Army Science Board
Fiscal Year 2018 Study

Multi Domain Operations

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EXECUTIVE SUMMARY

In October 2017, the Acting Secretary of the Army requested the Army Science Board (ASB) conduct a study entitled Multi-Domain Battle (MDB) II as a follow-on to the fiscal year (FY) 2017 study, Multi-Domain Battle. Shortly after the study was officially commissioned in its terms of reference (TOR), the concept of "Multi-Domain Battle" evolved to the more comprehensive "Multi-Domain Operations" (MDO), which appears hereafter.

The objectives of the study are to:

- Continue assessing how to re-balance the Army's capabilities to fight more effectively using an integrated application of options from all five Department of Defense (DoD) recognized military warfighting domains (land, air, sea/maritime, space, and cyberspace).

- Assess potential combat efficiencies and synergies realized through leveraging, synchronizing, and integrating joint, interorganizational, and multinational (JIM) capabilities across all domains.

The Army's motivation for pursuing MDO arose from the global advances in technology and warfighting capability that have rapidly evolved, leaving the domains in which the U.S. was once dominant now contested by rapidly advancing peer nations. The character of war has changed, and the Army recognizes it must be prepared for competition and conflict in new ways.

The FY 2017 MDB study found that a key to MDB success will be the development of several operational options to impose multiple dilemmas on the adversary. In addition:

- Greater integration will help synchronize activities across domains.

- Exploration of new technical options and concepts and development of new tactics, techniques and procedures (TTP), require experimentation in realistic environments, to include degraded C4ISR.

- There's a need for speed in several dimensions and a general sense of urgency in all that we do.

The team assembled for this study had a broad range of technical expertise and operational experience covering all five domains of MDO. Most members had also participated in the MDB study in 2017. The FY 2018 MDO study team made over 60 visits to Army, DoD, interagency, and multinational organizations actively involved in the development of the multi-domain concept. The data gathered validated the FY 17 study themes and emphasized a need for the engagement of Joint, Interagency, and Multinational (JIM) partners.

The National Defense Strategy (NDS), published concurrently with the FY 17 study, states:

> The central challenge to U.S. prosperity and security is the reemergence of long-term, strategic competition by what the National Security Strategy classifies as revisionist powers … China and Russia.[1]

The NDS affirms that all recognized domains are now considered contested and articulates the U.S. strategy to compete, deter, and win in this environment. The FY 2017 MDB study aligned well with the NDS, and this FY 2018 MDO study remains consistent with the key tenets of both the NDS and the recommendation from the FY 2017 study. That said, the current study evolved the MDB operational concept discussed in the FY 2017 study. Whereas the 2017 study focused on Army operations in armed conflict, the current study broadened its focus to examine Joint, Interagency, and Multi-national operations in both conflict and competition (Fig. E-1).

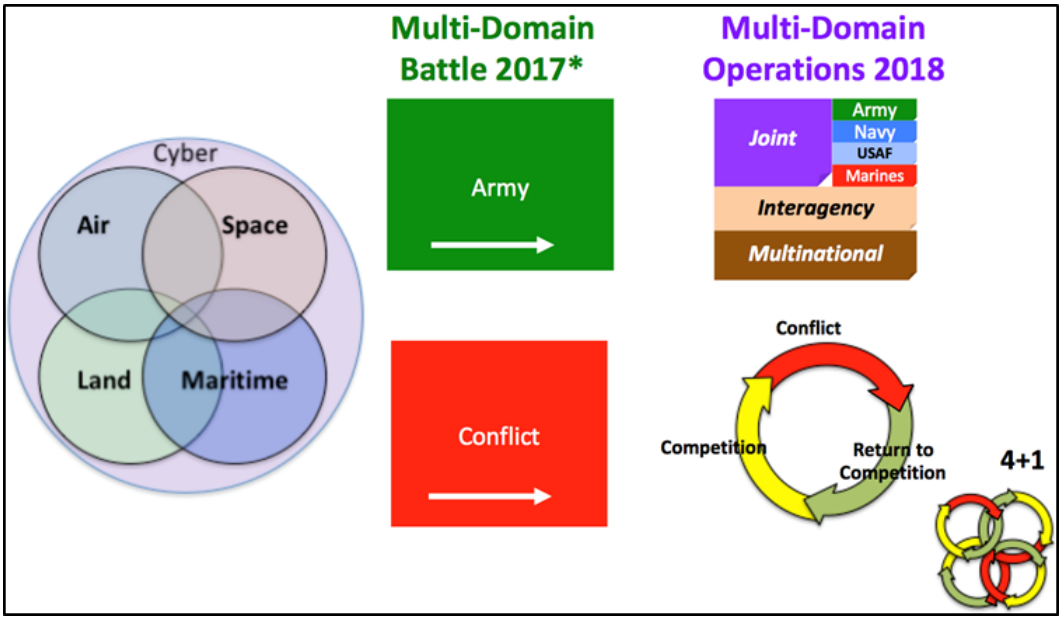

Figure E.1 Multi-Domain Battle is Now Multi-Domain Operations

The cycle at the lower right of the figure reflects the cyclical nature of war and the continuum of conflict defined as competition short of conflict (yellow), conflict (red), and the return to competition (green). The interlocking cycles represent the multiple stages of competition and conflict occurring simultaneously across the globe, each at their own pace, consistent with the "4+1" assumptions that provide context for the NDS.

The reduction of U.S. dominance in the individual domains can potentially be overcome in the aggregate via the use of MDO that leverage a highly integrated, JIM force to take positive and timely actions throughout the competition continuum (Fig. E.2). To that end, the study team developed ten sets of findings and recommendations in four categories:

[1] James N. Mattis, Summary of the 2018 National Defense Strategy of the United States of America, Sharpening of the American Military's Competitive Edge, 19 January 2018, https://www.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf

1. Joint – courses of action address the need for systems to be "Joint by Design," that is, deliberately designed as Joint from the beginning and not a merger of technologies developed separately and combined at the end. These courses of action also address the need for a system of systems (SoS) approach and for Joint modeling and experimentation.

2. Examples – the impact of MDO is illustrated in operations involving Dense Urban Environment (DUE) and Long-Range Precision Fires (LRPF).

3. Technology – development focused on the CSA priorities, Information Operations, Cyber, Counter-Unmanned Aerial Systems, and Air and Missile Defense.

4. The Role of People – as the operational environment becomes more complex and more dependent on rapidly advancing technology, the role of people must change to accommodate a faster pace of engagement.

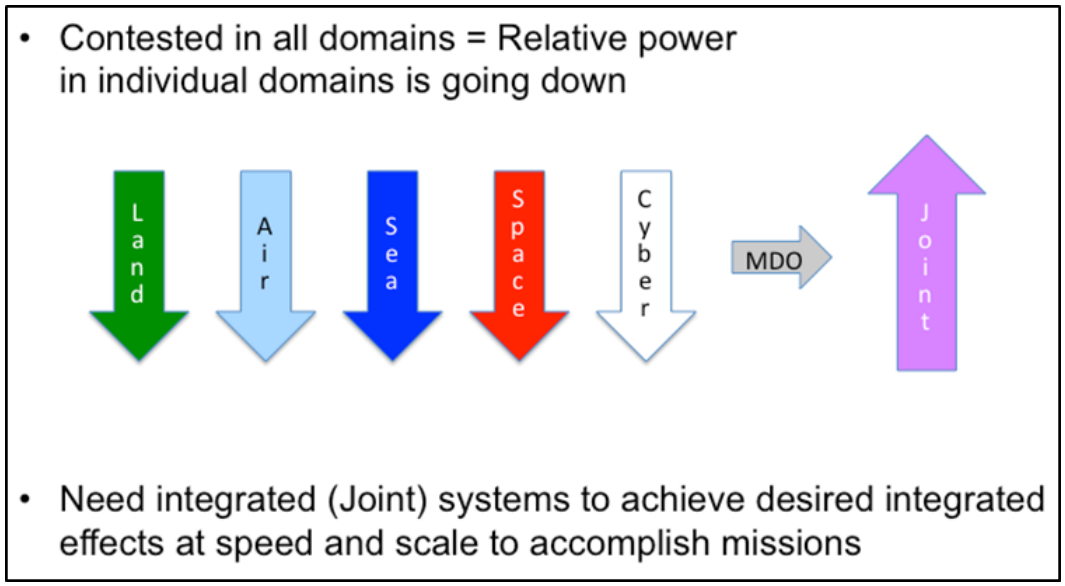

Figure E.2 Contested in All Domains

The study team's findings and recommendations are:

1. Joint, Interagency, and Multinational by Design

Findings:

- Army MDO must be Joint, Interagency, and Multinational by Design.

- Single Service-developed multi-domain concepts are not sufficient for a fully integrated Joint MDO concept.

- There is a limited set of DoD joint experiments and exercises with time horizons beyond 3 years.

  – The most successful experiments and exercises are Jointly planned and executed. Single-Service exercises that include other Services are a step in the right direction.

  – There is a history of interagency reluctance to participate in military exercises.

Recommendation: CJCS: Develop and resource a coherent organizational construct with Joint, Interagency, and Multinational partners to develop multi-domain concepts and doctrine, and evaluate them in realistic, integrated experimentation and exercises, particularly for the mid and long term.

2. System of Systems Approach

Findings:

- MDO requires a system of systems approach.

- The system of systems approach would expand the range of options critical to successful multi-domain operations in a contested environment (multi-functional "subsystems" and emergent behavior).

- There is no system of systems architecture for multi-domain operations in Conflict or Competition.

Recommendations:

- CG AFC: Develop a system of systems architecture of options for multi-domain operations in conflict and competition.

- SA: Establish a Systems Engineering CFT to integrate the other CFTs to facilitate more rapid advance of multi-domain capabilities and support requirements development.

3. Modeling and Experimentation

Findings:

- Modeling and experiments should inform MDO development.

- The Services do not have sufficient Joint, Interagency, and Multinational involvement in their models and experiments, nor do they fully exploit common advanced tools and technology.

Recommendations:

- CJCS and USDR&E: Develop and deploy to the Services, Joint models and experiments using common advanced tools and technology.

- CG AFC: Conduct multi-domain modeling, experimentation, exercises, and analyses of system of systems concepts that address capability gaps in realistic mid to far term threat environments.

  – Develop holistic approaches that include high/low mixes of collaborative manned/unmanned systems, higher levels of autonomy, PNT in degraded environments, attritable unmanned assets and enhanced Directed Energy.

  – As appropriate, leverage AI and machine learning.

  – Expeditiously develop and validate systems architectures and CONOPS.

4. Dense Urban Environment

Findings:

- MDO is critical to success in the Dense Urban Environment.

- Army MDO conceptual thinking properly recognizes Dense Urban Environment (DUE) operations as an inherently multi-domain environment that compresses physical and temporal spaces, compounds obstacles and demands simultaneous execution of innumerable tasks.

- The benefits of robotics, autonomy, AI, and big data analysis are essential for DUE situational awareness, effective decision making and adequate operational reach. Realization of these benefits can only be achieved with interagency integration.

- The "Three Block War" syndrome tests the limits of the human psyche which can, to some extent, be overcome through training.

Recommendations:

- CG AFC: Evaluate and adjust the Army's robotics, autonomy, AI and big data analysis programs to address Army capability shortfalls in DUE.

- CG AFC: Create a "Three Block War" laboratory to investigate advanced technologies and concepts.

- CG TRADOC: Evaluate and adjust the Army's training programs to be commensurate with the complexity and probability of DUE engagements.

5. Long-Range Precision Fires

Findings:

- Long-Range Precision Fires and MDO are interdependent.

- The Long-Range Precision Fires (LRPF) and Network CFTs are developing systems that have significant issues and shortfalls:

    1. The Network CFT is not currently recommending network options that link the aviation and space assets to the LRPF Command and Control Center and the LRPF munition in flight.

    2. The LRPF CFT is not currently recommending a munition that has the capability to receive position updates of target location in flight.

Recommendations:

- CG AFC: Design and develop a maneuvering Long-Range Precision Fires system that includes the network, sensing, and targeting required to make it effective.

- CG AFC: Design and develop a maneuvering munition for the Long Range Precision Fires System with the capability to receive commands in flight and to transmit SA and location information back to the LRPF Command and Control system.

6. CSA Priorities and MDO

Findings:

- CSA priorities (Long Range Precision Fires, Next Generation Combat Vehicle, Future Vertical Lift, Networks, Air & Missile Defense, and Soldier Lethality) are necessary but not sufficient for successful execution of MDO in all of its phases

    – Examples: Rapidly deployable expeditionary forces, enhanced wide-area and local-area situational awareness, precision targeting, systems interoperability, environmental mapping, social network access and exploitation, non-lethal and low collateral damage weapons (both kinetic and non-kinetic)

- To permit evolution of technologies, systems need to be able to accommodate integration into Army, Joint, and multinational formations.

- High/low mix provides possible entry points for multinational partners.

- Low cost unmanned systems could provide flexible, agile, attritable and/or expendable system options, but they must be compatible with higher end systems.

Recommendations:

- CG AFC: Develop a high/low mix of capabilities and options for near/mid/far-term multi-domain applications that provide more versatile, less exquisite systems for growing threats.

- CG AFC: Aggressively pursue research and development with potentially disruptive technical and operational options in areas such as autonomy, AI, decision theory, quantum technology, and hypersonics.

7. Information Operations (IO) and Cyber Electromagnetic Activities (CEMA)

Findings:

- Information Operations (IO) and Cyber Electromagnetic Activities (CEMA) are essential for MDO and will be contested in both conflict and competition. Current capabilities are not fully integrated.

- Adversaries are exploiting rapidly evolving and proliferating IO and cyber technologies.

- Multi-domain operations require innovative approaches to the integration of cyber operations, enabling maneuver across domains and creating dilemmas for the enemy.

Recommendation: Cyber COE: Develop an Integrated Multi-domain IO/CEMA Strategy that is responsive to the rapidly evolving MDO environment.

8. Counter-UAS and Air and Missile Defense

Findings:

- Counter-UAS and Air and Missile Defense are critical to MDO.

- Controlling multiple unmanned systems has been demonstrated and is being deployed around the world. This is both a threat and an opportunity.

- Within the next year there could be 10X drones in such configurations and the numbers will continue to grow even more rapidly going forward.

- Developing UAS formations for offensive and defensive applications has tremendous potential.

Recommendations:

- CG AFC: Develop cost-effective Counter-UAS and air & missile defense options based on MUM-T, Robotics and Autonomous Systems, AI, electronic warfare, and directed energy to support MDO.

- CG AFC: Develop and test UAS technologies and concepts for offensive and defensive capabilities using more advanced ranges such as the "Three Block War" laboratory.

9. Optimized Human-Machine Systems

Findings:

- The development and use of AI, machine learning, and autonomous systems are accelerating, including in military applications such as MUM-T and C4ISR.

- The massive amounts of data being produced in multiple domains can only be processed in relevant time scales by using advanced data analytics, machine learning and artificial intelligence.

- The speed needed to recognize, discriminate, target, and decide is moving beyond human capacity, driving the need for automation and/or optimized human-machine systems. Speed and accuracy trades must be undertaken and understood.

- Optimized human-machine system experimentation can improve understanding of technical performance and the value to the relevant CONOPS and support the culture change needed to operate in this high-speed environment.

- MDO effectiveness requires optimized human-machine systems.

Recommendation: ASA(ALT) and CG AFC: Develop and field optimized human-machine systems, which include trusted autonomy, AI and machine learning in operations, planning, wargaming, experimentation, acquisition, business processes, etc.

10. Defense Culture and MDO

Findings:

- Defense culture must be changed to embrace Joint, Interagency, and Multinational and advanced concepts for MDO to succeed in the mid-to-long term.

- "Jointness" has not advanced to a level to enable MDO.

- Changing the culture requires a change in training and education.

- While changes to training and education must occur at all levels, there must be particular focus on mid-level Service leadership.

- Successful MDO requires alignment of incentives and measures of success (example, promotion and assignments).

Recommendation: CG TRADOC: Develop Tactics, Techniques, and Procedures (TTPs) for MDO and establish a realistic training and education program that supports the cultural change to embrace Joint and advanced concepts necessary for success in multi-domain operations. Develop an MDO curriculum across professional military education.

1. INTRODUCTION

In October 2017, the Acting Secretary of the Army requested the Army Science Board conduct a study entitled "Multi-Domain Battle (MDB) II" as a follow-on to its FY 2017 study, "Multi-Domain Battle." The Commanding general (CG) of U.S. Army Training and Doctrine Command (TRADOC) sponsored the study, with the objectives to:

- Continue assessing how to re-balance the Army's capabilities to fight more effectively using an integrated application of options from all five Department of Defense (DoD) recognized military warfighting domains (land, air, sea/maritime, space, and cyberspace)

- Assess potential combat efficiencies and synergies realized through leveraging, synchronizing, and integrating joint, interorganizational,[2] and multinational capabilities across all domains.

This report describes the conduct of the study and provides its findings and recommendations. A comprehensive briefing of the study was presented to the ASB membership (see Appendix G) in plenary session, and the findings and recommendations were approved by the members on 18 July 2018.

1.1 TERMS OF REFERENCE (TOR)

The Acting Secretary's Terms of Reference (TOR) (see Appendix A) identified the TRADOC document "Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040,"[3] as the baseline for the study. In addition, the TOR specified four tasks for the study team to accomplish:

a. In competitions below armed conflict, how does the Army, working with Joint, interorganizational, and multinational partners:

   1) Contest adversary operations?

   2) Deter armed conflict and employment of adversary conventional forces?

   3) Implement command and control capabilities to actively compete and immediately respond to the escalation of violence?

   4) Set the theater (including CONUS) before hostilities?

b. During armed conflict, how does the Army, working with joint, interorganizational, and multinational partners:

[2] The term "interorganizational" as used in the TOR is now more commonly referred to as "interagency."
[3] TRADOC, "Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040," December 2017, http://www.tradoc.army.mil/multidomainops/docs/MDB_Evolutionfor21st.pdf

1) Defeat the peer adversary's fait accompli campaign?

2) Execute strategic and operational maneuver?

c. In the return to competition, how does the Army, working with joint, interorganizational, and multinational partners:

1) Contest the adversary's renewed subversion campaign?

2) Deter a return to armed conflict?

d. What are the technology gaps for enabling MDB and providing more operational options in the future?

1.2 STUDY TEAM AND DATA GATHERING

The study team established to address these tasks (see Appendix B) included ASB members with significant technical expertise and experience in a variety of disciplines, including:

- Armor/Anti-armor
- C4ISR
- Directed energy systems
- Electromagnetics
- Energy technology
- Aerospace technology
- Integrated air defense
- Intelligence
- Missile defense
- Robotics
- Turbulence & stochastic systems
- Signal processing
- Artificial Intelligence (AI)
- Surveillance systems
- Weapons systems
- Operations Analysis
- Engineering (Systems, Chemical, Electrical, Mechanical, and Nuclear)
- Materials Science
- Physics
- Acquisition
- R&D Programs
- Technology transition

Several study team members had significant operational experience covering all five domains of MDO (e.g., retired USMC and USAF flag officers, retired USA colonel). In addition, most members of the MDO study team had participated in the FY 17 MDB study.

To obtain the information required to address the TOR tasks, members of the study team made over 60 visits to Army and other DoD organizations actively involved in the development of the MDO concept, as well as interagency and multinational organizations (see Appendix C). Discussions were mostly held at the Secret level, though several were held at the TS/SCI level– DIA, MSIC, NASIC, NRO, NGA, NSA, DARPA, Cyber 1.8, Classified Space, MDA, and PACAF.

1.3 BACKGROUND & OVERVIEW OF THE FY 2017 MDB STUDY

Several themes emerged from the 2017 MDB study (Fig. 1.1):

- The development of multiple operational options to impose multiple dilemmas on the adversary
- Greater integration to help to synchronize activities across multiple domains
- Development of new technical options, concepts, and tactics, techniques and procedures (TTP) based on experimentation in realistic environments, to include degraded C4ISR
- A need for speed in several dimensions and a general sense of urgency in all that we do

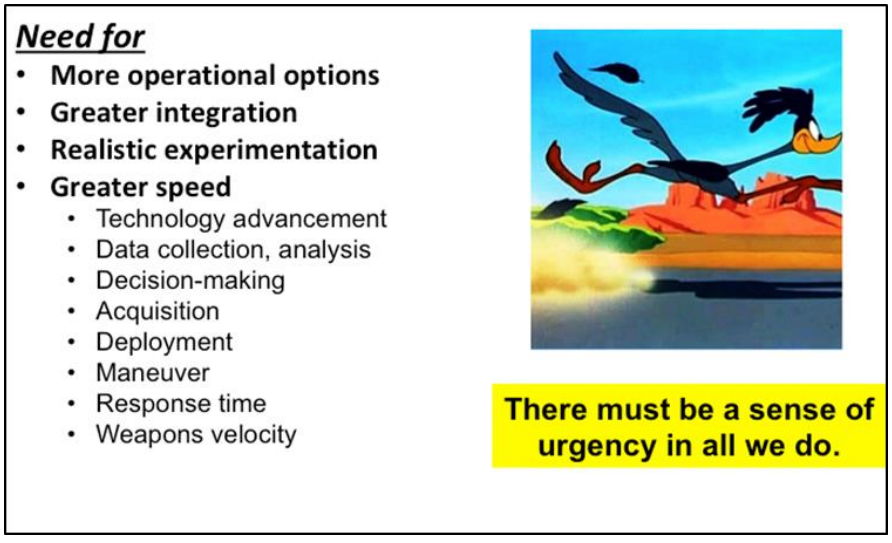

Figure 1.1 Key Themes from the FY 2017 MB Study

Opportunities arise from providing numerous options to the warfighter. For example, MDB transforms the usual kill chain of Find-Fix-Track-Target-Engage-Assess into a kill matrix across the five domains (Fig 1.2). In the traditional kill chain, all steps are in the same domain and may even be on the same platform. In the proposed multi-domain kill matrix, there are multiple paths

through the six steps that may involve multiple domains with options at many of the steps. For example, at the second step (Fix), the red path has three options, each of which can lead to a path to the bottom layer (Assess).

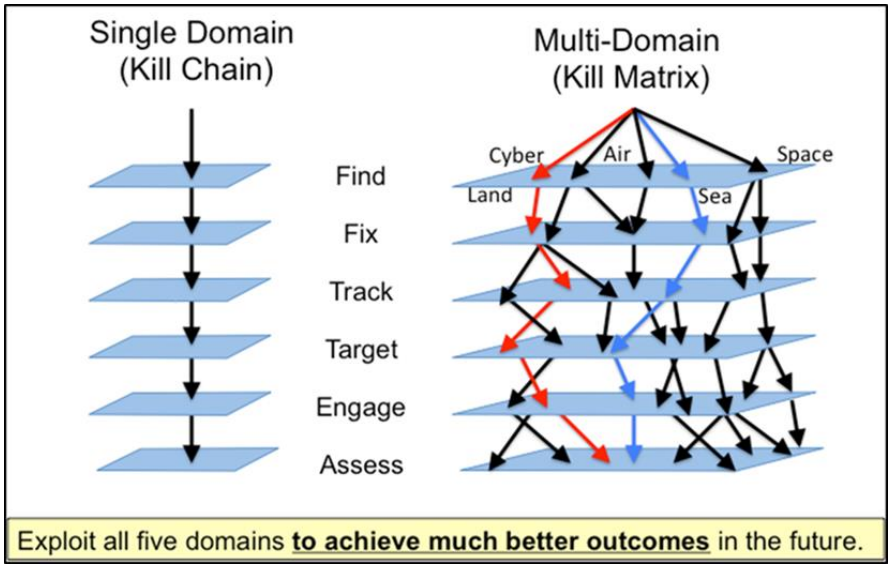

Figure 1.2 Multi-Domain Increases Operational Options

The FY 2017 study team developed a concept of future engagements involving massively distributed "bots" that leveraged technology advances in all domains to operationalize MDB in theater (Fig. 1.3). The technologies included:

- MUM-T (unmanned systems performing various functions including C4ISR, lethality, deception, logistics, etc.)
- Autonomy, AI, and decision-making tools
- Self-forming modular C4 networks

Initial emphasis on supervised autonomy with the potential deployment of many robotic elements is depicted.

