies and agents are becoming fundamental to life experience. Harnessing the ongoing acceleration in AI and autonomous technologies are two of the Army's top priorities (US Army 2019).

The emerging Operational Environment (OE) precipitates the need for re-envisioning the ways and means by which the Army fights as a member of the joint force (US Army 2019). The proposed operating concept, Multi-Domain Operations (MDO), requires simultaneous maneuver in all domains and across echelons (US Army Training and Doctrine Command 2018). AI/ML is seen as a core enabling capability for realizing this vision. According to the Army AI Strategy, AI will enable planning and decision-making as well as provide autonomy to virtual and physical agents. Incorporating these AI-enabled capabilities into training and doctrine will require reassessing and reimagining the roles of Soldiers on the battlefield. The rapid fielding of new technologies to the fighting force as envisioned in the Army Modernization Strategy will require Soldiers and systems to adapt together. This evolution will have to happen in the context of a rapidly evolving OE, where adversaries develop technologies and adapt tactics in parallel. Novel intelligent, adaptive technologies are envisioned to increase our speed and agility to incorporate new capabilities and respond to emerging threats in this environment. Inherent in this future vision is a paradigm shift to AI-enabled technologies functioning more as "teammates" to Soldiers than as tools for Soldiers.

Intelligent Technologies as Teammates. The US Department of Defense (DOD) AI Strategy identifies a need for future military teams to be equipped with an array of intelligent and networked technologies that anticipate the needs of the team and make decisions both independently and in coordination with their human teammates (DOD 2018a). We expect the future to include intelligent agents of various forms and functions that can learn, adapt, interact, and make decisions along with human counterparts. This vision includes intelligent agents that build and maintain rich representations of individuals, groups, and the environment; infer others' goals and predict actions; and aid missions through targeting actions and interventions at appropriate times to enhance performance and effectiveness.

Effectively adapting our military operations to incorporate novel human–AI interactions presents a multitude of complexities beyond current knowledge or human experience. Currently, Soldier teams rely on core capabilities inherent to human intelligence, including effective adaptability, creativity, common sense, forethought, heterogeneous approaches to decision making, and leadership. These attributes, while extremely valuable for teams to sustain functionality and capability in dynamic, adaptive, and complex environments, are *not* strengths of AI. The rapid evolution of AI/ML technologies without commensurate development of new models for human–AI interaction and the nature of teamwork stands to limit the effectiveness of these new capabilities and potentially leads to unintended or even disastrous consequences. In a domain of operations where teamwork is so critical, having teammates incapable of supporting team behavior would be devastating.

The US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) believes team performance can be revolutionized by technologies that understand and adapt how performance emerges from the information flow, processing, and behavior of each individual team member (Mait et al. 2017, p. 15–19). We know that team outcomes are not simply the sum of the individual team members. Instead, emergent team-level phenomena, such as shared mental models and team cognition; team efficacy and cohesion; and collaboration, decision-making, and collective action are the most proximal determinants of team effectiveness. These emergent team-level states and processes manifest nonlinearly from the bottom-up through a combination of individual dynamics, processes, and interactions (Kozlowski et al. 2013). A real-time understanding of how individual dynamics and team interactions influence emergent team properties and performance can be used to enable adaptive performance and effectiveness in the most complex environments. Specifically, the DEVCOM Army Research Laboratory envisions the capability to individualize the application of resources in the most effective manner at the time of need to enhance the performance of the collective. In Soldier–Soldier teams, this type of understanding and adaptability is inherent to human intelligence, unit-focused training, and experience over time. ARL aims to extend this critical capability to Soldier–AI teams and reduce the time needed to become a high-functioning team that is adaptive to internal and external changes and remains agile as the mission unfolds in complexity.

ARL has undertaken the challenge to discover and deliver leap-ahead technologies that will enable mixed teams of Soldier and AI to effectively perform in complex MDO environments. In the following sections we discuss a novel business model that aims to grow this Science and Technology (S&T) ecosystem within the framework of a new collaborative research program, Strengthening Teamwork for

Robust Operations in Novel Groups (STRONG). With the reorganization of Army S&T under Army Futures Command, ARL recognized the limitations of previous practices and proactively focused on factors influencing future impact. The new business model re-envisions strategy development, research partnerships, and transition plans. Focused on attributes deemed critical by the National Defense Strategy (DOD 2018b), including *failing fast* and targeting *high-impact transitions*, this business model is specifically aimed at creating a new scientific ecosystem that will undertake the current challenge as well as position the Army for the future.

2. Strategy Development

ARL believes it can revolutionize unit effectiveness through adaptive teaming between Soldiers and AI. By combining scientific and technical advances in individual Soldier sensing, AI, unit performance, autonomous maneuver, and human–robot interaction, ARL will develop the foundation for technologies that link individual dynamics to emergent teamwork. To begin, a research strategy to guide the development of the S&T ecosystem and set a vision for these potential future technologies is critical. Within this context, several challenges must be overcome in developing this strategy. First, achieving collective solutions to military problems requires concentrating the efforts of researchers with the right technical capabilities. However, the interdisciplinary nature of the problem requires building understanding of the vision across diverse scientific disciplines (e.g., computer science, biology, psychology, robotics, engineering, mathematics, business, and linguistics). Barriers currently exist between these fields, making it difficult for cross-disciplinary synergistic impact to emerge in short periods. Additionally, the rapid acceleration and proliferation of AI across the globe creates another challenge, where a high degree of flexibility is critical to deliver cutting-edge solutions to the military (Metcalfe et al. 2021). To address these challenges, ARL developed a novel strategic approach that aims to enable continuous learning, integrate expertise from numerous S&T fields, and evolve the focus as discoveries and innovations arise.

First, ARL held a series of Army Science Planning and Strategy Meetings (ASPSMs) to engage the diverse community (Mait et al. 2017). Critical in these initial discussions was convergence amongst academic, industry, and military subject-matter experts on the development of a concept that differs fundamentally from 1) the human-centered team concepts on which military doctrine and organizational psychology are built and 2) the focus on individual or additive performance within human–AI collectives. Presently, military teams train and operate with a host of advanced technology (e.g., night vision technology, smart weapon technology), but at their core, the technology endows human team

members with greater individual capabilities and does not effectively change the dynamics of human teamwork. Merely increasing individual member capabilities does not enhance the short- and long-term emergent properties of teamwork that are critical to team performance. This issue is exacerbated in teams that are expected to require close cooperation, coordination, and communication between dynamic assemblages of human and AI-based (e.g., robots, intelligent assistants, and intelligent sensors) teammates. Further, both Soldiers and AI, who are envisioned to have varied levels of training, experience, and operational capabilities, will need to adapt within and between missions in ways that induce novel challenges that the teams, not individuals, must overcome.

Through this series of meetings, one promising approach to addressing the larger problem of coordination and cooperation in human–AI teams began to emerge: individualized and adaptive technologies that focus beyond the individual, promoting effective teamwork and collective group performance in teams of humans and intelligent agents. Toward the goals of the new business model, and in partnership with the IEEE Brain Initiative, ARL conceived of a novel platform to build understanding within the broadest community and allow for continuous reshaping over time. Specifically, ARL published a foundational paper on the IEEE Brain Initiative website (open access) that allows for continuous brainstorming, engagement, feedback, and evolution of the initial strategy through various interactive mechanisms (https://brain.ieee.org/brain-storm/enhancing-human-agent-teaming/). This position paper articulates the future capabilities envisioned for the military, the recent scientific advancements across many disciplines that are paving the way for these future capabilities, and then openly strategizes the scientific and engineering approaches critical to enabling effective human–AI teaming in the future (DeCostanza et al. 2018). To continually evolve this strategy, the paper includes embedded polling questions and open-ended questions to engage the community, opportunity for open commentary within each section, and solicitations to upload full response papers within particular challenge areas including science, engineering, and innovation.