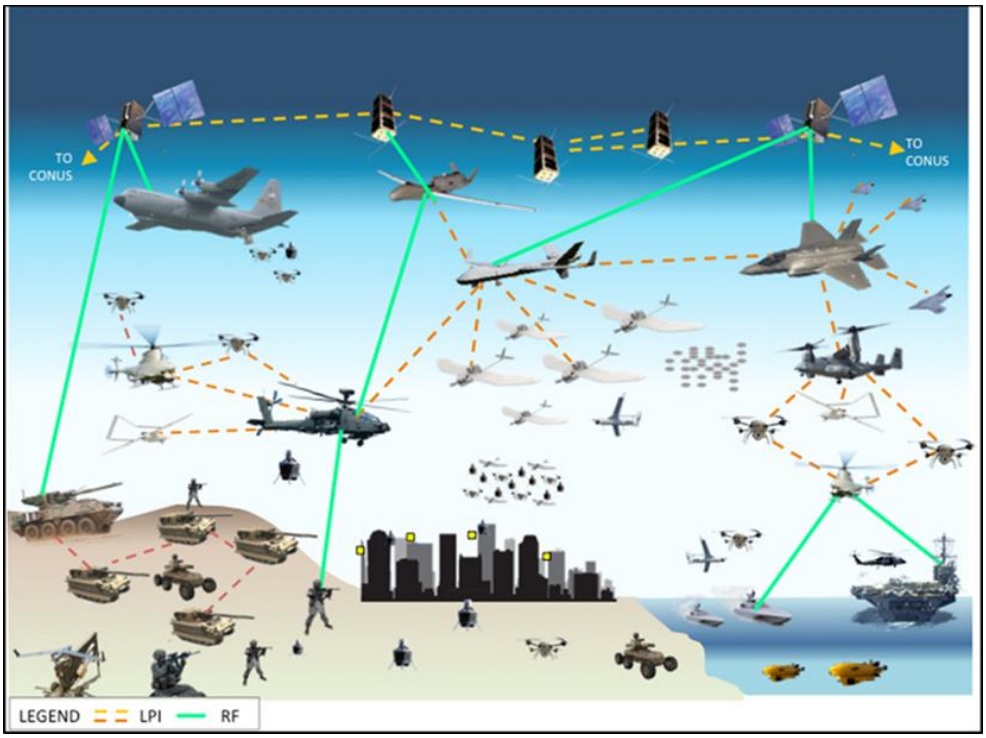

Figure 1.3 Massively Distributed "Bots"

The communications links depicted are a mix of RF and low probability of intercept links, and there would be substantially more than what's depicted in order to enable full integration of capabilities across multiple domains, multiple Services, and multiple functions, over extended area and time. In times of conflict when C4ISR functions would be severely degraded, the links shown in green could represent intermittent, low band communications only capable of relaying commander's intent (mission commanding) to the forces in the field. To execute the fight until more robust communications were restored, the local commander could use formations with attritable and expendable assets.

Such a configuration of massively distributed "Bots" increases operational options, provides greater speed, agility, and flexibility, and enables effective integration of operations in the contested environment. This vision provides a high/low mix with robust characteristics in degraded environments that enables winning in a contested and dynamic environment through improved battlefield outcomes.

As described in the 2017 MDB Report, the vision includes supervised autonomy of unmanned platforms. Over time, as trust in autonomy is built, the degree of autonomy will increase. The number of unmanned platforms will increase by factors of 10, 100, and eventually 1,000.[4]

[4] Appendix E provides the Executive Summary of the 2017 study report published January 2018.

1.4 THE NATIONAL DEFENSE STRATEGY (NDS)

The 2018 NDS[5] was published in January 2018, nearly simultaneous with the publication of the FY 2017 MDB report. The unclassified synopsis of the NDS defines inter-state strategic competition, especially with China and Russia, as the primary US security concern:

- Inter-state strategic competition, not terrorism, is now the primary concern in US national security.

- China is a strategic competitor using predatory economics to intimidate its neighbors while militarizing features in the South China Sea. Russia has violated the borders of nearby nations and pursues veto power over the economic, diplomatic, and security decisions of its neighbors. As well, North Korea's outlaw actions and reckless rhetoric continue despite United Nation's censure and sanctions. Iran continues to sow violence and remains the most significant challenge to Middle East stability. Despite the defeat of ISIS's physical caliphate, threats to stability remain as terrorist groups with long reach continue to murder the innocent and threaten peace more broadly.

- Nation's censure and sanctions. Iran continues to sow violence and remains the most significant challenge to Middle East stability. Despite the defeat of ISIS's physical caliphate, threats to stability remain as terrorist groups with long reach continue to murder the innocent and threaten peace more broadly.

- This increasingly complex security environment is defined by rapid technological change, challenges from adversaries in every operating domain, and the impact on current readiness from the longest continuous stretch of armed conflict in our Nation's history.

The NDS articulated the U.S. strategy necessary to compete, deter, and win in an environment where all recognized domains are now contested. The FY 2017 MDB Study aligned well with the NDS, echoing the guidance it provided (Fig. 1.4). This FY 2018 MDO study remained consistent with the key tenets of the NDS and the recommended courses of action from the FY 2017 study.

1.5 MULTI-DOMAIN BATTLE IS NOW MULTI-DOMAIN OPERATIONS

At the 2018 Association of the United States Army Land Forces in the Pacific (LANPAC) conference held 22-24 May in Honolulu, GEN Stephen Townsend, CG TRADOC, announced that the Multi-Domain Battle (MDB) Concept had evolved into the Multi-Domain Operations (MDO) Concept to recognize the importance of competition as well as conflict (Fig. 1.5). He elaborated on the issue, highlighting the importance of various partnerships that were crucial to the military during periods of competition before and after combat:

[5] Op. cit. Mattis.

Figure 1.4 Themes from the 2018 National Defense Strategy

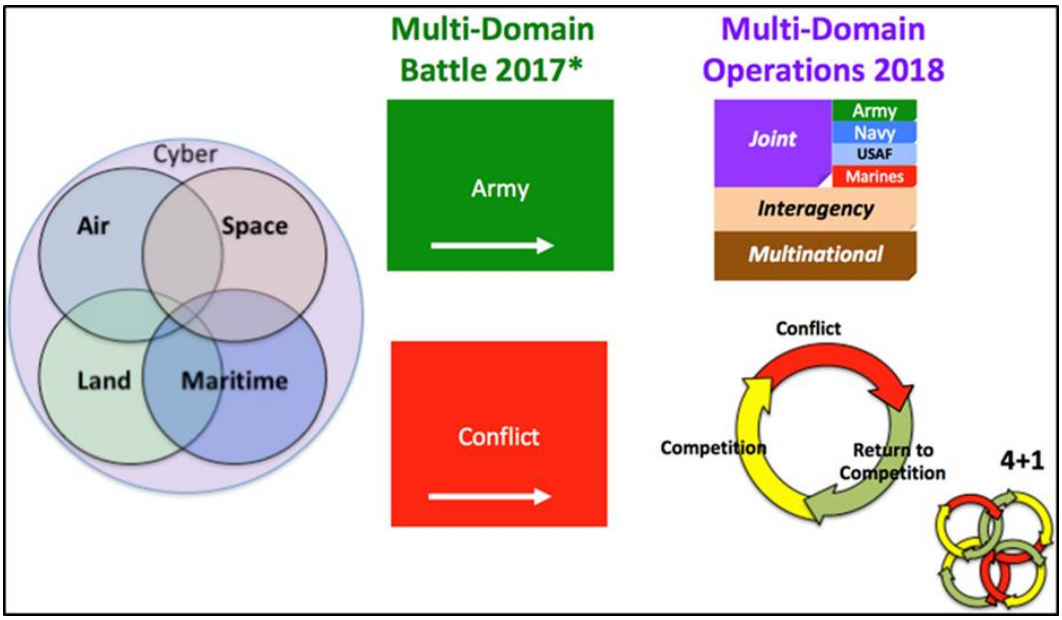

Figure 1.5 Multi-Domain Battle is Now Multi-Domain Operations

We cannot do this alone. The armed services can win battles and campaigns, but winning wars takes the whole of government. It helps the entire effort if our interagency partners are comfortable with and conversant in our warfighting concepts and doctrine. As highlighted to me by a former ambassador at a recent forum, talking in terms of operations instead of

> battles brings together those who want to get things done—whether they are civilians or the military.[6]

This study builds on the FY 17 ASB MDB study. As is depicted above, the previous study focused on Army operations in armed conflict. The current study broadened its focus to examine JIM operations in both conflict and competition. The cycle at the lower right of the figure reflects the cyclical nature of war and the continuum of conflict defined as competition short of conflict (yellow), conflict (red), and the return to competition (green). The interlocking cycles represent the multiple stages of competition and conflict occurring simultaneously across the globe, each at their own pace.

Gen Townsend also described attempts to use MDO in current conflicts as largely unsuccessful due to an inability to integrate effects:

> Today, and during combat operations against ISIS in Iraq and Syria, we conducted MDO but the best we can do is episodically synchronize effects from each domain. And that is against an opponent who cannot contest us in any domain. Future war, against a near-peer adversary, will require us to rapidly and continuously integrate our effects, while being contested, in all of the domains.[7]

In June 2018, the Army established the Army Futures Command (AFC) to lead its future force modernization enterprise:

> At Army Futures Command, we believe in utilizing the best expertise, whatever the source, to create innovative solutions faster and better. We're on a quest to modernize the way the Army does business by creating a space of endless possibilities to explore, develop, and test new methods, organizations, and technologies. Above all else, we want to make sure Soldiers have what they need, before they need it, to defend tomorrow…today.[8]

The study team believes MDO is best operationalized by leveraging capabilities across whole-of-government, industry, and academia, as well as multi-national partners. If AFC reaches out to all sources of expertise, it will be positioned to successfully enable MDO.

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[6] Stephen Townsend, "Accelerating Multi-Domain Operations: Evolution of an Idea," Modern War Institute, 23 July 2018, https://mwi.usma.edu/accelerating-multi-domain-operations-evolution-idea/

[7] TRADOC Briefing/Handout at TechNetAugusta 2018; 21 August 2018. events.afcea.org/Augusta18

[8] From AFC website; https://www.army.mil/futures#org-about.

2. THE FUTURE OPERATING ENVIRONMENT (OE)

The establishment of AFC demonstrates the Army understands the U.S. and its allies stand at an inflection point, where elements of the Operational Environment (OE) are converging to diminish the overmatch capabilities the West has enjoyed since the fall of the Soviet Union. In addition, rapidly evolving trends across the diplomatic, information, military, and economic spheres are transforming the nature of society and human life – including the character of warfare.

2.1 THE THREAT

The 2018 NDS identifies China and Russia as the primary U.S. security concerns. To better understand the Russian threat, the ASB funded the Center for Naval Analyses (CNA) to develop four reports which provided the following insights:

1. The Evolution of Russian Military Thought and Its Relevance to U.S. Army MDO – Russia sees modern technology as fundamentally changing the nature of warfare. Wars are no longer fought by armies standing shoulder-to-shoulder across open areas facing one another. To Russian strategists, battlefield advantages are gained before conflict erupts, with information confrontation seeking to change the very psychological landscape of the adversary. The battlefield itself is non-contiguous, electronically contested, and a competition over information with smaller, more efficient, and lethal forces fighting across domains.[9]

2. Russia's Hypersonic Weapons Program and its Implications for MDO – Over the last decade, Russia has gradually re-emerged as one of the leading powers in the field of hypersonic weapons technology. Over this period, Russia has steadily rebuilt its hypersonic weapons program, drawing upon its impressive Soviet legacy of accomplishments in the field. Since 2009, Russia has steadily expanded the country's knowledge and technology base, leveraging it to resume active development of an array of sophisticated new weapon systems (hypersonic boost glide vehicles, hypersonic cruise missiles, aero-ballistic missiles, etc.). Despite its progress, Russia's hypersonic weapons program continues to suffer from several deficiencies, including a shortage of modern infrastructure, an aging research staff, loss of institutional knowledge, funding limitations, and external sanctions. Consequently, deployment of these systems isn't expected to take place until the 2020-2025 timeframe. However, if Russia is able to overcome these challenges, and produce these new systems in sufficient numbers, they will present a significant challenge for U.S. MDO.[10]

[9] Jeffrey Edmonds, The Evolution of Russian Military Thought and Its Relevance to US Army Multi-Domain Operations, C N A Report DIM-2018-C-018541-1Rev, October 2018. (SECRET NOFORN), page 1.
[10] Paul Schwartz, Umida Hashimova, and Danielle Johnson, Russia's Hypersonic Weapons Program and its Implications for Multi-Domain Operations, C N A report DRM 2018-C-018540-Final, October 2018 (SECRET NOFORN), in abstract.

3. Russia's Lessons Learned in Syria and Their Implications for MDO – On 30 September 2015, the Russian armed forces commenced military operations in Syria; Russia's first expeditionary campaign since its war in Afghanistan. The Russian military has learned and applied important lessons, such as how to conduct a sustained expeditionary campaign, with all its attendant operational and logistical complexities. At the tactical level, Russia has developed a host of new TTP, while learning how to employ new weapons that it's acquired in recent years:[11]

    - Russian UAVs provided round-the-clock coverage, serving as the military's eyes and ears and supporting combat operations in various ways.[12]

    - The Russian military has gained greater appreciation for the value of precision weaponry in modem warfare.[13]

    - Some Russian helicopter losses should be attributed to a failure to properly plan for close air support between the air and associated Russian ground forces, but not to a lack of technology. Syria demonstrated that the technology to conduct a joint fight is already in place, but the instinct and service reflexes to use it effectively are not.[14]

    - Russian helicopters pose a serious threat to U.S. ground forces, having demonstrated the effectiveness of new weapons such as the Vikhr antitank guided missiles, the long arm of Russia's antitank forces. These improved Russian army aviation systems are in prime position to exploit an enduring weakness in U.S. forces, the lack of short-range air defense, and point defense systems, among Army formations.[15]

4. Memorandum: Russian Developments in AI – The Russian military establishment devotes considerable attention and resources to the development of AI. While currently lagging the global leaders, U.S. and China, the Russians are aiming for an "Al breakthrough" soon by spreading the effort across its military's numerous organizations; seeking to utilize an existing talent pool in its military academies, industrial corporations, and private sector. The Russian military is also opening the dialogue on Al with the international community, hosting events to monitor and learn from Al developments across the world. At the same time, the Russian military is already claiming certain Al-enabled success with specific technologies. The true extent of these efforts will become clear in the coming years, as many of Russia's military Al projects are at the very nascent stages of development and growth. Still, the Russian's

[11] Michael Kofman, Paul Schwartz and Paul Sanders, Russia's Lessons Learned in Syria and their Implications for Multi-Domain Operations, CNA Report DIM 2018-C-018582-1Rev, Oct 2018 (FOUO), in abstract
[12] Ibid, p. 20.
[13] Ibid, p. 26.
[14] Ibid, p. 32.
[15] Ibid, p. 33.

efforts deserve close attention, especially in their traditional military strengths, such as electronic warfare, missile and air defense, etc. It's likely that for the foreseeable future, Al as it's understood and deployed by the Russian armed forces, will serve as an instrument to augment decision-making, battlefield integration, and situational awareness among existing systems and their operators.[16]

Further details from the CNA reports are included in the classified annex to this report. A discussion of the threat from China is also included in the classified annex.

2.2 THE JOINT FORCE OF THE FUTURE

The Joint Staff's Joint Operating Environment (JOE) 2035 describes the future security environment and projects the implications of change for the Joint Force of the future. JOE 2035 identifies two overarching challenges: [17]

- Contested norms will feature adversaries that credibly challenge the rules and agreements that define the international order.

- Persistent disorder will involve certain adversaries exploiting the inability of societies to provide functioning, stable, and legitimate governance.

Confrontations involving contested norms and persistent disorder are likely to be violent, but also include a degree of competition with a military dimension short of traditional armed conflict.

Based on JOE 2035, the 2018 Joint Concept for Integrated Campaigning (JCIC)[18] concludes the Joint Force must accept four key principles:

- The Joint Force must eliminate institutional remnants of the obsolete peace/war binary construct.

- Commanders and planners must recognize the need to follow through in order to accomplish policy aims in both armed conflict and campaigning outside of armed conflict.

- Military power alone is insufficient to achieve sustainable political objectives.

- The operating environment demands a construct that employs the Joint Force in competition below armed conflict.

[16] Sam Bendett and Jeffrey Edmonds, Memorandum: Russian Developments in Artificial Intelligence, CNA Memorandum DME-2018-U-018700-Final, Oct 2018 (FOUO) p. 9.
[17] JJCS, Joint Operating Environment (JOE 2035) – The Joint Force in a Contested and Disordered World. jcs.mil/Portals/36/Documents/Doctrine/concepts/joe_2035_july16.pdf?ver=2017-12-28-162059-917
[18] JCS. Joint Concept for Integrated Campaigning. jcs.mil/Portals/36/Documents/Doctrine/concepts/joint_concept_integrated_campaign.pdf?ver=2018-03-28-102833-257.

The JCIC describes a competition continuum of cooperation, competition below armed conflict, and armed conflict (Fig. 2.1).

Figure 2.1 The Competition Continuum (Source: JCIC)

The three elements of the continuum are exclusive of each other and can co-exist at the same point in time:

1. Conflict– "In armed conflict the use of violence is the primary means by which an actor seeks to satisfy its interests."[19] Objectives in this phase are clear and well understood:

    - Defeat: create conditions to impose our will on the enemy
    - Deny the enemy's objectives
    - Degrade: reduce the adversary's ability and will within resource and policy constraints

2. Competition– "Competition below armed conflict exists when two or more actors have incompatible interests but neither seeks to escalate into armed conflict."[20] Objectives include:

    - Improve our overall strategic position
    - Counter competitor efforts to achieve further gains

[19] Ibid, p. 8.
[20] Ibid.

- Contest effectively to achieve the best strategic outcome.

3. Cooperation– "Cooperation includes mutually beneficial relationships between strategic actors with similar or compatible interests."[21] Objectives in this phase are to:

    - Engage selectively, remaining focused on achieving US aims
    - Maintain relationships without significant increases in resources
    - Expand cooperative activities

The challenge of defeating adversaries and achieving strategic objectives occurs in the cycle of competition, armed conflict, and return to competition (Fig. 2.2).

Figure 2.2 The Cycle of Competition and Conflict

The Joint force activities associated with each stage of the cycle include:

- Competition – The Joint Force expands the competitive space by countering the adversary's efforts at coercion, unconventional warfare and information warfare that have been directed against our partners. The intent is to deter escalation while setting favorable condition if conflict does take place.

- Conflict – The Joint Force makes full use of all domains to penetrate the enemy's operational space and dis-integrate the components of his military power while creating favorable conditions for the desired political outcome.

- Return to Competition - The Joint Force consolidates gains, deters slipping back into conflict and establishes a regional security order aligned with U.S. goals.

[21] Ibid.

3. JOINT, INTERAGENCY, AND MULTINATIONAL (JIM) PARTNERS

The NDS is based on the concept that every domain is contested and that the U.S. no longer enjoys dominance or superiority in any domain, thus the relative power in each domain with respect to a peer competitor is reduced. The reduction of relative dominance in the individual domains can potentially be overcome in the aggregate via the use of MDO that leverage a highly integrated JIM force to take positive, timely actions throughout the competition continuum (Fig 3.1). These actions could be selectively employed with multiple levels of intensity until the phase of the mission is complete. Due to the complexity and character of adversaries (including the fact that there are more than one at a time), no single entity such as the U.S. or one of our allies has the global reach to impact the shape and magnitude of the continuums.

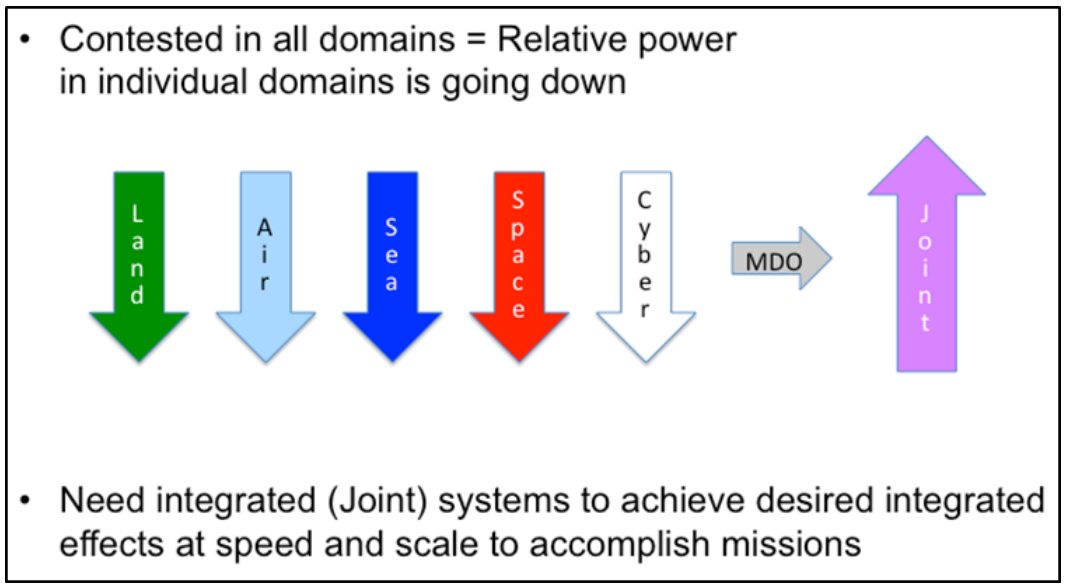

Figure 3.1 Contested in All Domains

3.1 JOINT SERVICE VIEWS OF MULTI-DOMAIN OPERATIONS

The study team encountered different views of Joint MDO from personnel of the various military Services. The Services had established some connection with respect to MDO, but there were also separate ideas of what constituted MDO and how each Service could contribute to the Joint fight. For example, the Army's multi-domain concept is MDO, the Air Force has worked on Multi-Domain Command and Control,[22] and the Navy and Marines have activities in Littoral Operations in Contested Environment. As the study team continued to meet and discuss MDO with the Services, their interaction in the conceptual development of multi domain appeared to be increasing. In addition, traditional, single-Service exercises had been adding other Services at later stages, such as the Air Force's 2018 Global Engagement Wargame and Red Flag 18-1, the

[22] The Air Force is currently discussing MDO. See Amy McCullough, "Goldfein's Multi-Domain Vision," Air Force Magazine, October 2018, at www.airforcemag.com/MagazineArchive/Pages/2018/October%202018/Goldfeins-Multi-Domain-Vision.aspx

Army's Cyber Quest 2018 which included Marine Corps operators (with plans to have Air Force participate next year), as well as liaisons from Germany, Netherlands, U.K., Australia, Belgium, and Norway. These are necessary first steps to developing an integrated JIM approach to MDO.