ARL's open approach to the strategic development of this research program aims to enhance understanding and engagement within a diverse S&T community as well as remain flexible over time to continually rethink, reshape, and evolve approaches for fast discovery and innovation toward Army priorities. As a grounding mechanism, three broad intertwined areas frame the technical and scientific challenges: 1) Individualized, Adaptive Technologies for Teamwork, which focuses on technologies that can adapt to individuals to optimize systems of interdependent agents for the purposes of enhancing overall team performance; 2) Adaptive Implementation, which focuses on the adaptive application of

individualized technologies based on the dynamics of task and environmental context and team members (e.g., state, knowledge, skills, and abilities); and 3) Training for Mutual Adaptation and Complex Teaming, which focuses both on how training must change for humans and AI to team in highly adaptive, highly intelligent technology contexts. Within each of these broad areas remains the flexibility to continually rethink the mechanisms that we employ to train personnel and perform complex team operations for MDO. These efforts to develop the initial research strategy and evolve the strategy over time set the research and technology vision for a new research program and mark the start of the novel ecosystem critical to achieving this vision.

3. Research Partnerships

Through open engagement in strategy development, ARL identified a critical enabling capability for MDO that focused on enhancing teamwork in heterogeneous teams of Soldiers and AI agents through individualized, adaptive mechanisms. While recent scientific and engineering advancements suggest that this future vision is possible (DeCostanza et al. 2018), critical scientific gaps still exist, and existing advancements are often stove-piped in disparate disciplines that rarely interact. To truly realize the envisioned leap-ahead technologies for future military teaming, ARL has developed a deliberate approach to unite the required communities into an ecosystem that continually evolves the strategy, achieves the necessary scientific advancements, and transitions research outcomes into delivered technologies that can revolutionize military training and operations. Here, we describe the execution of a novel collaborative research program that creates the basis for developing this S&T ecosystem, with focus on evolving the stakeholders and participants according to the dynamic needs of the program, accelerating the generation of effective collaborations, and generating a culture of continuous learning.

While civilian ARL researchers and other government transition partners make up a part of this S&T ecosystem, the broad expertise and specialized capabilities within external academic and industry partners are critical. More importantly, the needed expertise and capabilities critical to the execution of the program will change over time, as the program develops from theory and modeling to preparing and training for mutual adaptation in human–AI teams, culminating in approaches to individualize and adapt technologies with the goal of enhancing heterogeneous team performance. In each of 8 years starting in Fall of 2018, an open funding announcement features a specific call for proposals to address a sub-goal, or necessary intermediate achievement for the program, on the way to achieving the broad vision. From this call, approximately 10 small cooperative agreements per

year (seedlings) are awarded to single institutions or multiple collaborators for a 12-month effort focused on demonstrating a promising scientific concept addressing that year's sub-goal and building a multidisciplinary, collaborative team to execute a larger project incorporating that concept. In this way, the program recruits new efforts and perspectives to advance the program deliberately toward the vision. This allows ARL to "on-board" new participants with expertise that may not previously have been necessary, but is critical to achieve the sub-goal. Importantly, these sub-goals can be iteratively refined throughout the duration of the program, allowing ARL to rapidly attempt new ideas and incorporate the lessons learned in subsequent iterations. It also allows ARL to reprioritize sub-goals to target high-impact transitions.

The business model is designed such that the small cooperative agreements open the door for a larger-scale extension of the research for up to 3 years. The extension teams are expected to represent the diverse expertise and most-promising ideas from the seedling efforts. That is, seedling efforts will strategically merge and evolve to assemble the right team to achieve the cross-disciplinary scientific advancements critical to the vision. However, only two to three of these larger awards are available each year, so the business model encourages both collaboration and competition in a fast-paced cycle that allows the Army a diversity of approaches with a mechanism for a fail-fast down-select to focus resources on the most promising efforts. Moreover, a portion of ARL's internal research funding is refreshed each year in coordination with the sub-goals of this external program such that synergistic, interdependent collaborations can be developed between external partners and Department of Defense civilian researchers. This approach contrasts the single-award, enduring program of Collaborative Research and Technology Alliances. It also innovates on the Defense Advanced Research Projects Agency's (DARPA's) stage-gate/sprint model, which does not have the iterative feature of expanding the field of teams each year. As a byproduct of this new approach, many teams will participate in the program throughout its lifetime, expanding the pool of researchers who understand the program goals and can contribute to shaping the future.

Building a foundation on which the individuals within this program engage to build the collaborative partnerships and collective goals of the program is critical. Inspired by coworking spaces in which individuals rely on resident expertise to stimulate growth and best practices in team development, ARL created a yearly Innovation Summit Series. This is a multi-week research incubator that brings together researchers from ARL and other government organizations, external academic and industry researchers (required if funded under program), government stakeholders, and other industry representatives for a sustained engagement.

Focused on rapidly building the shared understanding necessary for fruitful cross-disciplinary, collaborative relationships, the Innovation Summit Series complements a targeted program of team-building and brainstorming activities with an extended engagement opportunity for recipients of seedling cooperative agreements to work collaboratively (together and with government) to develop follow-on research proposals in an incubator-like atmosphere. While many attendees come with the scientific expertise to tackle fundamental research, a deeper understanding of Army priorities is also critical to enhance proposed follow-on efforts. Therefore, the Innovation Summit Series also includes a series of speakers, panels, and activities focused on a deeper understanding of Army priorities and the scientific gaps that need to be overcome to achieve future-focused needs. In the spirit of constant learning and adaptation over time, the Innovation Summit Series is also an open forum for anyone to attend with programmatic activities focused on using the intellect of the masses to continually reshape the strategy over time. Each year, the culmination of the Innovation Summit Series is marked by the demonstration and selection of the larger-scale proposed collaborative follow-on efforts to address the specific sub-goal of that year.

To maintain the synergistic energy, growth mindset, and culture of continuous learning fostered during the Innovation Summit Series, ARL designed the Center for Agent–Soldier Teaming (CAST) in conjunction with this new business model. CAST builds a collaborative nexus for basic and applied research and is intended to co-locate and integrate highly invested and engaged researchers, novice and expert alike, from across the spectrum of science and engineering related to human–AI teaming. Currently, the CAST website (https://www.arl.army.mil/cast/) serves as an open invitation to share knowledge and build a collaborative community among a truly diverse set of experts from government, industry, and academia. Additionally, CAST provides collaborative resources for engaged researchers across the globe.

At the core of creating this novel S&T ecosystem is a culture of continuous learning focused on Army strategy and problems. The new business model aims to unite researchers from disparate scientific disciplines and across academia, industry, and government with a focus on executing Army-relevant research. Through collaboration venues such as the Innovation Summit Series and CAST, the program aims to enable teams to rapidly form new collaborations. This approach innovates on previous programs by crowdsourcing the vision, strategically growing the community of stakeholders, and continually adapting over time.

4. Ensuring Transition

A resounding theme across the modernization efforts is the breakdown of silos: silos between basic research and operational relevance, silos between defense-oriented research and commercial S&T, silos between researchers and Soldiers. Breaking down such silos and adopting a more integrated ecosystem model are critical if the modern defense S&T enterprise is to effectively leverage its early-stage investments and bridge the transition gap to fielded operational capabilities at the speed of relevance. A proactive understanding of now-published mandates of persistent modernization led to a first-of-its-kind business model for foundational research executed within ARL. The final piece of this business model is a novel focus on transitions.

The Army Modernization Strategy (US Army 2019) emphasizes modernization as a continuous process requiring collaboration across the entire Army and joint partners, wherein operating concepts are continuously tested and refined, drawing on emerging technologies, and anticipating changes in the operating environment. Throughout the entirety of the program, ARL aims to achieve transitionable outcomes; these outcomes take many forms to include scientific insights for concept developers, proofs-of-principle that can be continued in applied research and engineering programs, and early-stage technologies that can be transitioned to industry and government partners. The clearly defined and known value of this research program stems from targeted transition paths to applied research and engineering programs in the near- and mid-terms (3–10 years) and impact on future technologies in the far-term (10+ years). At the core of successful transition is ensuring the technological vision for the program is designed to address scientific gaps needed to achieve future concepts. In the earliest stages of development, ARL solicited significant input from external stakeholders, especially military leaders and concept developers through formal and informal means, rooting the scientific goals of the program to required capabilities ensuring mid- and far-term impact.