If the Services are to work together to operationalize MDO, they must train together in Joint exercises. Currently, the exercises sponsored by the combatant commands provide the best opportunity for Joint training, but the COCOMs are focused on daily operations out to 3 years. Almost no one is engaged in the planning, development, experimentation, etc. leading to exercises focused on longer time frames. In future conflicts, it's anticipated that we will be contested in all domains. Command and control will be particularly difficult, and units will have to rely on mission command, where commander's intent is communicated to lower echelons so the units can continue to operate if communication with higher echelons is degraded.

Joint exercises need to include these realistic threats that are disruptive to Joint operations. In a recent study, the Heritage Foundation advocated for the military to remake itself through experimenting and upgrading technology, rebuilding a force that "would be more 'current' and more operationally effective, than any competitor."[23] The study also advocated an incremental or spiral approach: "If you don't bang away at the problems, take smaller steps to solve them and incorporate all you've learned as you go along, then you won't really become more effective."[24]

As the Services and Joint Staff develop doctrine to address the emerging threat, care must be taken that doctrine isn't overly prescriptive, limiting the responses available to warfighters. The principles of agility, flexibility, adaptability, and speed should be integral components of all Joint and Service doctrine.

3.2 INTERAGENCY

For success in the competition phase, the strategic planning, programs development, execution, validation and revisions, etc. should be performed by an integrated interagency team. The team's leadership could change depending on the type of engagement. As a minimum, the interagency team should include the Departments of State, Defense, Homeland Security, Treasury, Commerce, Justice and Energy, as well as representatives from USAID and the Intelligence Community. Agencies other than the DoD may have the key leadership/ coordinating roles, depending on the situation.

3.3 MULTINATIONAL

One of the primary observations made by the study team involved the lack of clarity of command relationships. MDO involving JIM partners requires the integration of taskings across the whole

[23] Colin Clark, "Heritage to DoD: Do War Games, Experiments, Don't Write Requirements," Breaking Defense, 24 July 2018, https://breakingdefense.com/2018/07/heritage-to-dod-do-war-games-experiments-dont-write-requirements/
[24] Ibid.

of multiple governments with clear understandings of lines of authority and command relationships.

Since most future MDO engagements will be on foreign soil, host nations and Allies must be involved from the beginning. It won't be possible to operate without local assistance in several areas, including infrastructure (roads, bridges, connectivity) and legal, cultural, and policy issues. Each of the U.S, departments and agencies required for interagency cooperation have multinational counterparts that need to be fully integrated and interoperable. The Military Interoperability approach presented by NATO representatives (Fig. 3.2) is a good example of how close the relationships must be.

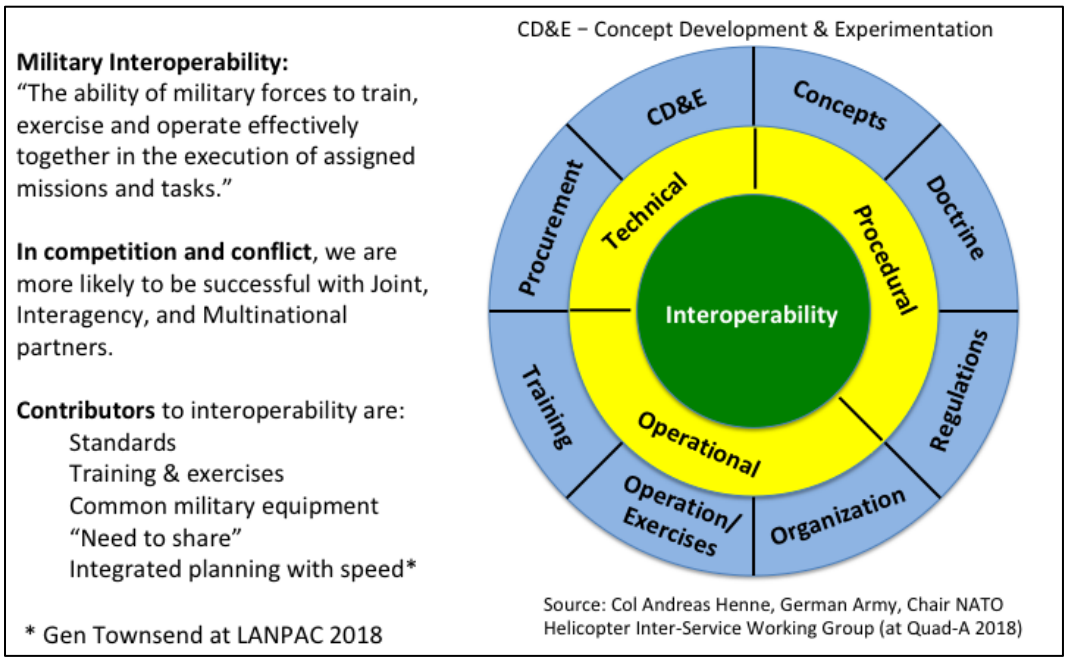

Figure 3.2 Multinational View of Interoperability

Additional components of JIM efforts include each nation's appropriate industries, universities, NGOs and other organizations in an 'all of Nation' approach.

3.4 IMPLEMENTING JIM MDO

A successful MDO concept will require a JIM system that's Joint by design. This means that the system will integrate all the known components from all the partners in the five domains when design begins. Deliberate design early on is a top-level requirement of the System of Systems (SoS) approach (Fig. 3.3). The components include military sub-systems such as communications, operations, command and control, training, and integration. The complexity of the overall system across the five domains will require a very structured approach. Beyond the military, additional sub-systems will be found in the diplomatic, economic, power, information, human, financial, and social media sectors. Since the SoS will need to function and operate in the continuum between competition and conflict, the development of the system architecture will require

informed and appropriate AI tools, experimentation, etc. This isn't a simple undertaking; it will require modeling and simulation of systems with emerging levels of validation and exercises.

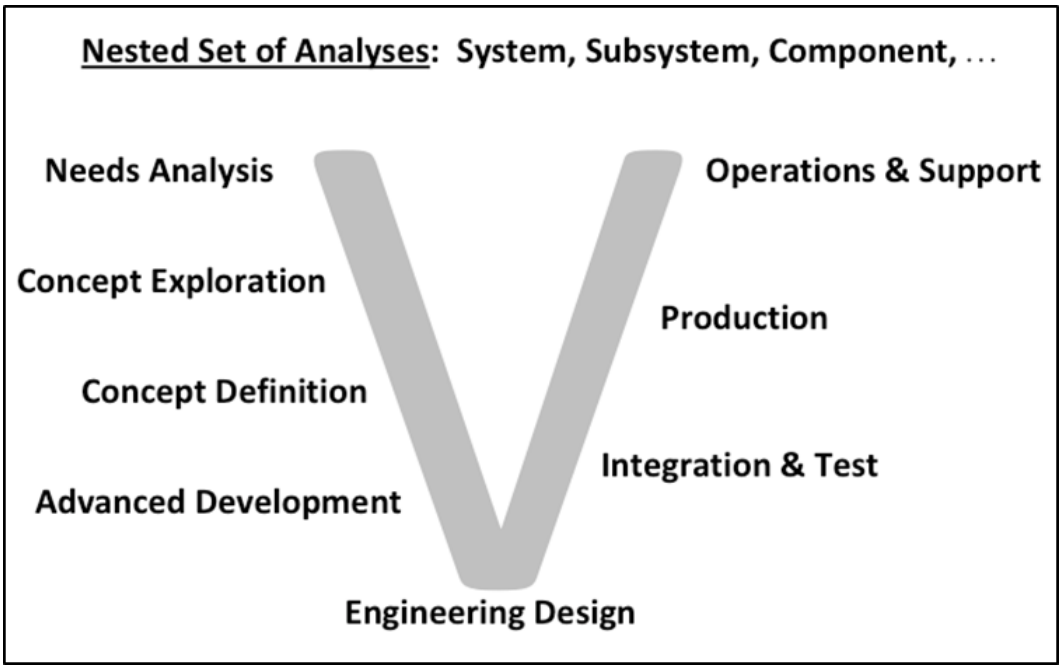

Figure 3.3 Systems Engineering

The study team developed examples of what might be included in an MDO SoS architecture:

- Conflict:
  - Manned-unmanned teaming with AI
  - Autonomous systems with various levels of supervision
  - Assured, secure communications
  - A robust C4ISR architecture with, at a minimum, assured intermittent communications for mission command
  - A model-based system engineering (MBSE) approach
  - A model validation strategy utilizing experimentation and exercises
- Competition:
  - Details of the infrastructure
  - Comms, transportation, water, power, commerce, media/news, banking, etc.

  - Human behavior modeling with ability to test and measure results and effects is required

  - Modeling of the environment and the population

The study team also observed that a high/low mix of cost-effective technical and operational options could provide flexibility and agility throughout the competition/conflict continuum. For example:

- A formation of unmanned expendable/ attritable vehicles with high-end manned vehicles allows new CONOPS and “system survivability”

- Modular, multifunctional characteristics that could lead to emergent behavior

4. EXAMPLES OF MDO OPTIONS

To illustrate the potential impact of MDO, the study team developed operational examples involving Dense Urban Environment (DUE) and Long-Range Precision Fires (LRPF).

4.1 DENSE URBAN ENVIRONMENT (DUE)

According to the U.N.'s Department of Economic and Social Affairs, one out of every eight people in the world lives in one of 31 megacities. Megacity is defined as greater than 10 million people, and 18 of those 31 megacities are in the U.S. Indo-Pacific Command's area of responsibility. By 2030, there will be 43 megacities and approximately another 100 large cities, defined as having populations of 5-10 million. These cities are densely populated with more than 2000 people per square kilometer and so large geographically that they have been called unboundable, i.e., conventional tactics of surrounding the city and controlling ingress and egress simply won't work.

Figure 4.1 "The Army will operate in large cities and megacities."[25]

The ubiquity of urban spaces all but guarantees potential adversaries will intentionally choose cities as a battlespace, giving them the best chance for success against the U.S. and its allies. The enemy has it right: the urban environment negates many of the Army's technological advantages. Citing his experience in Mosul, GEN Townsend described areas of concern:

- Maps, imagery and C2 systems had a hard time keeping up with the battle; the urban landscape changed faster than Soldiers could update imagery.
- The range of sensors was degraded.
- The range and effectiveness of weapons were degraded.

Given those conditions, the DUE is an inherently multi-domain environment. A DUE compresses physical and temporal spaces, compounds obstacles, and demands the simultaneous execution of numerous tasks.

The complexity of urban terrain and the kinds of operations that will need to be conducted there were described presciently by U.S.M.C. Gen Charles Krulak in the mid-1990s when he developed the concept of the "three block war." Soldiers and Marines may be confronted by the entire

[25] GEN Townsend, AUSA LANPAC, May 2018.

spectrum of tactical challenges (mid-high intensity conflict, peacekeeping, humanitarian operations, etc.) in the span of a few hours and within the space of three contiguous city blocks. Krulak emphasized the importance of the individual and the need to push capabilities and leadership down to the lowest levels:

> The individual … will be the most conspicuous symbol of American foreign policy and will potentially influence not only the immediate tactical situation, but the operational and strategic levels as well. His actions, therefore, will directly impact the outcome of the larger operation; and he will become … the Strategic Corporal. [26]

MDO in DUE are best characterized through the primary objectives of competition and conflict:

Competition:

- Objective #1: Stay in competition; avoid moving into conflict. Regardless of the type of operation, the primary objective during competition is to avoid conflict.
  - During competition, operations in an urban environment are likely to be led by the Department of State and/or possibly by the host nation. MDO concepts that emphasize the importance of integrating U.S. agencies and multinational capabilities are essential in this environment.
  - Understanding and exploiting the various dimensions represented in DUE requires operating in all those dimensions.
  - MDO will allow U.S. forces to address political, economic, food, energy, shelter, information, and security concerns.
  - Operating in multiple dimensions creates options that result in more time to achieve objectives through diplomatic means.
- Objective #2: Establish conditions for success in conflict should it occur. Staying in competition may not be possible, so the time in that phase needs to be used to prepare for conflict. Actions will include:
  - Dynamically mapping the terrain, understanding the environment, and building relationships. The intent here is to provide the ability to facilitate keeping up with the battle should that become necessary.
  - Adding resiliency to organic networks by exploiting local networks and providing alternate channels of communication and action.

[26] Krulak, Charles C., "Strategic Corporal: Leadership in the Three Block War," Marines Magazine, January 1999, http://www.au.af.mil/au/awc/awcgate/usmc/strategic_corporal.htm

- Preparing the force through synthetic training and rehearsals to operate in the DUE before they even leave home base, and even while they are in theater. The goal is to create a culture that fosters the development of the strategic corporal.

Conflict:

- Objective: Win the battle without losing the war; return to competition
  - MDO requires a smart C4ISR system to convert massive amounts of data and information into digestible knowledge for the warfighter.
  - Speed. Operations in DUE conflict need to tighten the Observe, Orient, Decide, Act Loop with the recognition that the strategic corporal may be the actor.
  - Less about range, more about reach. Modern weapons lose the benefits of their longer ranges in the channelized environment of DUE. Those benefits can be regained by giving the warfighter greater reach, i.e., access, to weapons effects from different platforms not necessarily collocated with the troops in contact.

The benefits of applying MDO principles to DUE include:

- Create more knowledge
  - Push it to the "Strategic Corporal"
  - Pull from universally available sensors, add micro-UAVs and robots
  - Use AI and machine learning to convert data to knowledge
  - Use activity-based intelligence to improve decision-making
  - Increase sharing of assets and knowledge to enable collaboration with partners
  - Increase speed and effectiveness of C4ISR at every echelon
- Create more options for action in both competition and conflict
  - Improve interactions with the local community through direct relationships using cyber, information operations and social media.
  - Improve the effectiveness and precision of weapons' effects: more "dial an effect" weapons, improved infantry weapons and greater individual soldier lethality

4.2 LONG RANGE PRECISION FIRES

Long Range Precision Fires (LRPF) is one of the six priorities set by the CSA and is the centerpiece to deter and, if deterrence fails, to defeat U.S. adversaries. Having a tactical missile that can travel several 100s of miles, "out sticking" the enemy's capability to respond in kind, relieves the need for rapid deployment of forces in order to prevent an adversary from establishing a *fait accompli* on its "home turf." It also negates enemy defenses without having U.S. air and sea assets to penetrate enemy territory.

Potential solutions for targeting at long range include:

- Use of aviation and space assets to provide a targeting location to the LRPF.

- Network capability updating targeting information to the LRPF munition in flight and receiving sensor information from the munition to communicate Battle Damage Assessment and other targeting opportunities.

While aviation and space sensors exist to detect and locate targets and transmit that information to an exploitation center, there's no pre or post-launch, real-time connection to the LRPF munition. The key technical capability needed to make LRPF effective is a resilient network that integrates all Service capabilities, so each Service can leverage capabilities of the others.

Development of such a network capability has been ongoing for several years. As reported a decade ago in Signal Magazine,[27] the DARPA Mobile Ad-Hoc Interoperability Gateway (MAINGATE) program permitted legacy radios to communicate across tactical networks. In 2013, DARPA reported that MAINGATE was nearing completion and the organization planned to transfer the system to Army warfighters still engaged in Afghanistan.

> The MAINGATE system combines two advanced technologies to provide a reliable, interoperable network for connecting current and future forces from the tactical edge. The first technology is MAINGATE's high capacity Wireless IP Network (WIPN) radio, which provides a terrestrial "Everything over IP" backbone with ample capacity to support multiple channels of voice, video and data. The second technology is MAINGATE's Interoperability Gateway, which provides interconnectivity for users with incompatible communications equipment.[28]

As of 2016, MAINGATE was being used to connect the Army's SOF Grey Eagle UAS to ground and air resources.[29] While the program appears to permit integrating Service capabilities to provide

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[27] Henry Kenyon, "Wireless Gateway to Connect Warfighters," AFCEA Signal Magazine, November 2009, https://www.afcea.org/content/wireless-gateway-connect-warfighters

[28] DARPA, *Radio Gateway Connects US and Allied Troops to a Common Mobile Network*, DARPA Website, 12 December 2013, https://www.darpa.mil/news-events/2013-12-12

[29] Anderson, Cory T., "United States Army Special Operations Forces Unmanned Aircraft," Army Aviation Magazine, 31 July 2016, http://www.armyaviationmagazine.com/index.php/archive

real-time targeting, the Army lacks an organization to develop, produce, and test the capabilities that integrate Army and other Services' capabilities.

Integration plays a critical role in LRPF, especially for targeting, which is a relatively new requirement. In the past, fires (including early rockets) may have used launch and target locations and an onboard navigation system, but they wouldn't be considered 'precision fires' because they were employed to inflict wide area damage. The development of the GPS satellite system and other advances have created the infrastructure required for precise strikes by today's long-range weapons.

Because it provides standoff capability—the advantage of inflicting damage at a farther range than the adversary's ability to fire back—LRPF can be decisive in battle, but it also offers a deterrent to potential adversaries, dissuading them from attacking in the first place. Potential near-peer adversaries such as China and Russia aspire to create that very dilemma for U.S. forces. They learned from Operations Desert Shield and Desert Storm never to allow the U.S. and its allies the time and space to deploy forces to an area where they could stage, build-up, and eventually employ. Keeping U.S. forces at a distance beyond tactical use would require long-range weapons that could be targeted for maximum effect. Thus, each country is developing standoff weapons and enabling technologies to keep U.S. forces at bay:

- China – to counter U.S. economic and military dominance in the Western Pacific, China cast itself as a "protector" for the region. One of its first steps was to outfit its Navy with anti-ship missiles that had a longer range than the equivalent missiles on U.S. ships. The Chinese also pursued the capability to defeat U.S. aircraft carriers, which would negate U.S. Naval airpower's ability to take over the ship-to-ship missiles role. To keep U.S. aircraft carriers at standoff distance, China developed the DF-21, believed to be a derivative of the U.S. Pershing missile, as an anti-ship ballistic missile with a maximum range exceeding 100s of miles.[30] Based on the DF-21 technology, China has also developed a conventionally armed, hypersonic, land-based, anti-ship ballistic missile.[31] The ranges of these and other weapons systems pose a challenge to U.S. Naval and Island assets in the Pacific (Fig. 4.2). In response, DARPA started a program to develop the Long-Range Anti-Ship Missile (LRASM), now entering deployment, to begin reestablishing U.S. ship-to-ship dominance. Eventually, hypersonic missiles will be launched from aircraft or ships outside China's standoff capability. Missiles might also be deployed on islands outside the range of Chinese weapons and constantly moved to avoid accurate targeting. Critical to developing these advanced systems: a network with the capability to transmit updated target locations to the LRPF system while the missile is in flight.

[30] Wikipedia, DF-21, https://en.wikipedia.org/wiki/DF-21
[31] Ibid

- Chinese missile capabilities continue to increase in range and integration.
- China is advancing its anti-access and area denial capabilities. The idea is first to push the US Navy beyond the "first island chain" and ultimately make it too dangerous for it to operate within the "second island chain".

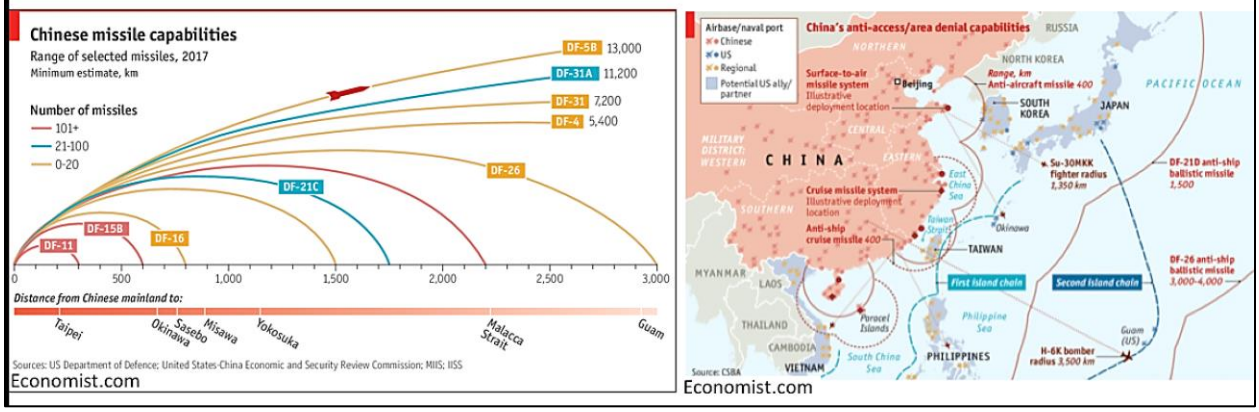

Figure 4.2 China Learns the Lessons of Desert Storm

- Russia – Russia has also learned from Desert Storm and is modernizing its forces (Fig. 4.3), to include developing long-range weapons that put pre-deployed U.S. forces in Eastern Europe at risk. It's estimated that Russia could invade and take control of any Baltic country in 60 hours or less, assuming they had their forces positioned on the borders. There seem to be few options for the U.S. and NATO to prevent that form or aggression. Pre-deploy forces again, as was done during the Cold War would require a massive undertaking and put Allied forces in range of Russian LRPF. A second option would be to develop a U.S. ground based LRPF system with a range well outside of Russian capability, or to use airborne LRPF. The likely quantity of LRPF missiles and the rate of fire needed to be effective would seem to drive up the number of airborne assets and to potentially favor ground-based systems. In either case, there will be a need for a network to initially target and then update the target location after launch.

- Russian indirect fire systems (MRLs, artillery, missiles) outrange U.S. systems.
- New Russian long range SSC-8 cruise missile enables attack at ranges ≥ 2,000 km
- Advanced IADS capabilities provide important Anti-access and Area Denial advantage that inhibit attack of enemy forces and supporting assets from combat aircraft

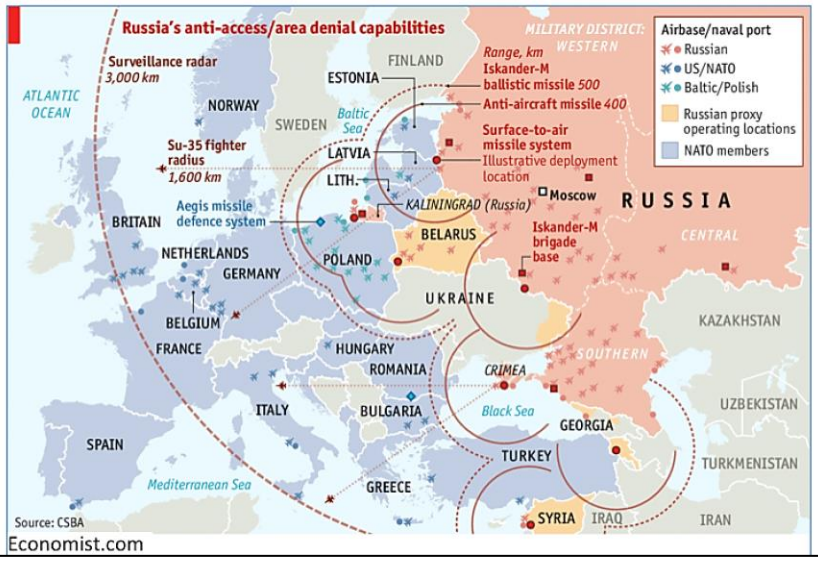

Figure 4.3 Russia Learns the Lessons of Desert Storm

The standoff qualities of LRPF, in the sense of who can shoot farther and more accurately, have historically been a major determinant of which side wins wars. Over time, the distance covered by LRPF has grown to the extent that "local to the missile launcher" targeting information is no longer viable. In addition, the time between firing the projectile and it hitting the target is now long enough that the target is likely to move. This creates a need to be able to update the target location while the projectile is in flight.

Having each Service create its own comprehensive, long distance targeting and communication system is cost prohibitive and potentially not resilient in a peer conflict. Since components of the long-range fires kill chain exist in each of the separate Services, the MDO concept can enable bringing them all together in a cohesive LRPF system. Each Service needs to establish a concept for integrating its capabilities.

5. TECHNOLOGY OPTIONS AND OPPORTUNITIES

The first finding of the FY 2017 MDB Study addressed the need for new capabilities:

> Rapid advances and new disruptive capabilities, employed in a fully integrated MDB manner, are needed to ensure overmatch.
>
> - Potential peer adversary capabilities are advancing rapidly and will continue to do so.
>
> - A peer conflict is unlikely to be won by multi-domain integration of existing and/or slowly evolving capabilities.[32]

The study team also reported its belief that "using current capabilities in different ways will likely not defeat potential peer adversaries." The 2018 MDO study team supports this finding and believes new technology options are needed.

5.1 TECHNOLOGIES CRITICAL TO MDO IN CONFLICT PHASE

Each Service has developed technologies that allow that Service to operate within its primary domain(s). MDO, demands that individual Service capabilities be able to assist another Service meet its objectives. For example, Army LRPF can be used to destroy anti-access capabilities employed against aircraft or to destroy artillery designed to threaten Naval ships.

The major technical capability required is a network that seamlessly allows the capability of each Service-supplied system to be used when appropriate. Such a network would also allow the Services to train together and learn how best to integrate other Service capabilities.

There are different ways to develop such a network capability:

- All Services procure and use a common network system. The development cost would be daunting and may not make use of the investments already made in each Service's systems, which currently satisfy their respective requirements.

- Develop a capability that integrates the existing networks seamlessly and transparently, such as MAINGATE (described previously).

Other technical capabilities can begin to address challenges presented in the conflict phase of MDO. For example, in addition to integrating across Services as described above, operationalizing MDO will require technical and operational integration across multiple domains and multiple functions over extended geographic regions and time. That integration will require operation in a degraded/denied communications and network environment as well as faster decision-making

[32] Army Science Board Fiscal Year 2017 Study, Multi-Domain Battle, Final Report, January 2018

capabilities (Fig. 5.1) It should be noted that some technologies could be developed and deployed more quickly than indicated if significant investments are made.

Operational Challenge	Near (Now-2025)	Mid (2026-2035)	Far (2036-2050)
Degraded/denied comms/networks; Pace of battle requires faster decision-making	Self-healing C4; Mission Command; Introduce commander's aids; Reduce CP size/signature; Data analytics; Small sats	Incorporate AI; Comm nodes available in multiple domains; Low probability of intercept	Small battle nets; Quantum communications
Survivable formations; Rapidly deployable expeditionary forces	MUM-T/Autonomy/AI for Wingman: Apache w/ Fire Scout/ Shadow, ARCV (UGV, 7-15 ton)	Fleets of multi-domain robots (10:1), Comms: LPD, LPI, AJ	Swarms of multi-domain autonomous robots (100:1)
Anti-Access & Area Denial; Long Range Precision Fires out-ranged	Deploy (2x range of ATACMS); Submunition warhead/ISR	Hypersonic glide (>50% flight) range 500-1000 nm; Smart submunitions	Hypersonic propulsion; Low cost cruise missile; Rail gun w/ scram shell
Timely ISR data Need to support long range precision fires	Targeting/fire control through UAS, space-based (LEO) SAR, EO/IR formations	Space-based MTI (LEO); Multi-domain fleets of robots	Ubiquitous ISR; Multi-domain swarms of autonomous robots
Counter-UAS (single/swarms)	"Iron Beam" on CAT 25-50 kW (UAS, rockets); Air-to-air UAS	Extend to RAM; Multi-domain fleets of robots	Multi-domain swarms of autonomous robots
Degraded/denied PNT	Miniaturized precision clock (CSAC); Digitized terrain map; Digitized compass/LRF; Celestial nav update	Precision INS on current GPS-guided munitions	Optimum mix of absolute and relative navigation

Figure 5.1 Examples of Technologies Critical to MDO in Conflict Phase

For example, in the near term (~2025) U.S. forces could begin using mission command[33] to minimize the amount of information needing to be transmitted. Combined with self-forming networks and other technologies, the operational impact of degraded communication environments would be reduced. Similarly, in the midterm (~2035), low probability of intercept communications could provide secure, short-range communications and enable formations of unmanned vehicles to provide multifunctional capability, including real-time updating of the battlefield environment.

5.2 TECHNOLOGIES CRITICAL TO MDO IN COMPETITION AND RETURN TO COMPETITION

The degree of difficulty returning to competition after conflict is largely driven by the intensity and duration of the conflict. Damage to physical and organizational infrastructure impacts efforts to return to competition. Several other inter-dependencies between conflict and return to

[33] The exercise of authority and direction using mission orders to enable disciplined initiative within the commander's intent.

competition make the technologies that are critical during conflict also act as supporting or enabling technologies needed to overcome some of the challenges in the return to competition (Fig. 5.2).

Operational Challenge	Near (Now-2025)	Mid (2026-2035)	Far (2036-2050)
Map and influence the environment and people	Imbedded and Unattended sensors for Situation Assessments. Social Media Analytics with Controls. Monitor & Control the health of the Infrastructure (power, water, etc.)	AI at the Edge & Machine Learning for rapid fusion of Information. Advanced use of genetic markers to guide treatments for diseases	Thought Controlled Operations. Imbedded human sensors. Auto detection & treatment of illness's and diseases. Weather Control
Attract partners	Ensure common goals & values, Share common tools and assets. Move from need to know to need to share.	Advanced joint technology & concept development	Continue partnership agreements
Comms for military & civilian in urban terrain. Wide area Knowledge capture	Bridge connections to existing cell networks. LEO small sats for comms and SA.	Comms: LPD, LPI, AJ; Data to knowledge using AI	Quantum Communication
Low collateral damage weapons	Non-lethal weapons, HPM, cyber, etc.	More compact and rapidly deployable systems	Advanced concepts
Robotics and Autonomy	Control multiple ground and air unmanned systems	Increased levels of autonomy	Multi-function and autonomous

Figure 5.2 Examples of Technologies Critical to MDO in Competition Phases

Technologies relevant to competition include sensors, communications, and information, including AI, that can aid in understanding the environment and positioning U.S. forces to succeed in conflict if deterrence fails. To collect and analyze extensive amounts of data in all domains, the Army must position itself to take advantage of and exploit the relatively perfect communications available in competition prior to conflict.

Other emerging developments that will support efforts in competition include:

- Continued expansion of the Internet of Things. Eventually, each person may have multiple devices (handhelds and wearables) capable of providing real-time information and sensing.

- Mobile and/or compact power sources. Some nanotech and chemical-based technologies could provide local power in remote locations.

- Real-time language conversion technology could advance the ability to build relationships and eventually trust.

5.3 Technology Trends and Planning Strategies

In several militarily important areas, including hypersonics and AI, the U.S. is competing with Russia and/or China to develop advanced systems.

There are two types of hypersonic weapons that travel at Mach 5 or greater–hypersonic cruise missiles (HCM) that are powered throughout flight and hypersonic glide vehicles (HGV) that are launched into near space and then glide to the target. Both types may be ready for military use in a decade or less.[34] The U.S., Russia, and China are currently leading hypersonic technology development, followed by other nations such as France, India, and others. Russian President Vladimir Putin introduced two hypersonic weapons in his State of the Union address in March 2018: one HCM (the Kinzhal) and one HGV (Avangard).[35] China has developed the DF-ZF HGV, which will reportedly be deployed in 2020, although some analysts believe it will take longer than that to develop a missile that can carry the HGV.[36] The US has had a hypersonics program for over two decades and it's now a top R&D priority. Under an Army Advanced Concept Technology Demonstration (ACTD) initiated in 1997, Lockheed Martin delivered 12 Line-Of-Sight Anti-Tank (LOSAT) systems. The system included 5,000 ft/sec kinetic energy missiles and a fire control system mounted on a HMMWV. Although testing was successful, the system was not taken to production.[37] However, an Army Advanced Technology Demonstration (ATD) of the Compact Kinetic Energy Missile (CKEM), a spiral development of LOSAT, was funded in 2003. The lighter CKEM, designed for the Future Combat Systems, exceeds Mach 6.[38] The final flight test of CKEM against a T-72 tank was successfully completed in February 2007. In August 2018, the Air Force announced the award of a $928M contract to Lockheed to design, develop, and test the Hypersonic Conventional Strike Weapon.[39] Global work in hypersonics continues.

Both China and Russia are investing heavily in AI. President Putin has said that the nation that leads in AI "will become the ruler of the world."[40] According to center for Naval Analyses (CNA) analyst Larry Lewis, "The major challenge for the U.S. is China; they are approaching the use of AI just like the U.S. approached going to the moon in the sixties."[41] In June 2018, DoD created a

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[34] Richard H. Speier, George Nacouzi, Carrie A. Lee, and Richard M. Moore, *Hypersonic Missile Nonproliferation – Hindering the Spread of a New Class of Weapons,* RAND Research Report RR2137, 2017, www.rand.org/t/RR2137 .
[35] Sam Brimelow, "Russia, China, and the US are in a hypersonic weapons arms race – and officials warn the US could be falling behind," Business Insider, 30 Apr 2018, https://www.businessinsider.com/hypersonic-weapons-us-china-russia-arms-race-2018-4
[36] Ibid
[37] "LOSAT Line-of-Sight Anti-Tank Weapon, Army Technology, https://www.army-technology.com/projects/losat/
[38] "CKEM", Directory of US Rockets and Missiles, Appendix 4: Undesignated Vehicles, last updated Jun 2009, http://www.designation-systems.net/dusrm/app4/ckem.html
[39] Marcus Weisgerber, "Lockheed Will Design Both of US Air Force's Hypersonic Missiles, Defense One, August 2018, https://www.defenseone.com/business/2018/08/lockheed-will-design-both-us-air-forces-hypersonic-missiles/150549/
[40] RT. 'Whoever leads in AI will rule the world': Putin to Russian children on Knowledge Day. 1 Sep 2017. https://www.rt.com/news/401731-ai-rule-world-putin/
[41] Sidney Freedberg Jr., "Joint Artificial Intelligence Center Created under DoD CIO," Breaking Defense, June 29, 2018, https://breakingdefense.com/2018/06/joint-artificial-intelligence-center-created-under-dod-cio/

new Joint Artificial Intelligence Center (JAIC) that will coordinate U.S. efforts. AI has a potential role to play in analyzing massive amounts of data, decision-making at speed, and autonomy, though there are ethical concerns around privacy and autonomy for lethal systems. The extent to which these concerns limit development and use of emerging technologies will likely differ significantly between the U.S. and its near peers.

It's important for the U.S. to recognize the need to aggressively pursue key technologies. In recent years, the U.S. has faced non-peer adversaries, against whom competing wasn't as challenging as it will be facing a peer or near-peer adversary. To use a duck hunting analogy, it's important to lead the target when aiming (Fig. 5.3). Focusing on an adversary's demonstrated capabilities is akin to aiming behind the duck, which will result in a miss. Likewise, focusing on potential, current capabilities is like aiming at the duck, which will also produce a missed shot. It's necessary to focus on an adversary's projected capability, i.e., to aim at where the target will be, to hit the duck.

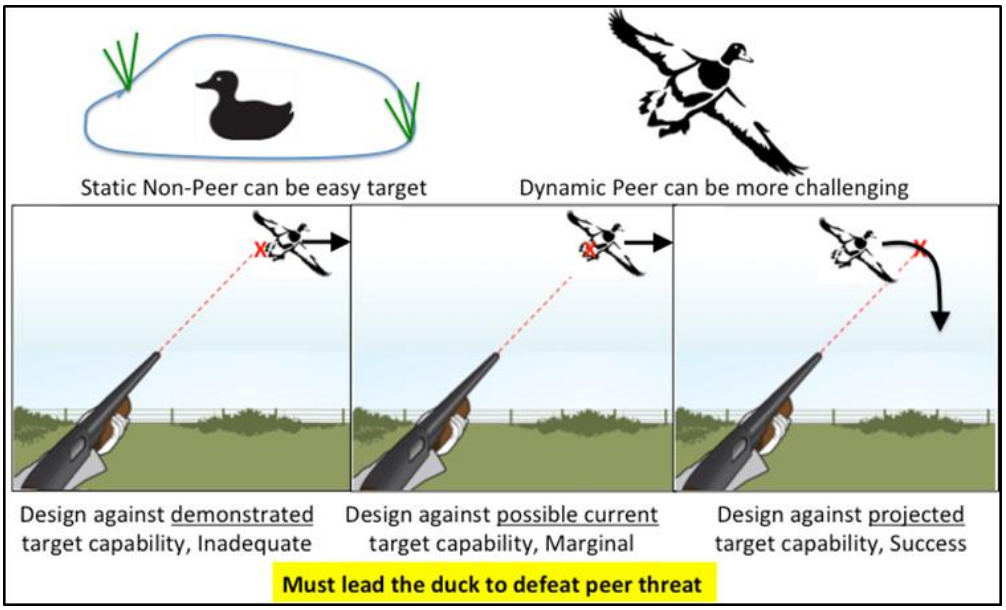

Figure 5.3 Potential Planning Strategies

The U.S. must consistently understand and project an adversary's technical capability and counter with its own demonstrated capabilities that exceed the adversary's at all times (Fig. 5.4).

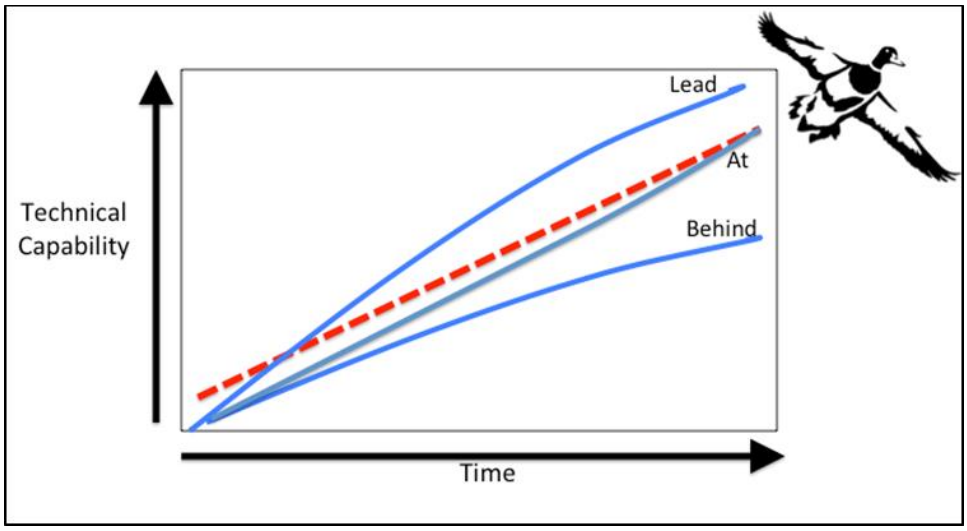

Figure 5.4 Where to Aim

5.4 CSA PRIORITIES

The CSA's modernization priorities (Long Range Precision Fires, Next Generation Combat Vehicle, Future Vertical Lift, Networks, Air & Missile Defense, and Soldier Lethality) tend to focus primarily on capabilities needed in the conflict stage and are therefore necessary but not sufficient for successful execution of MDO in all of its phases. The Army has roles in the competition and return to competition phases and needs to equip for those. Some important capabilities include rapidly deployable expeditionary forces, enhanced wide-area and local-area situational awareness, environmental mapping, social network access and exploitation, and non-lethal and low collateral damage weapons.

Army systems and concepts need to be designed for and capable of integrating with Joint and multinational formations as well as across the Army. For example, a high/low mix operating concepts offer the potential for less capable partners to play key roles in the competition continuum. In addition, low cost, unmanned systems could provide flexible, agile, attritable and/or expendable system options, but they must be compatible with higher end systems.

A set of cross-cutting disciplines provides potentially disruptive technical and operational options. These include autonomy, AI, decision theory, quantum technology, and hypersonics. These also need to be addressed in Army S&T efforts and coordinated with JIM communities.

These considerations lead the study team to recommend that a Systems Engineering Cross-Functional Team (CFT) be established to facilitate integration across the other CFTs and all Army entities.

5.5 CYBER, INFORMATION ENVIRONMENT OPERATIONS AND CYBER ELECTROMAGNETIC ACTIVITIES

Highly integrated and effective cyber, Information Environment Operations (IEO) and Cyber Electromagnetic Activities (CEMA) are critical for successful MDO, because they support all the other domains in competition, conflict and return to competition. The 2018 NDS identified that cyber threats are impacting our national security and will continue to develop. It also indicated a necessity for the U.S. to prioritize investments for the modernization of cyberspace capabilities and the continued integration of these functions into the full spectrum of military operations. The study team believes that both defensive and offensive cyber capabilities will enhance the broad spectrum of competition and conflict in MDO.

An evaluation of the Russian cyber threat by CNA found:

> In a conflict, the Russian government could use debilitating cyber operations against U.S. infrastructure as a psychological operation to, for example, convince the U.S. populace that any conflict with the Russian Federation would have a high cost and should not be pursued. It stands to reason that the Russian government would also employ cyber operations to target military logistical, communications, and C2 systems on the battlefield.[42]

The Army's vision to counter these capabilities focuses on networked, decentralized forces. For example, at TechNetAugusta 2018, the Deputy Commanding General of TRADOC explained, "Integration, not synchronization is key to effective delivery and results of warfighting systems. Technology and new war fighting doctrine is focusing on disaggregation of forces for protection."[43] The TRADOC Capability Manager for cyber said that the Army lacks:

> A comprehensive understanding of cyberspace (broadly defined as cyber, electromagnetic spectrum, space and social media). In multi-domain operations it is imperative that someone develop systems for understanding cyberspace and the Army is in the process of prototyping a program that in 2020 will be called cyber situational understanding (cyber SU). This tool will help pull information from all types of sensors that provides greater intelligence and allows commanders to visualize and understand what is happening in the nonphysical battlespace under their command that could have drastic impacts on operations.[44]

The Army Cyber CoE at Ft. Gordon is a focal point for developing defensive and offensive cyber capabilities. According to the Commander, the Army has initiated one pilot project with the Army

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[42] Jeffrey Edmonds, "The Evolution of Russian Military Thought and Its Relevance to US Army Multi-Domain Operations," CNA Report DIM-2018-C-018541-1Rev, October 2018 (SECRET NOFORN), page 19.
[43] Theodore Martin, Keynote at TechNetAugusta 2018, 21 August 2018, http://events.afcea.org/Augusta18/Public/SessionDetails.aspx?FromPage=Sessions.aspx&SessionID=6504&SessionDateID=505
[44] Steven Rehn, speaking at TechNetAugusta 2018, 21-23 August 2018.

Pacific Command and is seeking to begin another within the continental U.S. to better define formations that will integrate cyber, electronic warfare, signal, and intelligence capabilities.

> We've got an effort on board to where we will actually stand up a CEMA section inside each one of our operational formations where we bring the various [elements] together so they can collaborate and operate in an integrated fashion. In cyberspace … it's all got to be wrapped together with the right intelligence underpinnings. If you don't have intelligence in cyberspace, you're not effective. It's that simple.

The change is being driven in part by the service's new doctrine covering cyberspace and electronic warfare operations.

> We've got to come up with an integrated formation that's actually going to start executing CEMA," An integrated formation, he said, will "bring it together and really start getting after the tenets of multi-domain battle in a fused, synchronized and integrated fashion.[45]

The purpose is to "learn by doing." The Army will determine what the force structure needs to look like, what capabilities are needed, and how to reach back to cyber elements in distant locations, such as Fort Gordon and Fort Meade. In the future, each operational formation may have some cyber capabilities (e.g., enabled by AI at the edge). "If you buy into CEMA, this is all about integrating and everybody bringing core competencies to the table to support one person—the maneuver commander," Gen. Morrison said.[46]

Cyber COE is expeditiously fielding and testing prototype systems through competitions known as Cyber Quest (industry competition of systems) and Cyber Blitz (government system testing and demonstration). Members of the study team attended one of these exercises and de-briefings. Cyber Quest is a model that could be used throughout the Army Acquisition process for industry to demonstrate iterative implementations of operations, technologies, exercises and feedback for continuous improvements. The Soldiers using the systems in field environments can provide valuable feedback to both industry developers and government.

Cyber concepts are being operationalized in exercises at the major command level. For example, PACOM is focusing on the future Army MDO organization along with others in the JIM community. Exercises and operations to counter enemy CEMA operations allow allies and partners access to cutting edge technologies and protocols that are essential for MDO**.** One of the challenges in CEMA is the classification of information for sharing with allies. Attempts are being made to ensure that information is pushed to the lowest level and out to allies without classification whenever possible.

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[45] George Seffers, "US Army Conducts Cyber Integration Projects," Cyber Edge, Signal Magazine, 8 Aug 2017, https://www.afcea.org/content/us-army-conducts-cyber-integration-projects

[46] Ibid

5.6 COUNTER-UAS AND AIR AND MISSILE DEFENSE

Controlling multiple unmanned systems has been demonstrated and is being deployed around the world, representing both a threat and an opportunity. For example, the opening ceremony at the Pyeongchang Olympics demonstrated formations of 1,200 Intel UAVs that created the image of a snowboarder, and then morphed into the Olympic rings (Fig. 5.5). It's likely that the number of vehicles will increase significantly over time in both commercial and military applications.