Mid- and Far-Term Impact: At the core of the development of the programmatic goals is the understanding that the dramatic uptick in the rate of operationally disruptive change envisioned for MDO requires Soldiers and systems to adapt together. Additionally, decreased time to field new technologies creates a constant need to effectively integrate and upgrade technologies into existing technological ecosystems. The Army and their allied partners must have the capability to rapidly adapt in response to adversarial technological evolution as well as that of their own and partners' forces. As such, a critical challenge for success in MDO is to increase the speed in which teams of Soldiers and intelligent agents evolve to meet these mission demands. In response, the strategic execution of this program is designed

to discover individualized, adaptive techniques that can be implemented to optimize human–AI team behaviors with improved performance over time to ensure Army teams of Soldiers and AI (lethality, maneuver, and communications) can adapt rapidly to MDO challenges occurring at multiple scales. The scientific advancements achieved in this program will permit new team capabilities formed in the field, the rapid reformation of teams under conditions of degraded and lost team members, and rapid adaptability to novel mission challenges and situations with lower Soldier burden.

The initial and ongoing input from numerous stakeholders helps to ensure that if the proposed technical program succeeds, the outcomes will address the most important scientific and technical challenges that arise from the future OE and the realization of MDO. Importantly, clearly defined transition paths into 6.2 are also developed. Specifically, the program includes a transition pathway for knowledge of team-level emergence in human–AI teams through iterative deliverables within ARL's Essential Research Program focused on human–autonomy teaming. Knowledge gained in the basic research domain can be quickly tested in mission-relevant laboratory environments, including simulated Next-Generation Combat Vehicles incorporating manned and unmanned teams, and immediately fielded in prototype systems through unique partnerships across the Research and Development community.

To promote transition at the speed of relevance, ARL is diligently building and defining these targeted transition paths as well as leveraging unforeseen transition paths through an open innovation model. The most exciting transitions that will arise from this program are those that are not yet envisioned. We expect that developing familiarity and understanding of the problems associated with the future OE and realizing MDO among program participants will break the traditional hierarchical model of government innovation and technology development, with everybody involved in the program capable of identifying and activating toward the most promising scientific concepts and technologies to address the Army needs. To foster an environment conducive to rapid identification and development of early-stage leap-ahead technologies, the Innovation Summit Series adopts best practices from the start-up ecosystem, providing an incubator- or accelerator-like atmosphere. Additionally, incorporation of start-ups, business incubators, and technology accelerators in the Innovation Summit Series creates shared knowledge and opportunities for dual-use, spin-off technologies to emerge. Through new business mechanisms bringing external technological advancements into Army programs and systems, ARL encourages and expects that multiple parallel, evolving systems of funding, innovation, and technology development will lead to much broader and faster impact toward Army priorities.

5. Conclusions

ARL is focused on developing the S&T ecosystem that incorporates the knowledge, relationships, and culture necessary for leap-ahead technologies for future military teaming. To build this S&T ecosystem, a new business model for the STRONG Collaborative Research Alliance arose from novel approaches to strategy, research partnerships, and transition. Through an open and evolving long-term research strategy with a technological guiding vision, the planned incorporation of necessary expertise consistent with the long-term strategy, and the heightened focus on both traditional and nontraditional transition pathways, ARL is creating the ecosystem to solve problems and position the Army for the future.

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List of Symbols, Abbreviations, and Acronyms

AI	artificial intelligence
ASPSM	Army Science Planning and Strategy Meeting
ARL	Army Research Laboratory
CAST	Center for Agent–Soldier Teaming
DARPA	Defense Advanced Research Projects Agency
DEVCOM	US Army Combat Capabilities Development Command
DOD	US Department of Defense
MDO	Multi-Domain Operations
ML	machine learning
OE	Operational Environment
S&T	Science and Technology
STRONG	Strengthening Teamwork for Robust Operations in Novel Groups

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