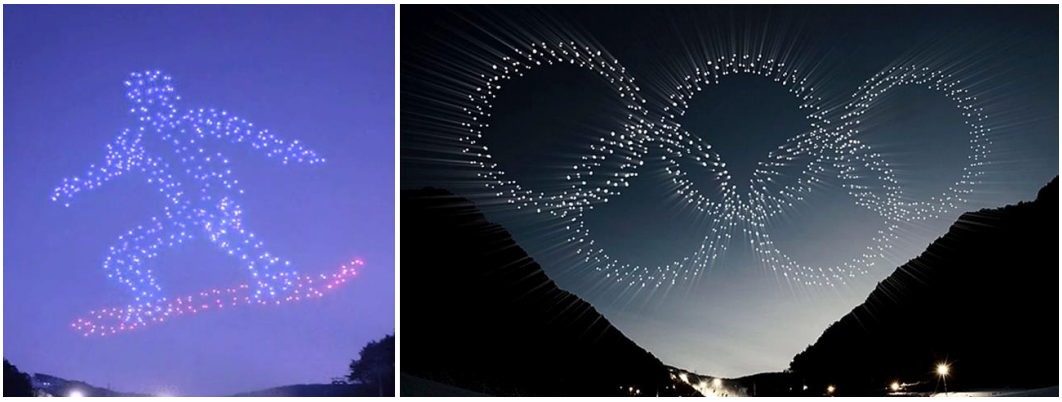

Figure 5.5 The Snow Boarder and Olympic Rings

UAS are already used extensively for intelligence and logistics, and other uses are emerging. There have been numerous reports of the weaponization of drones for offensive purposes.[47] Systems have proliferated from the Middle East to the Ukraine. It will be necessary to develop a cost-effective (i.e., favorable cost-exchange ratio) counter to this capability. Counter-UAS systems would most likely use advances in MUM-T, Robotics and Autonomous Systems, AI, electronic warfare (EW), and directed energy, along with innovative solutions not yet envisioned. A suite of UAS-based defensive systems offers potential options for both countering UAS and air and missile defense. Such systems can play a role in the urban environment and could be valuable in the "Three Block War."

[47] Christian Davenport, "How the Pentagon is preparing for the coming drone wars," The Washington Post (Business Section), 24 November 2017, https://www.washingtonpost.com/business/economy/how-the-pentagon-is-preparing-for-the-coming-drone-wars/2017/11/24/3e4ff736-cfd1-11e7-81bc-c55a220c8cbe_story.html?utm_term=.1a5653254290

6. ROLE OF PEOPLE

There are significant changes coming for human roles in a future environment where the character of conflict and competition has changed. With potential adversaries having the ability to contest all domains and to rapidly develop future capabilities, the U.S. will need to develop key partnerships and to leverage advancing technology. Personnel in each Service will need to view the world in more JIM terms and recognize the increasing scale and speed of operations in the future.

As the OE becomes more complex and more dependent on rapidly advancing technology, the role of people must change to accommodate the faster pace of engagement, with some activities being accomplished beyond human speed. Instead of developing an architecture in which the computer is designed to help the person, it may be preferable to design a system in which the person becomes involved only when the machine needs help. In addition, the talents and strengths of people working closely with machines may emphasize highly complex thinking capabilities. They also may not need to meet the traditional physical standards for Army personnel in certain specialties.

6.1 AUTONOMY AND AI

In June 2018, OSD established the JAIC under the DoD Chief Information Officer. The establishing memorandum from the Deputy Secretary of Defense stated:

> The 2018 National Defense Strategy (NDS) foresees that ongoing advances in artificial intelligence (AI) 'will change society and, ultimately, the character of war.' To preserve and expand our military advantage and enable business reform, we must pursue AI applications with boldness and alacrity while ensuring strong commitment to military ethics and AI safety. A new approach is required to increase the speed and agility with which we deliver AI-enabled capabilities and adapt our way of fighting. [48]

AI-enabled autonomous systems can help to operationalize MDO in many domains. Levels of autonomy vary from remote controlled vehicles which have no autonomy, to vehicles that navigate using waypoints, to vehicles that can be given a task with certain constraints, to full autonomy. There are diverse views on the use of autonomy within the Army. Supervised autonomy is more probable in the near term for reasons ranging from ethical man-in-the-loop considerations to the simple fact that full autonomy is unlikely to work in contested environments.[49] In the longer term, exercises and experiments will help inform the use of greater autonomy as well as provide information on potential adversary capabilities. For ground systems,

[48] Sidney Freedberg, Jr., "Joint Artificial Intelligence Center Created under DoD CIO," Breaking Defense, June 29, 2018, https://breakingdefense.com/2018/06/joint-artificial-intelligence-center-created-under-dod-cio/
[49] Scott Gourley, "Make Way for Autonomy," 20 March 2018, Army Magazine April 2018, https://www.ausa.org/articles/make-way-autonomy

current development envisions a manned vehicle that controls multiple remote-controlled vehicles. As autonomy and AI capabilities improve, the number of vehicles per controller can increase, e.g., evolving cooperative behavior among multiple systems, such as swarms. For successful MDO, dynamic integration of human and machine assets across all domains will be required.

A critical challenge for the development of autonomy is the trust a human controller/supervisor has in the subordinate machines. Trust can only be developed through practice in realistic environments at increasing levels of complexity.

6.2 OPTIMIZED HUMAN-MACHINE SYSTEMS

The massive amounts of data being produced in multiple domains can only be processed in relevant time scales by using advanced data analytics, machine learning, and artificial intelligence. The speed needed to recognize, discriminate, target, and decide is moving beyond human capacity, driving the need for automation and/or optimized human-machine systems. Speed and accuracy trades must be understood to be properly undertaken.

In such applications, the machine enhances the decision-making capability of the human. In complex scenarios, the human may enhance the decision-making capability of the machine (AI at the edge). The goal is to optimize across a spectrum of dynamic human-machine combinations. In other applications, the machine may enhance the physical reach of the human by carrying a payload of some sort (surveillance equipment, lethal mechanisms, logistics) to a remote location.

Optimized human-machine systems will necessarily evolve in time, and if the rate of change of technology is high throughout this century, then one would expect continuous change in challenges and opportunities. Thus, the optimized solutions/options must evolve at a high rate as well.

The Army will need to develop and field optimized human-machine systems for the battlefield and encourage the development of the next generation of capabilities. This will require the Army to assist in various endeavors such as improved business practices, policy, data creation and analysis, training, R&D, etc. Public-private partnerships could provide an efficient means to continuously explore evolving options.

Optimized human-machine system experimentation must be performed to improve understanding of technical system performance and the value to the relevant CONOPS. Experimentation across many endeavors will also support the culture change needed to operate in this high-speed environment.

6.3 DEFENSE CULTURE AND MDO

The challenge to adapt a new role for people in partnering and optimized human-machine systems scenarios is heavily dependent on accepting cultural change within the Army and other Services.

The speed enabled by advanced human-machine systems also requires approaching these future capabilities from a Joint/JIM perspective from the beginning. The architectures and system designs must allow for rapid insertion of new capabilities through high-low mix constructs and modular design approaches. An important part of the cultural change will be increased comfort with and trust of AI across many activities.

MDO inherently involves JIM forces, but the culture within the Services tends to emphasize Service-specific capabilities and goals. Pride in one's Service should not interfere with cooperation with others. Changing the culture requires a change in training and education.

Entry-level staff will tend to follow the more senior leadership. Very senior leadership tends to have more experience and perspective on Joint operations. Thus, while training and education should occur at all levels, a focus on mid-level Service leadership must be a priority. Similarly, there must be alignment of incentives and measures of success (example, promotion and assignments).

7. FINDINGS AND RECOMMENDATIONS

The study team developed ten sets of findings and recommendations in the broad categories of Joint, Examples, Technology, and People.

7.1 JOINT BY DESIGN

As is described in Section 3.4, a successful MDO concept will require a JIM system that is Joint by Design. This means that the system will integrate all of the known Components from all of the partners in the five domains when the design begins. This will be the top-level requirement of the system of systems approach. As is captured in Figure 7-1 the first recommendation is for DoD to develop and resource a coherent organizational structure to develop multi-domain concepts and doctrine and evaluate them in realistic, integrated experimentation and exercises.

Findings:

- Army MDO must be Joint, Interagency, and Multinational by Design.
- Single Service-developed multi-domain concepts are not sufficient for a fully integrated Joint MDO concept.
- There is a limited set of DoD joint experiments and exercises with time horizons beyond 3 years.
  - The most successful experiments and exercises are Jointly planned and executed. Single-Service exercises that include other Services are a step in the right direction.
  - There is a history of interagency reluctance to participate in military exercises.

Recommendation: CJCS Develop and resource a coherent organizational construct with Joint, Interagency, and Multinational partners to develop multi-domain concepts and doctrine, and evaluate them in realistic, integrated experimentation and exercises, particularly for the mid and long term.

7.2 SYSTEM OF SYSTEMS APPROACH

The complexity of an overall SoS across the five domains will require a very structured approach that includes (but isn't limited to) diplomatic, economic, power, information, human, financial, and social sub-systems. The SoS will need to function and operate in the continuum between competition and conflict, requiring a SoS architecture of options for MDO. It's also recommended that a Systems Engineering CFT be established to integrate the other CFTs.

Findings:

- MDO requires a system of systems approach.
- The system of systems approach would expand the range of options critical to successful multi-domain operations in a contested environment (multi-functional "subsystems" and emergent behavior).
- There is no system of systems architecture for multi-domain operations in Conflict or Competition.

Recommendations:

- CG AFC: Develop a system of systems architecture of options for multi-domain operations in conflict and competition.
- SA: Establish a Systems Engineering CFT to integrate the other CFTs to facilitate more rapid advance of multi-domain capabilities and support requirements development.

7.3 MODELING AND EXPERIMENTATION

Development of a SoS architecture must be based on modeling and simulation of systems with emerging levels of fidelity. Joint models tested in Joint experiments should explore common tools and technologies. In addition, Army Futures Command should conduct multi-domain modeling, experimentation, exercises, and analyses.

Findings:

- Modeling and experiments should inform MDO development.
- The Services do not have sufficient Joint, Interagency, and Multinational involvement in their models and experiments, nor do they fully exploit common advanced tools and technology.

Recommendations:

- CJCS and USDR&E: Develop and deploy to the Services, Joint models and experiments using common advanced tools and technology.
- CG AFC: Conduct multi-domain modeling, experimentation, exercises, and analyses of system of systems concepts that address capability gaps in realistic mid to far term threat environments.
  - Develop holistic approaches that include high/low mixes of collaborative manned/unmanned systems, higher levels of autonomy, PNT in degraded environments, attritable unmanned assets and enhanced Directed Energy.
  - As appropriate, leverage AI and machine learning.
  - Expeditiously develop and validate systems architectures and CONOPS.

7.4 DENSE URBAN ENVIRONMENT

The ubiquity of urban spaces will drive the Army to focus on competition and conflict in DUE. Potential adversaries will intentionally choose cities as a battlespace to afford their best chance

for success, because the urban environment will negate many of the Army's technological advantages. The Army will need to create more knowledge using robotics, AI, and machine learning, as well as more options for action in both competition and conflict. A review of these programs should be performed, and shortfalls addressed. Experiments and training for DUE engagements should be increased.

Findings:

- MDO is critical to success in the Dense Urban Environment.
- Army MDO conceptual thinking properly recognizes Dense Urban Environment (DUE) operations as an inherently multi-domain environment that compresses physical and temporal spaces, compounds obstacles and demands simultaneous execution of innumerable tasks.
- The benefits of robotics, autonomy, AI, and big data analysis are essential for DUE situational awareness, effective decision making and adequate operational reach. Realization of these benefits can only be achieved with interagency integration.
- The "Three Block War" syndrome tests the limits of the human psyche which can, to some extent, be overcome through training.

Recommendations:

- CG AFC: Evaluate and adjust the Army's robotics, autonomy, AI and big data analysis programs to address Army capability shortfalls in DUE.
- CG AFC: Create a "Three Block War" laboratory to investigate advanced technologies and concepts.
- CG TRADOC: Evaluate and adjust the Army's training programs to be commensurate with the complexity and probability of DUE engagements.

7.5 LONG RANGE PRECISION FIRES

For LRPF to be successful, it's necessary to directly update the projectile's target location while in flight. It's also necessary for the Services to establish a concept for integrating all their individual targeting capabilities to act as one. An integrated munition and targeting system should be developed.

Findings:

- Long Range Precision Fires and MDO are interdependent.
- The Long-Range Precision Fires (LRPF) and Network CFTs are developing systems that have significant issues and shortfalls:
  - The Network CFT is not currently recommending network options that link the aviation and space assets to the LRPF Command and Control Center and the LRPF munition in flight.
- The LRPF CFT is not currently recommending a munition that has the capability to receive position updates of target location in flight.

Recommendations:

- CG AFC: Design and develop a maneuvering Long Range Precision Fires system that includes the network, sensing, and targeting required to make it effective.
- CG AFC: Design and develop a maneuvering munition for the Long Range Precision Fires System with the capability to receive commands in flight and to transmit SA and location information back to the LRPF Command and Control system.

7.6 CSA PRIORITIES AND MDO

The CSA's priorities (Long Range Precision Fires, Next Generation Combat Vehicle, Future Vertical Lift, Networks, Air & Missile Defense, and Soldier Lethality) are necessary but not sufficient for successful execution of MDO in all of its phases. These priorities tend to focus on the conflict stage, which is primarily the responsibility of DoD. DoD can also play a role in some scenarios in competition, especially for deterrence. There's also a need for all systems to be able to accommodate integration into Army and JIM formations. The Army needs to develop a high/low mix of capabilities as well as to pursue research and development in potentially disruptive options.

Findings:

- CSA priorities (Long Range Precision Fires, Next Generation Combat Vehicle, Future Vertical Lift, Networks, Air & Missile Defense, and Soldier Lethality) are necessary but not sufficient for successful execution of MDO in all of its phases
  - Examples: Rapidly deployable expeditionary forces, enhanced wide-area and local-area situational awareness, precision targeting, systems interoperability, environmental mapping, social network access and exploitation, non-lethal and low collateral damage weapons (both kinetic and non-kinetic)
- To permit evolution of technologies, systems need to be able to accommodate integration into Army, Joint, and multinational formations.
- High/low mix provides possible entry points for multinational partners.
- Low cost unmanned systems could provide flexible, agile, attritable and/or expendable system options, but they must be compatible with higher end systems.

Recommendations:

- CG AFC: Develop a high/low mix of capabilities and options for near/mid/far-term multi-domain applications that provide more versatile, less exquisite systems for growing threats.
- CG AFC: Aggressively pursue research and development with potentially disruptive technical and operational options in areas such as autonomy, AI, decision theory, quantum technology, and hypersonics.

7.7 INFORMATION OPS AND CYBER ELECTROMAGNETIC ACTIVITIES

It's imperative that the Army develop systems for understanding cyberspace. The Army is working on a tool that allows commanders to visualize and understand what's happening in the nonphysical battlespace under their command. The Cyber Center of Excellence should develop an integrated strategy for this area.

Findings:

- Information Operations (IO) and Cyber Electromagnetic Activities (CEMA) are essential for MDO and will be contested in both conflict and competition. Current capabilities are not fully integrated.
- Adversaries are exploiting rapidly evolving and proliferating IO and cyber technologies.
- Multi-domain operations require innovative approaches to the integration of cyber operations, enabling maneuver across domains and creating dilemmas for the enemy.

Recommendation: CYBER COE Develop an integrated Multi-domain IO/CEMA Strategy that is responsive to the rapidly evolving MDO environment.

7.8 COUNTER-UAS AND AIR AND MISSILE DEFENSE

A suite of UAS-based defensive systems offers potential options for both countering UAS and air and missile defense. Such systems can play a role in the urban environment and could be tested in the "Three Block War" laboratory recommended above, Counter-UAS and air and missile defense options should be developed and tested in realistic environments.

Findings:

- Counter-UAS and Air and Missile Defense are critical to MDO.
- Controlling multiple unmanned systems has been demonstrated and is being deployed around the world. This is both a threat and an opportunity.
- Within the next year there could be 10X drones in such configurations and the numbers will continue to grow even more rapidly going forward.
- Developing UAS formations for offensive and defensive applications has tremendous potential.

Recommendations:

- CG AFC: Develop cost-effective Counter-UAS and air & missile defense options based on MUM-T, Robotics and Autonomous Systems, AI, electronic warfare, and directed energy to support MDO.
- CG AFC: Develop and test UAS technologies and concepts for offensive and defensive capabilities using more advanced ranges such as the "Three Block War" laboratory.

7.9 OPTIMIZED HUMAN-MACHINE SYSTEMS

The massive amounts of data being produced in multiple domains can only be processed in relevant time scales by using advanced data analytics, machine learning, and artificial intelligence. The speed needed to recognize, discriminate, target, and decide is moving beyond human capacity. In such applications, the machine enhances the decision-making capability of the human. In complex scenarios, the human may enhance the decision-making capability of the machine (AI at the edge). In other applications the machine may enhance the physical reach of the human by carrying a payload of some sort (surveillance equipment, lethal mechanisms, logistics) to a remote location. The Army needs to develop and field optimized human-machine systems.

Findings:

- The development and use of AI, machine learning, and autonomous systems are accelerating, including in military applications such as MUM-T and C4ISR.
- The massive amounts of data being produced in multiple domains can only be processed in relevant time scales by using advanced data analytics, machine learning and artificial intelligence.
- The speed needed to recognize, discriminate, target, and decide is moving beyond human capacity, driving the need for automation and/or optimized human-machine systems. Speed and accuracy trades must be undertaken and understood.
- Optimized human-machine system experimentation can improve understanding of technical performance and the value to the relevant CONOPS and support the culture change needed to operate in this high-speed environment.
- MDO effectiveness requires optimized human-machine systems.

Recommendation: ASA(ALT) and CG AFC develop and field optimized human-machine systems, which include trusted autonomy, AI and machine learning in operations, planning, wargaming, experimentation, acquisition, business processes, etc.

7.10 DEFENSE CULTURE AND MDO

The culture within the Services tends to emphasize Service-specific capabilities and goals. Changing the culture requires a change in training and education. The Army should establish a realistic training and education program to support the cultural change needed to achieve MDO.

Findings:

- Defense culture must be changed to embrace Joint, Interagency, and Multinational and advanced concepts for MDO to succeed in the mid-to-long term.
- "Jointness" has not advanced to a level to enable MDO.
- Changing the culture requires a change in training and education.
- While changes to training and education must occur at all levels, there must be particular focus on mid-level Service leadership.
- Successful MDO requires alignment of incentives and measures of success (example, promotion and assignments).

Recommendation:

- CG TRADOC: Develop Tactics, Techniques, and Procedures (TTPs) for MDO and establish a realistic training and education program that supports the cultural change to embrace Joint and advanced concepts necessary for success in multi-domain operations. Develop an MDO curriculum across professional military education.

8. CONCLUSIONS

The study team conducted over 60 data-gathering visits and interviews during the first half of 2018, which afforded the team the opportunity to recount the ASB's FY 2017 MDB study and receive valuable feedback from a wide range of organizations. The feedback received validated the findings and recommendations of that study and gave the study team confidence that the direction of the MDO study was consistent with the challenges and opportunities facing JIM partners in the competition-conflict continuum.

The rapid pace of change in technology and international dynamics are important contextual elements for this work. The Army must focus on creating options relevant for competition and conflict with potential peer adversaries. Thus, the themes of the FY 2018 MDO study remain unchanged from the themes of the FY 2017 MDB study, with the exception that there must be a greater sense of urgency in all we do, including JIM partners (Fig. 8.1).

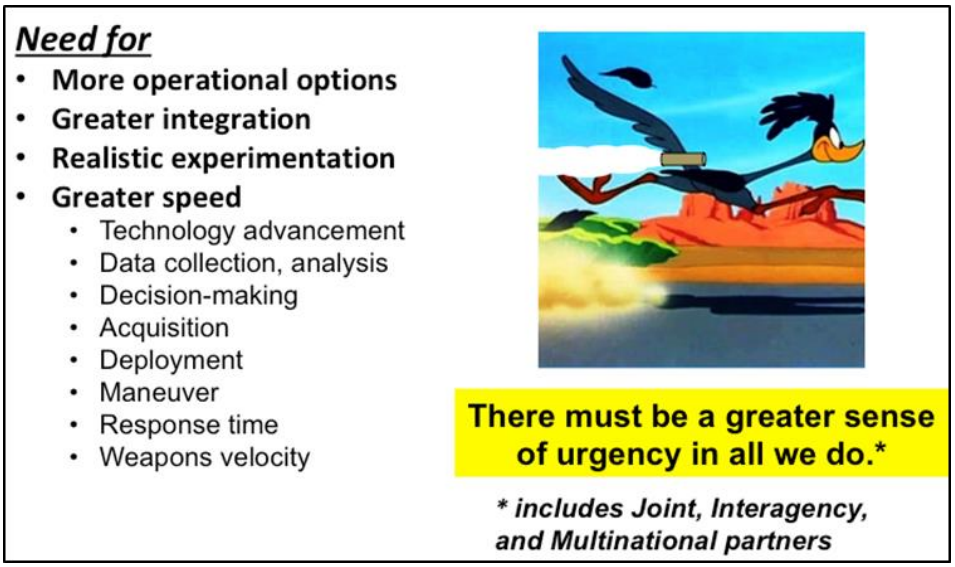

Figure 8.1 FY 2018 Study Themes (with added Jet Assisted Take Off (JATO) bottles)

The findings and recommendations developed by the study team are in four categories: Joint, Examples, Technology, and the Role of People. The Joint courses of action address the need for systems to be "Joint by Design," not a merger of technologies developed separately and combined at the end. These courses of action also address the need for a system of systems approach and for Joint modeling and experimentation. Two examples, the DUE and LRPF, were selected from numerous possible examples to describe the ASB's thinking on the impact of MDO. The recommendations on technology development focus on the CSA priorities, Information Operations and Cyber, and Counter-Unmanned Aerial Systems and Missile Defense. Finally, the last two recommendations address the issues that arise as the operational environment becomes more complex, and more dependent on rapidly advancing technology, so that the role of people must change to accommodate the faster pace of engagement. These recommendations address the optimization of human-machine systems and defense culture.

APPENDIX A. TERMS OF REFERENCE

SECRETARY OF THE ARMY
WASHINGTON

MEMORANDUM FOR

Deputy Under Secretary of the Army, 110 Army Pentagon, Room 3E650, Washington, DC 20310-0110
Chairman, Army Science Board, USAG Fort Hamilton, 113 Schum Avenue, Brooklyn, NY 11252

SUBJECT: Army Science Study entitled "Multi-Domain Battle (MDB) follow on study"

1. I request the Army Science Board (ASB) conduct a study entitled "Multi-Domain Battle (MDB) II" as a follow-on to the fiscal year 2017 study, "Multi-Domain Battle." The objective of the study is to continue assessing how to re-balance the Army's capabilities to fight more effectively using an integrated application of options from all five Department of Defense (DoD) recognized military warfighting domains (land, air, sea/maritime, space, and cyberspace). The study team should also assess potential combat efficiencies and synergies realized through leveraging, synchronizing, and integrating joint, interorganizational, and multinational capabilities across all domains.

2. The baseline for the study will be *The United States Army and Marine Corps Concept, Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040.* The study team will seek to expand on the concepts contained in that document in the following areas:

a. Shaping, reinforcing and amplifying the MDB concept.

b. Exploring opportunities where joint, interorganizational, and multinational capabilities enhance combat efficiencies.

c. Examining methods to impose multiple, simultaneous dilemmas on our adversaries.

d. Assessing techniques to degrade enemy capabilities, enable close-combat overmatch, and counter enemy A2/AD strategies.

3. Specifically, the ASB study team's tasks shall include, but not be limited to, determining technology and/or capability-based solutions for the following:

a. In competitions below armed conflict, how does the Army, working with joint, interorganizational, and multinational partners:

1) Contest adversary operations?

2) Deter armed conflict and employment of adversary conventional forces?
3) Implement command and control capabilities to actively compete and immediately respond to the escalation of violence?
4) Set the theater (including CONUS) before hostilities?

b. During armed conflict, how does the Army, working with joint, interorganizational, and multinational partners:
   1) Defeat the peer adversary's fait accompli campaign?
   2) Execute strategic and operational maneuver?

c. In the return to competition, how does the Army, working with joint, interorganizational, and multinational partners:
   1) Contest the adversary's renewed subversion campaign?
   2) Deter a return to armed conflict?

d. What are the technology gaps for enabling MDB and providing more operational options in the future?

4. The Commanding General of U.S. Army Training and Doctrine Command is the sponsor of this study and will assist the study team in accessing classified information up to Top Secret and including Sensitive Compartmented Information and Special Access Programs.

5. A briefing with findings and recommendations will be provided by September 30, 2018 to the Secretary of the Army and the Chief of Staff of the Army. The study will operate in accordance with the Federal Advisory Committee Act and DoD Directive 5105.4, DoD Federal Advisory Committee Management Program. It is not anticipated that this study will need to go into any particular matters regarding the meaning of United States Code, nor will it cause any member of the study team to be placed in the position of acting as a procurement official that may constitute a conflict of interest.

Ryan D. McCarthy
Acting

CF:
Commanding General, U.S. Army Training and Doctrine Command

APPENDIX B. STUDY TEAM MEMBERS

The 2018 ASB Multi-Domain Operations study consisted of the following ASB members and support staff:

Maj Gen (Ret) Ron Sega, PhD – Chair

Mark Glauser, PhD – Vice-Chair

Nancy Chesser, PhD	COL (Ret) Susan Myers, PhD
LtGen (Ret) Emerson Gardner	Bill Snowden, PhD
Bill Guyton	Tony Tether, PhD

Red Team Advisors:

Jeff Isaacson, PhD

Jim Tegnelia, PhD

Study Manager:

LTC Marco Lyons, TRADOC

Tech Writer/Editor:

Mark Swiatek

APPENDIX C. LINES OF INQUIRY AND VISITATIONS

The study team gathered data from the following organizations and individuals:

Army

- Acting SECARMY McCarthy
- TRADOC, GEN Perkins +
- G-2, Deputy
- ARCIC, MG Dyess, BG Odom +
- Maneuver COE, MG Wesley +
- Futures, MG Hix
- Precision Fires CFT, MG Richardson
- Networking CFT
- CSA Future Studies Group
- Cyber COE
- SMDC/ARSTRAT
- HQDA DAMO Force Management
- Army War College
- Army Research Laboratory
- AMRDEC
- Army Aviation Quad A
- AUSA Global Force Symposium
- AUSA LANPAC
- TRADOC Mad Scientists

Navy/Marine Corps

- Future Fleet Design & JAM-GC
- OPNAV N9
- USMC M-2
- Marine Corps Warfighting Lab

Air Force

- Air Combat Command, Gen Holmes
- Space Command, Gen Raymond
- AFMC, Gen Pawlikowski
- CIO, Lt Gen Shwedo
- National Academy AF Studies Board C2 Workshop Lt Gen (Ret) Hamel
- USAF A-2
- Air Force Research Lab
- 711th Human Performance Wing
- Air Force Institute of Technology
- Air University, LeMay Center

Joint

- STRATCOM, Gen Hyten
- PACOM, J5
- USD R&E, Dr. Griffin
- OSD, PD EC&P, Dr. Perkins
- Joint Staff, J7 Suffolk
- Joint Staff J-8 Innovations
- DARPA
- Missile Defense Agency
- Joint Modernization Command
- ADM (Ret) G, formerly JFCOM
- GEN (Ret) Ham, formerly AFRICOM
- DSB Multi-Domain Effects Study, Gen (Ret) Breedlove
- National Defense University
- Defense Threat Reduction Agency

Intelligence Community

- Defense Intelligence Agency (DIA)
- Missile and Space Intelligence Center National Air and Space Intelligence Center
- National Reconnaissance Office (NRO)
- National Ground Intelligence Center (NGIC)
- National Geospatial-Intelligence Agency
- National Security Agency (NSA)

Inter-organizational

- Center for Naval Analyses - Russia Studies Program
- Institute for Defense Analyses
- National Security Council
- Central Intelligence Agency
- Department of Homeland Security

Multi-national

- TRADOC Liaisons (France, Germany, Spain)
- NATO Collaboration Support Office
- NATO Chief Scientist

Other

- Industry
- MG(Ret) Scales
- Georgia Tech Research Institute
- National Academy of Sciences
- Center for Strategic & Budgetary Assessment

Several documents were provided to organizations prior to visists with the MDO study team:

- SA Memo: Secretary of the Army Memorandum for Deputy Under Secretary of the Army and Chairman, Army Science Board, Subject: Army Science Study entitled "Multi-Domain Battle (MDB) follow on study," no date (see Appendix A)
- Bios: Army Science Board Multi-Domain Battle Study team members biographies
- Outbrief: Army Science Board, "2017 Multi-Domain Battle Study Outbrief," 20 July 2017, Powerpoint presentation
- MDB Final Report: Army Science Board Fiscal Year 2017 Study, Multi-Domain Battle, Final Report, January 2018
- MDB version 1.0: US Army Training and Doctrine Command, Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040, Version 1.0, December 2017

Lines of inquiry for most organizations followed the Tasks listed in the TOR.

Maneuver Center of Excellence (MCoE)/9-11 January 2018/Fort Benning, Georgia
The MDO study team provided to the MCoE: SA Memo, and Bios.
The following lines of inquiry were provided to MCoE: Tasks from TOR listed above.
MDO study team members engaged with then MG Eric Wesley, COL William Voorhies and MCoE Directorate of TRADOC, Mr. Mike Obermayer and MCoE Maneuver Battle Laboratory, and Mr. Donald Sando and MCoE Capabilities, Development and Integration Directorate about development of the MDO concept, wargaming multi-domain capabilities and effects, and unit training for multi-domain operations. Additionally, participants discussed MCoE Maneuver Force Modernization Strategy and MCoE input to the MDB concept. Study team members received a briefing on MCoE Maneuver Battle Laboratory priorities and activities.

Center for Naval Analyses (CNA); National Security Council (NSC); United States Air Force (USAF) LeMay Center; Chief of Staff of the Army Future Studies Group (CSA FSG); et al./1-2 February 2018/National Capital Region
The MDO study team provided to CNA, NSC, USAF LeMay Center, CSA FSG, et al.: SA Memo; Outbrief; MDB version 1.0; and Bios.
The following lines of inquiry were provided to CNA, NSC, USAF LeMay Center, CSA FSG, et al.: Tasks from TOR listed above.
MDO study team members engaged with members of the CNA Russia Program; LTC Matthew M. Zais, National Security Council; Lt Col David Lyle, USAF LeMay Center; MG (Ret) Bob Scales; COL Bradley Martsching, Army Futures Studies Group (AFSG); and COL Scott Kendrick about Russian military capabilities and concepts, CSA's guidance on futures studies, and the JCIC. Additionally, participants discussed Air Force operational concepts, and improving US Army and US Marine Corps small unit lethality. MDO study team members received a briefing on Army Futures Studies Group activities.

United States Army Training and Doctrine Command (TRADOC); Joint Staff (JS) J7, Joint Force Development; and Defense Intelligence Agency (DIA)/13-14 February 2018/Hampton Roads, Virginia

The MDO study team provided to TRADOC, JS J7, and DIA: SA Memo; Outbrief; MDB version 1.0; and Bios.

The following lines of inquiry were provided to TRADOC, JS J7, and DIA: Tasks from TOR listed above.

MDO study team members engaged with LTC Richard "Scot" Peeke, ARCIC Science, Technology, Research and Accelerated Capabilities Division (STRACD); then GEN David Perkins; then MG Robert "Bo" Dyess; BG Mark Odom; COL Scott Mitchell and others from TRADOC Commander's Planning Group (CPG); COL Michael Runey and others from TRADOC Joint and Army Concept Development (JACD); members of JS J7 Concepts Division; and analysts from DIA about science and technology requirements for MDO, evolution MDO to a Joint concept, and Russian and Chinese capabilities that may challenge MDO. Additionally, MDO study team members and others discussed DARPA's Strategic Technology Office work on "mosaic warfare," and the developing System of System-Enhanced Small Units (SESU) program. MDO study team members received briefings on Russian and Chinese regional military plans and capabilities.

United States Strategic Command (USSTRATCOM); Center for Strategic and Budgetary Assessments (CSBA); et al./27-28 February 2018/National Capital Region

The MDO study team provided to USSTRATCOM, CSBA, et al.: SA Memo; Outbrief; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to USSTRATCOM, CSBA, et al.: Tasks from TOR listed above.

MDO study team members engaged with CNA Russia Program analysts; Mr. Ed Haugland and others, HQDA, G-2; Gen John E. Hyten, USAF, CG USSTRATCOM; and Mr. Bryan Clark, CSBA Senior Fellow about developing Russian science and technology, Russian future military options and capabilities, USSTRATCOM multi-domain operations challenges, and future concepts for electromagnetic warfare. MDO study team members also participated in an AUSA "Hot Topic" Army Air and Missile Defense Conference with Gen Hyten, LTG James Dickinson, and LTG(R) Richard Formica. Additionally, MDO study team members and others discussed United States Intelligence Community interest in Army multi-domain operations concept, Russian New Generation Warfare, and Russian information competition concepts and capabilities. MDO study team members received briefings on air and missile defense threats, air and missile defense capabilities, and electromagnetic warfare (EW) and escalation dominance.

Army Futures Command Task Force (AFC TF); Headquarters Department of the Army G-2/Plans and Integration (HQDA G-2/PI); United States Army Research, Development and Engineering Command, Army Research Laboratory (RDECOM ARL); United States Army War College (USAWC); Joint Staff (JS) J8 Innovation Group; National Academy of Sciences Air Force Studies Board (NAS AFSB)/12-15 March 2018/National Capital Region

The MDO study team provided to AFC TF, HQDA G-2/PI, RDECOM ARL, USAWC, JS J8 Innovation Group; and NAS AFSB: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to AFC TF, HQDA G-2/PI, RDECOM ARL, USAWC, JS J8 Innovation Group; NAS AFSB, and DSB: Tasks from TOR listed above.
MDO study team members engaged with then MG Bill Hix, AFC TF; Mr. James Stockmoe and a team from HQDA G-2/PI; Dr. Alexander Kott, RDECOM ARL; the USAWC MDB Study team; LTC Jim Armstrong, Chief of Operational Plans, JS J8 Innovation Group; and Lt Gen Mike Hamel (USAF, retired), NAS AFSB about findings and recommendations of the 2017 ASB MDB Study, best approach for engaging the Intelligence Community (IC), and MDB-related ARL research and development. Additionally, MDO study team members and others discussed NAS AFSB multi-domain operations research. MDO study team members received briefings on Army Futures Command, the Internet of Battle Things (ARL), and the USAWC MDB Study.

United States Air Force Chief Information Officer (USAF CIO)/A6; Headquarters Department of the Army, Department of the Army Management Office - Force Management (HQDA DAMO-FMO); Institute for Defense Analyses (IDA); United States Navy Future Fleet Design and Architecture/Strategic Concepts (USN OPNAV N501/503); and United States Army Research, Development and Engineering Command, Edgewood Chemical Biological Center (RDECOM ECBC)/3-4 April 2018/National Capital Region
The MDO study team provided to USAF CIO/A6, HQDA DAMO-FMO, IDA, USN OPNAV N501/503, and RDECOM ECBC: SA Memo; MDB Final Report; Bios; and MDB version 1.0.
The following lines of inquiry were provided to USAF CIO/A6, HQDA DAMO-FMO, IDA, USN OPNAV N501/503, and RDECOM ECBC: Tasks from TOR listed above.
MDO study team members engaged with Lt Gen Bradford "B.J." Shwedo, USAF CIO/A6 and team; HQDA DAMO-FMO representatives; Dr. Kevin Woods and Mr. Tom Greenwood, IDA; CAPT Geoffrey S. Gage, USN OPNAV N501/503; and Dr. Augustus W. Fountain III, Senior Research Scientist (ST) for Chemistry, RDECOM ECBC, about command control (C2) in multi-domain operational environments; experimenting with, testing, evaluating, modeling, and simulating multi-domain capabilities; multi-domain task force design; and Navy fleet design and implications for multi-domain operations. Additionally, MDO study team members and others discussed cyberspace capabilities for multi-domain operations. MDO study team members received briefings on the Army multi-domain task force and Synthetic Theater Operations Research Model (STORM) implications for multi-domain operations analysis.

United States Air Force Air Combat Command (USAF ACC)/9-11 April 2018/Hampton Roads, Virginia
The MDO study team provided to USAF ACC: SA Memo; MDB Final Report; Bios; and MDB version 1.0.
The following lines of inquiry were provided to USAF ACC: Tasks from TOR listed above.
MDO study team members engaged with Gen. Mike Holmes, USAF ACC Commander; Mr. Jeffrey Zeller, USAF ACC Commander's Action Group (CAG); Maj. Gen. Andrew J. Toth, Mr. Ted Uchida, and others from USAF ACC A3; Mr. Shane Hamilton and others from USAF ACC A2; Dr. Janet Fender, USAF ACC, Scientific Advisor to the Commander; Col. Patrick Sutherland and staff members of 363rd Intelligence Surveillance Reconnaissance Wing, about TRADOC and USAF ACC tabletop exercises, USAF multi-domain command and control, and USAF concepts for cyberspace and space. Additionally, MDO study team members and others discussed different

aspects of multi-domain battlespace management. MDO study team members received multiple Air Combat Command headquarters staff and functional briefings, as well as a command and operations brief from 363rd ISRW.

United States Army Research, Development and Engineering Command, Army Research Laboratory, Army Research Office (ARL ARO); Georgia Institute of Technology (GATECH); Georgia Tech Research Institute (GTRI)/24-25 April 2018/Atlanta, Georgia

The MDO study team provided to ARL ARO, GATECH, and GTRI: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to ARL ARO, GATECH, and GTRI: Tasks from TOR listed above.

MDO study team members engaged with Mr. Matthew Munson and others from ARL ARO by video teleconference; Mr. Don Davis, GTRI; Dr. Zsolt Kira, GATECH; and Dr. Panagiotis Tsiotras, GATECH, about basic Army research and multi-domain operations, robotics and autonomous systems, and artificial intelligence and machine learning. Additionally, MDO study team members and others discussed current and possible future sensor technology.

Joint Staff (JS) J8 Innovation Group; United States Marine Corps (USMC) M-2; United States Air Force (USAF) A2; United States Marine Corps, Marine Corps Warfighting Laboratory (USMC MCWL); and Department of Homeland Security (DHS)/3-4 May 2018/National Capital Region

The MDO study team provided to JS J8 Innovation Group, USMC M-2, USAF A2, USMC MCWL, and DHS: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to ARL ARO, GATECH, and GTRI: Tasks from TOR listed above. The following additional lines of inquiry were provided to USMC M-2, USAF A2:

1. How to integrate intelligence from all domains and intelligence disciplines, with operations under degraded electromagnetic spectrum (EMS) conditions to support commanders' situational understanding for decision making.
2. How to employ robotic and autonomous systems and artificial intelligence to conduct information collection and analysis to increase situational understanding in time and information competitive environments.
3. How to share intelligence among allies and partners and provide accurate assessment of the environment to interorganizational partners to support commanders' situational understanding in all operational environments.
4. How to provide space, cyberspace, EMS, and information environment situational understanding to facilitate decision making, maneuver planning, collaboration, and synchronization.
5. How to integrate a secure and robust intelligence architecture, encompassing sensors, platforms, and organizations, that is scalable and enables timely processing, exploitation, and dissemination, with shared analytics, distributed analysis, and collaboration tools in conditions of limited bandwidth and network outages to support commanders' situational understanding in all operational environments.

6. How to conduct continuous reconnaissance, surveillance, security, and intelligence operations across all domains, and within dense urban and complex terrain, during competition and armed conflict.
7. How to conduct and support Information Environment Operations (IEO), Unconventional Warfare (UW), and ISR during competition to support information collection and to deter escalation by adversaries.
8. How to develop situational awareness regarding threat missiles, mines, air defenses, improvised explosive devices, cyberspace capabilities, and unmanned systems to enable rapid employment of friendly capabilities to exploit or open windows of advantage.
9. How to understand the operational environment, to include: military features, natural and man-made terrain, hydrography, "human terrain" in the area (culture, society, economy, technology, and population concentration/dispersion), civilian traffic (air, sea, and land), the climate, and regional weather patterns.
10. How to employ, at the tactical level, interoperable ground- and ship-launched/recovered family of UAS for reconnaissance, surveillance, and attack missions that are interoperable with 5th generation aircraft to improve resilience and effectiveness of semi-independent formations.
11. How to conduct armed aerial reconnaissance from austere, unprepared landing zones (runway-independent) and maritime assets with improved speed, payload, endurance, survivability, reliability, and maintainability to increase situation awareness of semi-independent formations.
12. How to conduct improved processing of multi-intelligence data, including that from non-traditional sources such as social media, blogs, internet, and periodical media, to support deterrence and shaping operations short of armed conflict and during combat operations.
13. How to employ improved intelligence collection, analysis, and synthesis capabilities, particularly with regard to understanding and characterizing human terrain, the cognitive dimension, and indications/warnings for threats in competition.
14. How to create cross-domain synergy through complementary collection layers (space, aerial, subsurface, and terrestrial) of Service and intelligence partner collectors to support commanders' situational understanding in all operational environments.
15. How to integrate information collection across the Services and the intelligence enterprise to support commanders' situational understanding in all operational environments.
MDO study team members engaged LTC James E. Armstrong III, Analyst, and others from JS J8 Innovation Group; Ms. Margaret Schalch, Acting Chief, Intelligence, Plans and Policy Division, and others from HQMC Intelligence Department; SES Kenneth E. Bray, USAF AF-A2, Associate Deputy Chief of Staff for ISR; Col Donald R. Wright, Director, Operations/Futures Integration, and LtCol Edmund G. Clayton, Plans Officer, MCWL; and Mr. Scott Tousley, Deputy Director, Cyber Security Division, Homeland Security Advanced Research Projects Agency, DHS Science and Technology. Additionally, MDO study team members and others discussed multi-domain battle and operations technology requirements; multi-domain operations, intelligence requirements, and the Marine Corps Operating Concept; ISR requirements for multi-domain command control and operations; government versus industry perspectives on cyberspace security; and homeland defense/security dimensions of future multi-domain operations. MDO study team members received briefings on USMC MCWL priorities, activities, and operations.

NVIDIA Corporation/9 May 2018/Santa Clara, California
The MDO study team provided to NVIDIA: SA Memo; MDB Final Report; and Bios.
The following lines of inquiry were provided to NVIDIA:
1) How do NVIDIA autonomous systems use AI and deep learning to deliver safe, efficient, and effective transportation options? How is the AI computing distributed?
2) How might an architecture combining deep learning, sensor fusion, and surround vision influence the design and building of future combat vehicles? And how might these designs change the way formations of fully or partially autonomous combat vehicles operate?
3) How will vehicle capabilities change with the introduction of NVIDIA AI platforms in 10 years? 20 years?
4) How does NVIDIA exploit deep learning and neural networks to achieve fully autonomous vehicle operation?
MDO study team members engaged with Ms. Margaret Amori, NVIDIA Government Outreach, and other NVIDIA researchers and representatives to review NVIDIA technologies and projects. Additionally, MDO study team members and others discussed advances in data sciences, deep learning capabilities, autonomous systems technology, GPU computing, AI "at the edge," and high-performance AI processors. MDO study team members received briefings on Autonomous Car Development Platforms, Smart Cities, and computing and AI technology demonstrations, including Isaac, the robot simulator.

Army Capabilities Integration Center, Future Warfare Division (ARCIC FWD); United States Army War College, Strategic Studies Institute (USAWC SSI); United States Army War College (USAWC); United States Army War College, Center for Strategic Leadership (USAWC CSL); National Defense University (NDU)/16-18 May 2018/Carlisle Barracks, Pennsylvania
The MDO study team provided to ARCIC FWD, USAWC SSI, USAWC, USAWC CSL, and NDU: SA Memo; MDB Final Report; Bios; and MDB version 1.0.
The following lines of inquiry were provided to ARCIC FWD, USAWC SSI, USAWC, USAWC CSL, and NDU: Tasks from TOR listed above.
MDO study team members engaged with various members of ARCIC FWD overseeing execution of Unified Quest 18, Deep Future Wargame (DFWG); Professor Nathan Freier, Study lead for the USAWC MDB study; Professor Al Lord, Director, Joint Warfighting Advanced Studies Program; Professor William "Trey" Braun, Director, National Security Affairs, Strategic Research Department; Dr. Steven Metz, Director of Research, Strategic Research Department; Mr. Samuel R. White, Jr., Deputy Director Center for Strategic Leadership; Dr. Brian R. Shaw, Deputy Provost for Academic Affairs, NDU; and Professor Antulio Echevarria, USAWC. MDO study team members and others discussed operationalization of robotic and autonomous systems (RAS) for multi-domain battle and operations, how the Army can contribute to the multi-service, multi-domain capabilities required to defeat a near-peer adversary in a 2035 operational environment, and multi-domain operations in warfare as imagined ten to twenty years in the future. MDO study team members received briefings on Army S&T needs, concepts, and requirements; and the USAWC study of MDO.

Assistant Secretary of Defense for Research and Engineering (ASD(R&E)); Central Intelligence Agency (CIA) Directorate of Analysis, Strategic Insights Group; Defense Advanced Research

Projects Agency (DARPA) System of System-Enhanced Small Units (SESU) Program Manager (PM); Defense Advanced Research Projects Agency (DARPA) Multi-Domain Command and Control (MDC2) Program Manager (PM)/25 May 2018/National Capital Region

The MDO study team provided to ASD(R&E); CIA, Strategic Insights Group; DARPA SESU PM; and DARPA MDC2 PM: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to ASD(R&E); CIA, Strategic Insights Group; DARPA SESU PM; and DARPA MDC2 PM: Tasks from TOR listed above.

MDO study team members engaged with Dr. Charles W. Perkins, Principal Deputy, Emerging Capability and Prototyping, and others in the Office of the Assistant Secretary of Defense for Research and Engineering; Dr. George A. Nowak, SESU PM; Mr. Joseph C. Cyrulik, Chief, Strategic Perspectives Branch, and analysts with the Strategic Insights Group, CIA Directorate of Analysis; and Dr. Craig Lawrence, MDC2 PM; about autonomy, electronic warfare/protection, energy and power technology, sensors and processing, DARPA research and programs, and strategic foresight for national security intelligence. MDO study team members received briefings on SESU, MDC2, and Strategic Insights for the US Intelligence Community.

Defense Threat Reduction Agency, Global Futures Office (DTRA GFO); Army Capabilities Integration Center, Science, Technology, Research and Accelerated Capabilities Division (ARCIC STRACD); Army Capabilities Integration Center, Joint Modernization Command (ARCIC JMC); Army Research Laboratory, Adelphi (ARL-Adelphi); Army Research Office (ARO)/30-31 May 2018/National Capital Region

The MDO study team provided to DTRA GFO, ARCIC STRACD, ARCIC JMC, ARL-Adelphi, and ARO: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to DTRA GFO, ARCIC STRACD, ARCIC JMC, ARL-Adelphi, and ARO: Tasks from TOR listed above.

MDO study team members engaged with Mr. Jonathan D. Fox, Senior Strategic Planner, DTRA GFO; Mr. Douglas L. Fletcher, Chief of Staff, and other staff officers of ARCIC JMC; and Dr. Philip Perconti, Director, and scientists, engineers, and researchers, ARL; about concept and capabilities assessments and multinational interoperability for multi-domain operations. Additionally, MDO study team members and others discussed the Blue Flag/Joint Warfighting Assessment Enterprise, Mission Partner Environment, and Multi-Domain Operations (BF/JWA 18) Near-Future Operating Environment. MDO study team members received briefings on Joint Warfighting Assessment (JWA) 18.1; and ARL research updates on ballistics, cyberspace-electronic warfare (including networks and communications) capabilities, artificial intelligence, robotics, and unmanned (including human-agent integration) systems, and cognitive-social capabilities.

Air Force Research Laboratory (AFRL); Air Force Research Laboratory, Information Directorate (AFRL/RI); Air Force Materiel Command (AFMC); National Air and Space Intelligence Center (NASIC); Air Force Institute of Technology (AFIT)/5-7 June 2018/Wright-Patterson Air Force Base, Ohio

The MDO study team provided to AFRL, AFRL/RI, AFMC, NASIC, and AFIT: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to AFRL, AFRL/RI, AFMC, NASIC, and AFIT: Tasks from TOR listed above.
MDO study team members engaged with Mr. Jack Blackhurst, Dr. Michael Eismann, Dr. Greg Spanjers, and other AFRL scientists, engineers, and researchers; Gen. Ellen M. Pawlikowski, Commander, Air Force Materiel Command, and AFMC staff officers; Mr. Matthew L. Hampton, Senior Intelligence Analyst, and analysts of the NASIC - Regional Threats Analysis Squadron; Dr. Richard Deckro, Distinguished Professor of Operations Research for Information Operations; Dr. David Jacques, Associate Professor for Autonomous Agents/Decentralized Systems; Dr. Brett Borghetti, Associate Professor for Machine Intelligence; Dr. Gary Lamont, Professor for Network Centric Warfare; and Dr. Michael Grimaila, Professor for Artificial Intelligence and Machine Learning/Quantum Information; about cyberspace research and capabilities; autonomous systems and behavior, and aerospace engineering for hypersonics. Additionally, MDO study team members and others discussed AFIT student research topics including Fuzzy Risk Appraisal for Joint Operation Planning and operational analysis. MDO study team members received briefings on Command and Control Air-to-Ground Communications, UAS Platforms and Missions, Small Unmanned Systems Exploitation (SUSEX), Array at Commercial Timescales (ACT), BATMAN (711th Human Performance Wing), and various topics from AFRL-Rome.

United States Army Aviation and Missile Research Development and Engineering Center (AMRDEC); AMRDEC Aviation Development Directorate (ADD); AMRDEC Air and Missile Defense (AMD); United States Army Space and Missile Defense Command/United States Army Forces Strategic Command (SMDC/ARSTRAT); Missile and Space Intelligence Center (MSIC); Missile Defense Agency (MDA)/13-15 June 2018/Redstone Arsenal, Alabama
The MDO study team provided to AMRDEC, AMRDEC ADD, AMRDEC AMD, SMDC/ARSTRAT, MSIC, and MDA: SA Memo; MDB Final Report; Bios; and MDB version 1.0.
The following lines of inquiry were provided to AMRDEC, AMRDEC ADD, AMRDEC AMD, SMDC/ARSTRAT, MSIC, and MDA: Tasks from TOR listed above.
MDO study team members engaged with Dr. Juanita Harris, Executive Deputy to the Commanding General, US Army Research, Development and Engineering Command, and various engineers at AMRDEC; COL James W. Crossley, Deputy Director, SMDC/ARSTRAT Future Warfare Center; Mr. Scott MacDonald, senior defense intelligence analyst for weapons analysis, MSIC; about manned and unmanned teaming technologies; developing fires capabilities; and space and missile defense forces and required capabilities. Additionally, MDO study team members and others discussed autonomy and teaming, models and simulation, low-cost tactical extended range missile (LC-TERM), land-based anti-ship missile (LBASM), long range maneuvering fires (LRMF), precision target acquisition seeker (PTAS), mobile theater precision strike (MTPS) missile system, space and high altitude capabilities, and global ballistic missile defense. MDO study team members received briefings on AMRDEC Air Defense Missile Science and Technology, Low-cost Extended Range Air Defense (LowER AD), Maneuver Air Defense Technologies (MADT), Digital Array Radar Testbed Update, Fire Support Science and Technology Demonstration Programs, and MSIC and MDA organizations and programs.

National Reconnaissance Office (NRO); Defense Advanced Research Projects Agency (DARPA); NATO, Collaboration Support Office (NATO CSO); NATO Headquarters, Office of the Chief

Scientist (NATO OCS); United States Navy Headquarters, Navy Integrated Fire Control/Counter Air and Integration & Interoperability (OPNAV N9IX); and Association of the United States Army (AUSA)/19-20 June 2018/National Capital Region

The MDO study team provided to NRO, DARPA, NATO CSO, NATO OCS, OPNAV N9IX, and AUSA: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to NRO, DARPA, NATO CSO, NATO OCS, OPNAV N9IX, and AUSA: Tasks from TOR listed above.

MDO study team members engaged with Dr. Byron F. Knight, Deputy Director, NRO Systems Engineering for Future Conflict Capabilities, and NRO analysts; various DARPA program managers; Mr. Alan Shaffer, Director, NATO Collaboration Support Office; CAPT Joker L. Jenkins, Branch Head, and planners and analysts from Deputy Chief of Naval Operations for Warfare Systems (DCNO N9); Dr. Thomas Killion, NATO Chief Scientist; General (Retired) Carter F. Ham, President and Chief Executive Officer, AUSA; about specific NRO programs; various DARPA programs relating to command control, intelligence, and AI; Navy multi-domain concepts; and NATO science and technology programs and priorities. Additionally, MDO study team members and others discussed GEOINT, SIGINT, and NRO projects regarding ground architectures and sensor to shooter capabilities. MDO study team members received briefings on NATO STO Collaborative Programme of Work, Enabling Future Innovation and Capabilities; NATO S&T and the NATO S&T Organisation; and the following DARPA programs: C2 - Insight/Causal Exploration; EdgeCT; Gremlins; Big Data - XDATA, Memex, Data-Driven Discovery of Models (D3M); and SeeMe.

Cyber Center of Excellence (CCoE); CCoE Capability Development Integration Directorate (CDID); Army Cyber/Joint Forces Headquarters – ARCYBER (JFHQ-C) Cyber Protection Brigade (CPB)/27-28 June 2018/Fort Gordon, Georgia

The MDO study team provided to CCoE, CCoE CDID, and JFHQ-C CPB: SA Memo; MDB Final Report; Bios; and MDB version 1.0.

The following lines of inquiry were provided to CCoE, CCoE CDID, and JFHQ-C CPB: Tasks from TOR listed above.

MDO study team members engaged with Mr. Robert V. Kazimer, Mr. David W. Laflam, and leaders from CCoE CDID; and COL Benjamin A. Rink and leaders from JFHQ-C CPB about cyberspace operations, signal communications networks and information services, and electronic warfare. Additionally, MDO study team members and others discussed cyber, electronic warfare, and space capabilities convergence. MDO study team members received briefings on ARCYBER command and capabilities, TRADOC Capability Manager (TCM) Cyber and TCM EW concepts and capabilities, and Cyber Protection Brigade JFHQ-C capabilities.

APPENDIX D. EXECUTIVE SUMMARY OF FY 17 ASB MDB REPORT

In February 2017, the Secretary of the Army requested the Army Science Board (ASB) conduct a study entitled "Multi-Domain Battle" (MDB). The Commanding General (CG), U.S. Army Training and Doctrine Command (TRADOC), was identified as the study sponsor. Objectives laid out by the Secretary included:

- Assessing how expanding and re-balancing the Army's focus on AirLand Battle to fighting more effectively in all five Department of Defense (DoD)-recognized military warfighting domains (land, air, sea (maritime), space, and cyberspace, as well as operational environments such as the electromagnetic spectrum and cognitive) could significantly enhance tactical, operational, and strategic outcomes.

- Assessing potential combat efficiencies and synergies gained by better leveraging, synchronizing, and integrating joint, interorganizational, and multinational (JIM) capabilities across all present and future domains.

This report describes the conduct of the study; discusses the MDB concept and the global operational environment, as well as technical concepts that could help enable MDB; and provides numerous findings and recommendations important to the multi-domain concept. A comprehensive briefing describing the study in detail was adopted by a unanimous vote of the members of the ASB in July 2017.

The study team assembled for this study has a broad range of technical expertise and operational experience covering all five domains of MDB. To obtain the information required to address the specified tasks, members of the study team made over 30 visits to Army and other organizations actively involved in the development of the MDB concept.

As stated in the Terms of Reference (TOR) for the study (Appendix A):

> Today, … near-peer adversaries contest U.S. superiority in multiple domains, including areas where U.S. forces have come to expect and exploit superiority, if not supremacy. In the future, U.S. forces will likely have to confront adversaries who seek to gain direct and indirect control of contested spaces, employing anti-access and area denial (A2/AD) strategies, through the asymmetric use of force in all five domains, as well as EMS activities and cognitive operations. This complex threat puts at risk current U.S. operational constructs and challenges U.S. ability to achieve its military objectives.

The team recognized that the character of warfare has already changed, and even greater changes will occur at an accelerating pace in the years to come. The global environment will continue to be characterized by increasing complexity, uncertainty/ambiguity and rapid rates of change in technological development and societal norms. All these factors drive the need for a new MDB concept.

In March 2017, the Army's strategic communication platform, "Stand-To!" released an information paper from TRADOC on MDB:

> Multi-domain battle provides commanders numerous options for executing simultaneous and sequential operations using surprise and speed of action to present multiple dilemmas to an adversary in order to gain physical and psychological advantages and influence and control over the multi-domain operational environment.[50]

The goals of MDB are applicable not only during conflict but also during competition prior to conflict and post-conflict competition. Gaining influence and control over the multi-domain operational environment is key to success.

In this study, the team focused on the technical challenges and opportunities for the Army in the conflict phase of operations. The team was able to leverage several previous ASB studies that had direct bearing on the MDB concept.[51] It's anticipated that a follow-on ASB study will explore the JIM aspects of the evolving MDB concept and the opportunities and challenges associated with pre-conflict and post-conflict campaigns.

The team identified several themes important to developing and operationalizing the MDB concept:

- More operational options
- Greater integration
- Realistic experimentation
- Greater speed in:
  - Technology advancement
  - Data collection and analysis
  - Decision-making
  - Acquisition
  - Deployment
  - Maneuver
  - Response time
  - Weapons velocity

To realize the potential of the evolving MDB concept, the team recommends a campaign of learning based on realistic experimentation in which threats and scenarios include degraded communications, complex environments, cyber/electronic warfare (EW) attacks.

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[50] TRADOC, U.S. Army STAND-TO! Information Paper, *Multi-Domain Battle*, 8 March 2017, https://www.army.mil/standto/2017-03-08

[51] The 2015 Aviation Study, the 2016 Armor/Anti-Armor Study, the 2016 Countering Indirect Fires Study and the 2016 study on Robotic and Autonomous Systems were particularly relevant.

The team also recognized the trend of increasing reliance on autonomy and artificial intelligence (AI) in the future. As the amount of data increases, the operational tempo increases, and the number of unmanned systems increase, optimized human-machine systems will play critical roles in meeting the needs of the commander. The role of people will change as the level and broader application of autonomy are implemented–not every Soldier (or platform) will need the same skills and/or equipment.

Based on these ideas, the team developed a vision of future engagements leveraging technology advances in all domains to enable MDB operations in theater (Fig. E.1). Technologies include:

- MUM-T (unmanned systems performing various functions including C4-intelligence, surveillance, reconnaissance (ISR), lethality, deception, logistics, etc.)
- Autonomy, AI, and decision-making tools
- Self-forming modular C4 networks

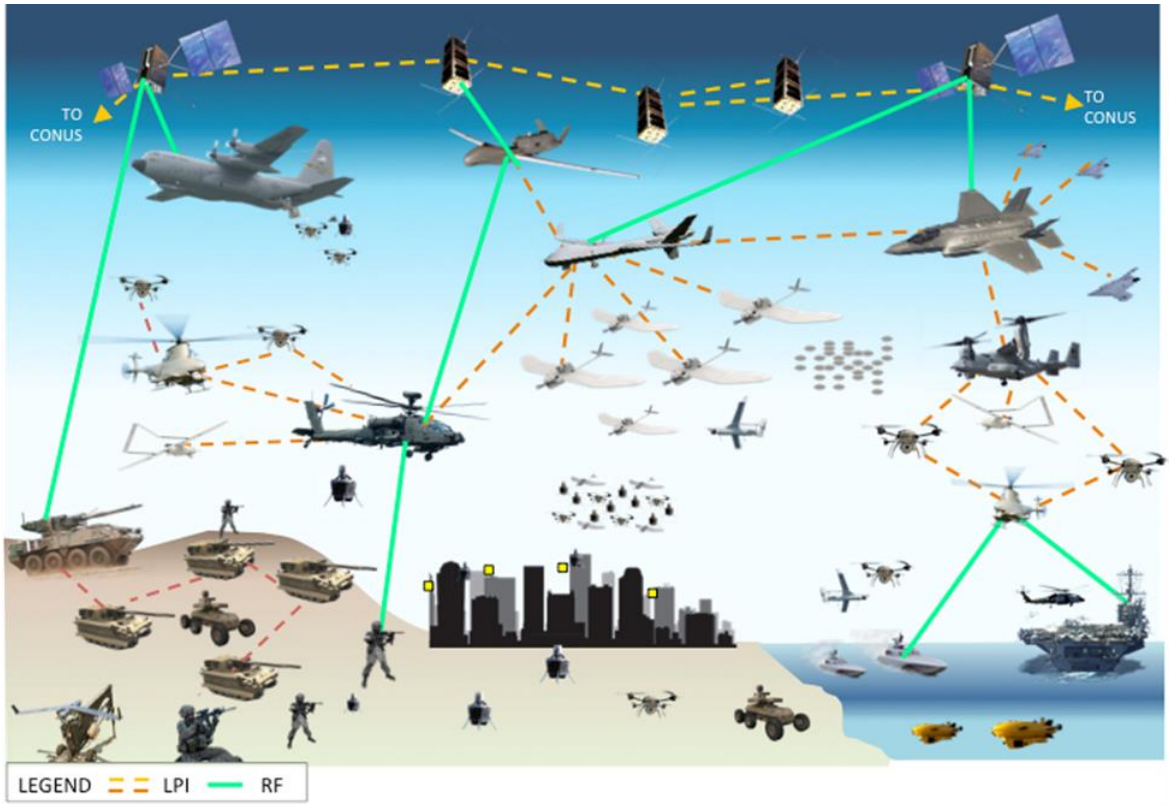

Figure E.1 Massively Distributed "Bots"

This vision is a system-of-systems configuration of massively distributed "Bots" that increases operational options, provides greater speed, agility and flexibility, and enables effective integration of operations in the contested environment. The construct provides a high/low mix

with robust characteristics in degraded conditions that enables winning in a contested and dynamic environment through improved battlefield outcomes. The vision includes supervised autonomy of unmanned platforms. As trust in autonomy is built, greater autonomy will emerge, additional capabilities will be enabled, and the number of unmanned platforms will increase significantly.

External challenges to MDB include those presented by peer competitors, including A2/AD, the increasing range of fires, the tyranny of time and distance for logistic support, and degraded networks. The Army's internal challenges include organizational authorities, integration, and processes.

Key characteristics of MDB include increasing speed, agility, and flexibility as well as more options for friendly forces and more dilemmas for adversary forces. Increased integration is essential. Decreased size, weight, and cost of systems, as well as a decreased sustainment burden will also be key to enable deployment and maneuver. These considerations led to the study team's findings (Fig. E.2) and recommendations (Fig. E.3).

1. Rapid advances and new disruptive capabilities, employed in a fully integrated Multi-Domain Battle (MDB) manner, are needed to ensure overmatch. • Potential peer adversary capabilities are advancing rapidly and will continue to do so. • A peer conflict is unlikely to be won by multi-domain integration of only existing and/or slowly evolving capabilities.
2. Based on team visits and review of MDB documents, the assumed pace of technology insertion and availability is overly conservative (e.g., availability of robotics and automation). • Technical advancements will enable greater operational opportunities and options than assumed (e.g., draft MDB concept document as of Apr 2017).
3. While a qualitative case has been made for a MDB approach, comprehensive detailed integrated analyses and validation have not been performed and capability gaps for MDB are not well understood. • Limited evidence has been found of in-depth MDB analysis and realistic experimentation, which are crucial to defining and refining the concept as well as validating models and simulations; ASB studies have consistently recommended more experimentation. • Insufficient examples were found of exercises and training based on realistic threats that stress current concepts and technologies (e.g., degraded comms/networks & GPS, cyber effects, advanced A2/AD, UAS utilization, long-range fire effects).
4. It is unclear to ASB how existing organizations and processes will support integrated development of MDB CONOPS and doctrine to their full potential.
5. Achieving MDB's full potential needs integrated multi-domain command, control, communications, and computers (C4) to obtain the necessary speed and synchronization among all JIM participants. • Current C4 capabilities are insufficient for MDB (e.g., incompatible data protocols and limited ability to communicate between Joint and Allied forces) and will be highly challenged in expected MDB scenarios. • C4 for MDB requires examination of new enabling technologies (e.g., timing and frequency issues, self-forming modular networks, low probability of intercept, autonomy, operation at the speed of machines, and quantum communications) and development as appropriate.

6. Cyber technologies are advancing globally and present an ever increasing threat as well as opportunities in all domains. Experimentation with cyber is constrained by perishability and policy considerations.

7. There is strong synergy among autonomy, artificial intelligence (AI), and big data supporting MDB, which enables operational flexibility and increased options.
   - Currently manned-unmanned teaming (MUM-T) in the Army is principally focused on ground and air vehicles in logistics, explosive ordnance disposal, and ISR, and its utility can be expanded to other areas.
   - Autonomy, AI, and big data are currently being applied to operations and infrastructure decisions in many sectors. Military is exploring applications in the following areas: situational awareness, manpower efficiency, sensitive site seizure, swarms of unmanned platforms, etc.
   - The role of people will change as autonomy evolves. Not every Soldier (or platform) will need the same skills and/or equipment.

8. Speed enhances MDB integrated combat operations:
   - Decision-making to get inside the OODA (Observe-Orient-Decide-Act) loop
   - Data collection, analysis
   - Deployment
   - Maneuver
   - Response time
   - Weapons delivery

Figure E.2 Study Team Findings

1. CSA, as a member of JCS, in conjunction with the CMC: Engage the JCS to design an appropriate organizational construct to develop integrated MDB concepts and test them through integrated exercises and experimentation.

2. TRADOC, in collaboration with DoD counterparts: Perform MDB modeling, exercises & experimentation, and conduct operational effectiveness analyses of potential integrated system of systems concepts in a cost-constrained environment, consistent with JIM operations, that address capability gaps in complex threat environments using realistic threats.
   - Develop holistic MDB approaches that include high/low mixes of collaborative manned/unmanned systems, higher levels of autonomy, PNT in denied GPS environments, attritable unmanned assets and enhanced lethality of Directed Energy.
   - Expeditiously develop CONOPS & operational architectures for the most promising concepts.
   - Determine what elements of the concept are valuable under what conditions.
   - Identify MDB requirements.

3. TRADOC/ARCIC in collaboration with RDECOM: Develop a system of systems architecture to achieve an integrated solution across all domains for an effective implementation of MDB, that includes:
   - Manned-unmanned teaming
   - Autonomous systems with various levels of supervision
   - Assured, secure communications
   - A robust C4 architecture with, at a minimum, assured intermittent communications for mission command
   - A model-based system engineering (MBSE) approach
   - A model validation strategy utilizing experimentation and exercises

4. ASA(ALT) in collaboration with TRADOC/ARCIC : Develop and field Army MUM-T capabilities at scale, which include sensors, C4 networks, human-machine interfaces, autonomy, AI/decision-making tools, and big data in all domains of MDB operations, with initial focus on the land domain.
5. ASA(ALT) in collaboration with Joint counterparts: Develop and field high/low mix of capabilities and options in near/mid/far term, informed by results of operational effectiveness analysis and experimentation, including but not limited to: • Unmanned systems with various levels of autonomy • Longer range high velocity fires • C4 networks to control formations of unmanned systems
6. CYBER COE in collaboration with Joint counterparts: Develop an integrated Multi-Domain Cyber/EW Strategy to support MDB development
7. ASA(ALT) in collaboration with Joint counterparts: Employ alternative approaches to acquisition that can accelerate system development, experimentation, and integration for MDB at scale.

Figure E.3 Study Team Recommendations

APPENDIX E. HISTORY OF LONG-RANGE PRECISION FIRES (LRPF)

To fully understand the impact of Long-Range Precision Fires (LRPF) and MDO, this Appendix discusses the historical development of LRPF and why the targeting issue is a relatively new requirement.

Since the beginning of time, weapons whose range was greater than the adversary's capability have been sought. The advantage of being able to inflict damage at a range greater than the enemy's capability can fire back usually won the battle and deterred enemies from attacking in the first place. It probably started with slingshots which could hurl a stone further than a human could throw it using just his arm.

In more recent history, the most well-known example is the longbow which could throw an arrow (spear) further than an ordinary bow and arrow. The longbow was finally replaced by cannons that could throw many projectiles per shot further than the longbow. Cannons became the long-range weapon of choice for many years until the advent of airplanes. Airplanes allowed a new dimension for inflicting damage at a distance that was adopted by all adversaries of any consequence.

During WW2, the Germans used missiles (V-2) that inflicted damage on Britain at ranges beyond the ability to see the enemy. However, their use required knowing the firing location with respect to the center of the earth as well as the impact point, plus an onboard navigation system. At the time the Germans were the most advanced force in the world for launching missiles.

However, none of these early weapons should be considered "precision fires," but were effectively used to inflict wide area killing and damages.

In the early 1950s, it was believed that any Russian attack would be by long-range bombers and the US was busy building an Air Defense system known as SAGE (Semi-Automatic Ground Environment). In addition, the public was involved in the Ground Observer Corp program manning outposts and reporting airplane flights near their location as well as flight direction since there were no long-range in-depth radars for detecting and tracking aircraft.

But on October 4 1957, the whole world changed. The Russians launched Sputnik, the first artificial satellite, into orbit around the world. It was obvious that if the Russians could launch an object into orbit, it could launch an object half-way around the world with a time from launch to impact being on the order of 30 minutes. And the Russians had nuclear weapons so ultimate accuracy was not important.

This led to the US building the TRIAD system comprised of long-range bombers (Strategic Air Command), land-based Intercontinental Ballistic Missiles (ICBMs) and Submarine Launched Ballistic Missiles (SLBMs). There were two types of targets: Soft (cities) and hard (ICBM silos). Each of the elements in the TRIAD was capable of destroying these targets, assuring deterrence

since an enemy could not be guaranteed the destruction of all three elements, especially the SLBMs because the launch point locations were by design constantly changing.

In response, Anti-Ballistic Missile (ABM) systems, Anti- Submarines Warfare (ASW), detecting the launch of ICBMs and SLBMs were all developed to assure that the Soviets could not guarantee a surprise attack neutralizing our retaliatory capability. The consequences to the US and Soviet Union, as well as to the rest of the world, if these weapons were ever used, brought about treaties between the two countries.

SPUTNIK, however, created a new technology that would have a huge impact on warfare and the world in general. Effective targeting for launches from submarines required that the submarine know its launch location as an input to the SLBM guidance and control system. In order to do this, the submarine had to surface. Existing navigation techniques were slow and not accurate leading to poor accuracy on target. Cities were still at risk but going after ICBM silos was difficult.

Observations of the Sputnik Beep signal led to the discovery that radio frequency Doppler shifts of the Beep signal allowed the position of the satellite to be calculated. On the other hand, it was realized that if you knew the satellite's location, you could calculate the earth receiver's location accurately. This led to the early Transit and Timation programs which led to the GPS satellites system we have today. This in turn created the infrastructure absolutely required for many of today's long-range capabilities. GPS capability was recognized by countries such as China and Russia to be so strategic that they have developed their own GPS satellite systems in order to not be dependent on a US system that could be programed to not allow its use.

In Europe, there was constant tension between the US and Europe (NATO) and the Soviet Union and European Buffer countries (WARSAW Pact) arising from concerns that the Warsaw Pact might invade NATO. This led to the US pre-deploying troops and capabilities in Europe to deter the Soviets from trying a surprise attack on Europe to create a fait accompli before the US could respond. Long range fire capabilities were developed which would provide a deep strike capability. This was especially important for NATO since the Soviets had far more resources closely deployed than the US had pre-deployed and US resources could not be replaced quickly.

The AirLand Battle concept using Long Range fires delivered by aircraft and missiles was created to attack the 2nd and 3rd Soviet echelons, keeping them from reinforcing the 1st echelon that was fighting US forces at the Fulda Gap. Eventually the Soviet Union dissolved and treaties between the US and Russia were created which banned long-range tactical missile strike systems.

The Lessons of Desert Storm

It seemed in the late 1980s that perhaps the world would be at peace. There was no question that the US Military was the dominant force with no apparent weakness. But on August 2 1990, Iraq invaded Kuwait and annexed it.

The US almost immediately started sending forces to Saudi Arabia and deployed and built up, along with other Coalition forces, an extraordinary force in Saudi Arabia. Iraq had long range SCUD missiles bought from Russia. However, they were mostly ineffective since they could not be accurately targeted.

On 17 January 1991, after 5 months of deploying forces into Saudi Arabia, the US and its Coalition bombed the Iraqi tank formations and other forces for nearly 5 weeks. On 24 February 1991, the US and Coalition ground forces entered Kuwait and within 100 hours declared a cease fire since it was obvious that the Iraqi forces were nearly destroyed. In this operation, known as Desert Storm, the coalition human and equipment kill ratios were greater than 100 to 1.

This was a stunning victory against what was considered the 4th largest military in the world. But the world learned an important lesson. Never allow the US the time to deploy forces in an area where they could be easily used against you. The world also learned that keeping US deployment at a distance beyond tactical use required weapons that could reach a long distance but also could be targeted for maximum effect.

China Becomes An International Force

It is hard to say exactly when China decided to open its economy and join the world economy but in the 1980s, it began signing a number of regional trade agreements. On 11 December 2001, China became a member of the World Trade Organization (WTO) which was clearly a defining moment.

China knew that the US was the dominant country in their part of the world both economically and militarily. It is believed that China felt that for it to become the dominant economic force in their hemisphere, they also had to become the dominant military force and act as a “protector” for the area. China no doubt watched Desert Storm and came to the conclusion that you never allowed the US to pre-deploy forces which would then constrain your freedom of action.

It is not known for sure, except that it seemed logical, that in order to become the dominant nation in their hemisphere, China needed to control the ability of the US Navy to gather forces and always be a pre-deployed threat.

The first step towards this goal was for Chinese Navy ships have anti-ship missiles which had a longer range than the equivalent missiles of US ships. In addition, they also needed to have the capability to defeat US carriers which had airplanes that could take over the ship-to-ship US missiles.

The Chinese Navy capability to “out-stick” US capability happened in the middle 2000s and led to DARPA starting a program to develop a missile which could negate China’s capability. The resulting Long-Range Anti-Ship Missile (LRASM) missile now entering deployment will help reestablish US ship-to-ship dominance.

China also knew that the US carriers were a constantly pre-deploying threat that they needed to keep from getting close enough to China to be a threat. China's DF-21, believed to be a derivative of the US Pershing missile, is an anti-ship ballistic missile that has a maximum range exceeding 100s of miles and has reached initial operating capability (IOC).[52] Based on the DF-21, China has also developed a conventionally armed hypersonic land-based anti-ship ballistic missile.[53] The figure below illustrates the range at which China now threatens US Naval and Island assets in the Pacific.

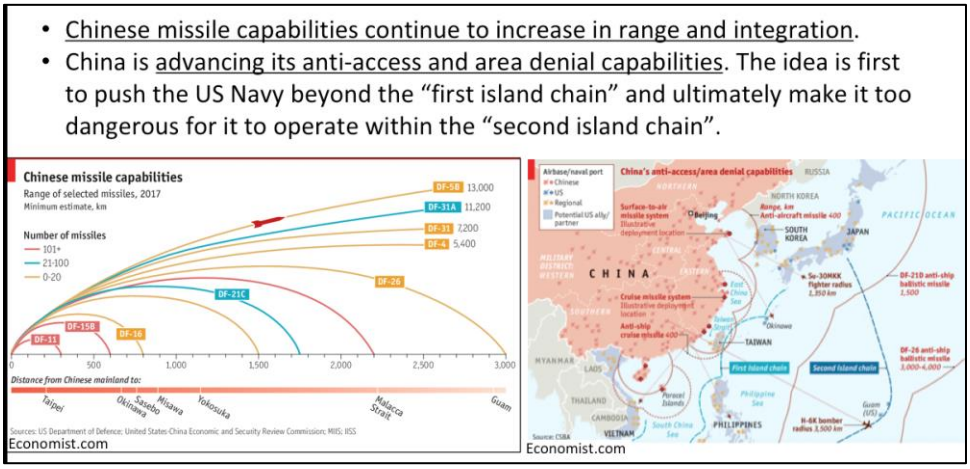

Figure AE.1. China Learns the Lessons of Desert Storm

The US response is to develop hypersonic Long Range Precision Fire missiles to be launched from airplanes or ships not threatened by China's long range capability. There is a possibility that LRPF missiles might also be deployed on islands outside of range of Chinese weapons and constantly moving to avoid accurate targeting.

A major need however for the LRPF system to be effective is the previously mentioned network that can not only transmit the target locations to the LRPF system for initial targeting but can also provide subsequent updates to the missile inflight.

Russia Regain its Status

The figure below shows that Russia has learned from Desert Storm and is modernizing its forces. They have developed long range weapons that would make it difficult for the US to pre-deploy a force in Eastern Europe that could threaten Russia. It is estimated that Russia could invade and take over any Baltic country in 60 hours or less assuming that they had their forces positioned on the Eastern borders.

There seem to be few choices for the US to deter this from happening. One option is to pre-deploy forces much as was done during the Cold War years in near proximity to the Baltic

[52] Wikipedia, DF-21, https://en.wikipedia.org/wiki/DF-21
[53] Ibid

countries. This would be a massive undertaking and would put the forces under the gun of Soviet LRPF. The second option is to develop a US ground-based LRPF system whose range was well outside of Russian LRPF capability, or to use airborne LRPF capability. The likely required quantity of LRPF missiles and the rate of fire needed to be effective would seem to drive the number of airborne assets to high values which tend to potentially favor ground based systems. In either case as with the China solution, there is a major need for a network to be able to initially target and then update the target location after launch.

- Russian indirect fire systems (MRLs, artillery, missiles) outrange U.S. systems.
- New Russian long range SSC-8 cruise missile enables attack at ranges ≥ 2,000 km
- Advanced IADS capabilities provide important Anti-access and Area Denial advantage that inhibit attack of enemy forces and supporting assets from combat aircraft

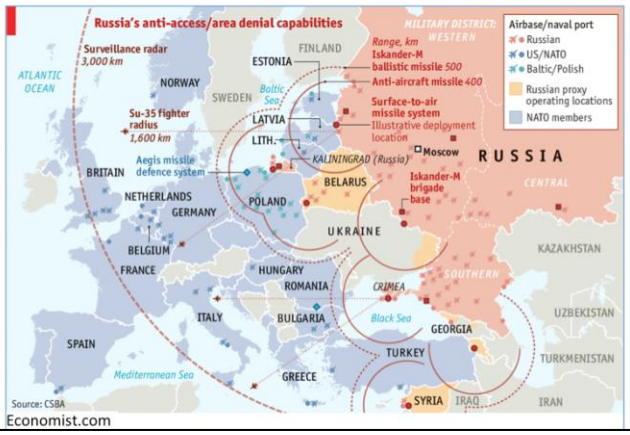

Figure AE.2 Russia Learned from Desert Storm

Army Science Board

Multi-Domain Operations (MDO)

(Follow on to the 2017 Multi-Domain Battle Study)

18 July 2018
Final

Agenda

- Introduction (Members, TOR, Visits)
- 2017 MDB Study Overview
- 2018 MDO Study Discussion
- Two examples
  - Dense Urban Operations
  - Long Range Precision Fires
- Observations
- Findings & Recommendations

Study Team Members

- Maj Gen (Ret) Ron Sega, PhD – Chair
- Mark Glauser, PhD – Vice Chair
- Nancy Chesser, PhD
- LtGen (Ret) Emerson Gardner
- Bill Guyton
- COL (Ret) Susan Myers, PhD
- Bill Snowden, PhD
- Tony Tether, PhD

Red Team:

- Jeff Isaacson, PhD
- Jim Tegnelia, PhD

Study Manager:

- LTC Marco Lyons, TRADOC

2018 MDO Study TOR: Overview

- Follow-on to FY2017 study
- Objectives
  - Continue assessing how to re-balance the Army's capabilities to fight more effectively using an integrated application of options from all five DoD-recognized military warfighting domains (land, air, sea/maritime, space, and cyberspace).
  - Assess potential combat efficiencies and synergies realized through leveraging, synchronizing, and integrating joint, interagency, and multinational (JIM) capabilities across all domains.
- Baseline: *Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040, dated December 2017.*

TOR signed by SA 10/18/17
Sponsored by CG TRADOC

2018 MDO Study TOR: Tasks

A. In **competitions** below armed conflict, how does Army, working with joint, interagency, and multinational (JIM) partners:
   1. Contest adversary operations?
   2. Deter armed conflict and employment of adversary conventional forces?
   3. Implement command and control capabilities to actively compete and immediately respond to the escalation of violence?
   4. Set the theater (including CONUS) before hostilities?

B. During armed **conflict**, how does Army, working with JIM partners:
   1. Defeat the peer adversary's fait accompli campaign?
   2. Execute strategic and operational maneuver?

C. In **return to competition**, how does Army, working with JIM partners:
   1. Contest the adversary's renewed subversion campaign?
   2. Deter a return to armed conflict?

D. What are the **technology gaps** for enabling MDB and providing more operational options in the future?

2018 MDO Study Visits (64 organizations)

Army
- Acting SECARMY McCarthy
- TRADOC, GEN Perkins +
- G-2, Deputy
- ARCIC, MG Dyess, BG Odom +
- Maneuver COE, MG Wesley +
- Futures, MG Hix
- Precision Fires CFT, MG Richardson
- Networking CFT
- CSA Future Studies Group
- Cyber COE
- SMDC/ARSTRAT
- HQDA DAMO Force Management
- Army War College
- Army Research Laboratory
- AMRDEC
- Army Aviation Quad A
- AUSA Global Force Symposium
- AUSA LANPAC
- TRADOC Mad Scientists

Navy/Marine Corps
- Future Fleet Design & JAM-GC
- OPNAV N9
- USMC M-2
- Marine Corps Warfighting Lab

Air Force
- Air Combat Cmd, Gen Holmes
- Space Cmd, Gen Raymond
- AFMC, Gen Pawlikowski
- CIO, Lt Gen Shwedo
- National Acad AF Studies Board C2 Workshop Lt Gen (Ret) Hamel
- USAF A-2
- AF Research Lab
- 711th Human Performance Wing
- AF Institute of Technology
- Air University, LeMay Center

Inter-organizational
- Center for Naval Analysis - Russia Team
- Institute for Defense Analyses
- National Security Council
- CIA
- Department of Homeland Security

Multi-national
- TRADOC Liaisons from France, Germany, Spain
- NATO Collaboration Support Office
- NATO Chief Scientist

Joint
- STRATCOM, Gen Hyten
- PACOM, J5
- USD R&E, Dr Griffin
- OSD, PD EC&P, Dr. Perkins
- Joint Staff, J7 Suffolk
- Joint Staff J-8 Innovations
- DARPA
- Missile Defense Agency
- Joint Modernization Command
- IC: DIA, MSIC, NASIC, NRO, NGIC, NGA, NSA
- ADM (Ret) G, formerly JFCOM
- Gen (Ret) Ham, formerly AFRICOM
- DSB Multi-Domain Effects Study, Gen (Ret) Breedlove
- National Defense University
- Defense Threat Reduction Agency

Other
- Industry
- MG(Ret) Scales
- Georgia Tech Research Institute
- National Academy of Sciences
- Center for Strategic & Budgetary Assessments

MDO 2018 Study Visits at TS/SCI Level

- DIA
- MSIC
- NASIC
- NRO
- NGA
- NSA
- Classified Space
- Cyber 1.8
- DARPA
- MDA
- PACAF

Recurring Themes from 2018 MDO Visits

Theme	Sources
Integrated effects	STRATCOM
Joint by Design	USAF ACC
Need for speed	Cyber Command (AUSA), STRATCOM (AUSA), OSD(AT&L) (Quad A), AFRL
Experimentation	USAF AMC, Cyber Command (Cyber Quest)
Realistic training	Cyber Command (AUSA), MCCDC, Unified Quest
NOFORN and Releasability are issues for multi-national	TRADOC Liaisons, Panel on Partners (AUSA AMD), Panel Quad A, NATO CSO 6/21

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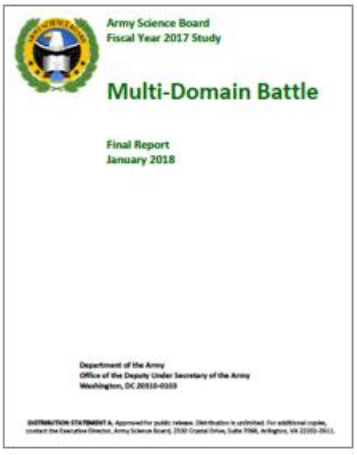
- Findings & Recommendations

2017 MDB Study Provided Foundation for MDO 2018

ASB Multi-Domain Battle Study

- Published January 2018



From 2017 Outbrief

Key MDB 2017 Study Themes

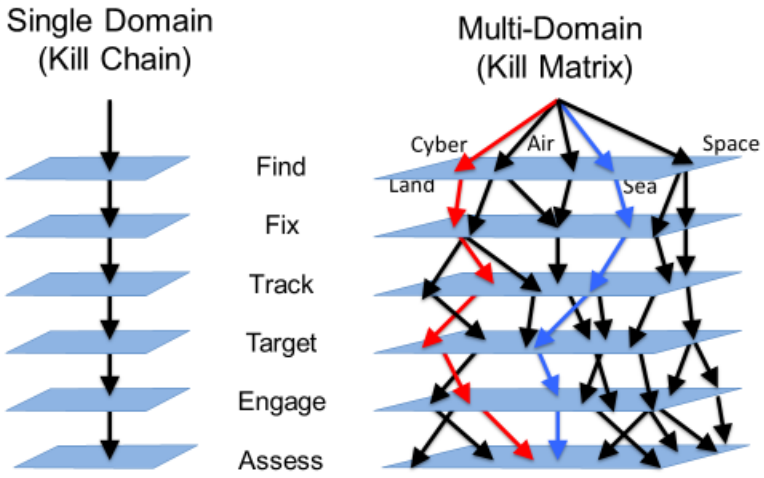
Need for

- **More operational options**
- **Greater integration**
- **Realistic experimentation**
- **Greater speed**
  - Technology advancement
  - Data collection, analysis
  - Decision-making
  - Acquisition
  - Deployment
  - Maneuver
  - Response time
  - Weapons velocity

There must be a sense of urgency in all we do.

From 2017 Outbrief

Multi-Domain Increases Operational Options



Exploit all five domains **to achieve much better outcomes** in the future.

From 2017 Outbrief

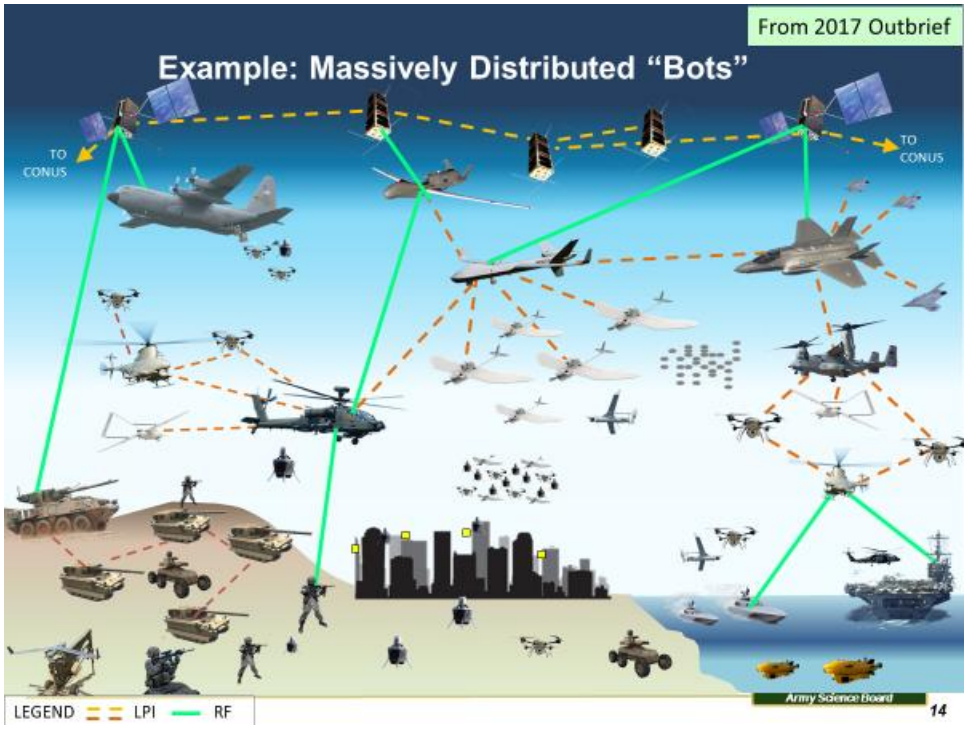
Football has evolved to be a more complex sport:

Rush (Land), Pass (Air), Coach in Press Box (Space), Crowd Noise (Cyber)

Having options is crucial in an uncertain, dynamic environment.

From 2017 Outbrief

Example: Massively Distributed "Bots"



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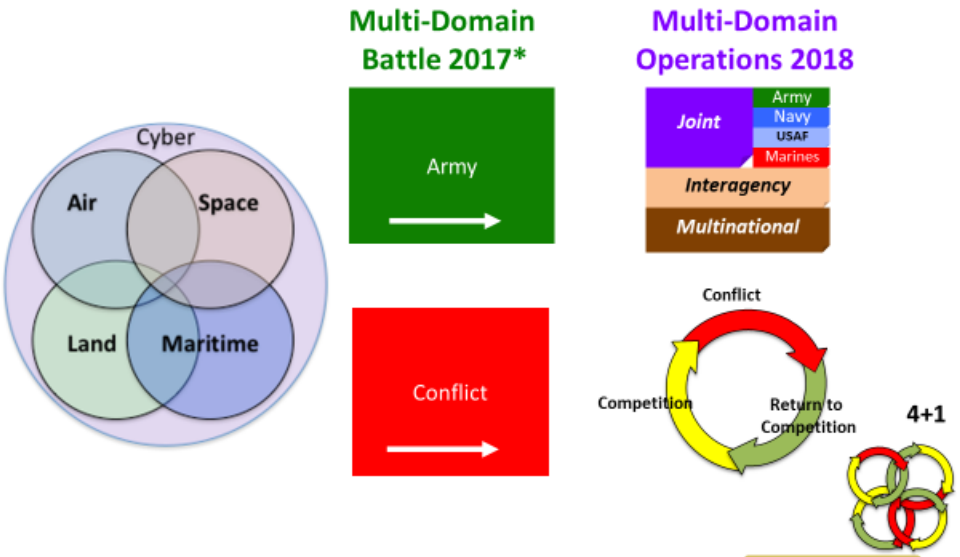
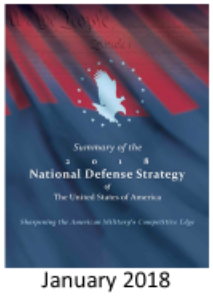
*"Multi-Domain Battle (MDB) is now Multi-Domain Operations (MDO)."**



*Gen Townsend at AUSA LANPAC 2018

Guidance from 2018 National Defense Strategy

- Acknowledge challenges to the US military advantage
  - Every domain is contested—air, land, sea, space, and cyberspace
  - More lethal and disruptive battlefield, combined across domains
- Regard rapid technological advancements and changing character of war
  - Advanced computing, "big data" analytics, artificial intelligence, autonomy, robotics, directed energy, hypersonics, and biotechnology
- Evolve innovative operational concepts
  - Foster a culture of experimentation and calculated risk-taking
- Strengthen alliances and attract new partners
  - Deepen interoperability
  - Integrate with U.S. interagency
- Reform the Department
  - Deliver performance at the speed of relevance
  - Experiment and use prototyping

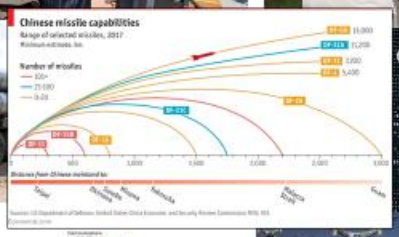


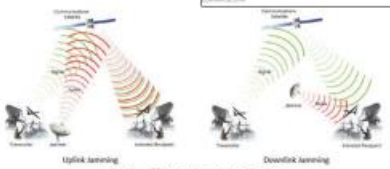
January 2018

MDB and MDO Findings & Recommendations Align Well with NDS

Excerpts from National Defense Strategy (Classified chart)

Why We Need MDO in Competition and Conflict





19

Peer Adversary Objectives

- **Competition**
  - Destabilize partners and allies; separate U.S. and alliances politically
  - Penetrate and reconnoiter friendly systems
  - Support and enable information warfare (IW) with unconventional warfare (UW)
  - Reinforce UW and IW, and set conditions for fait accompli campaign with conventional capabilities
- **Armed Conflict**
  - Separate Joint Force strategically across distances with ISR-strike, UW, IW, cyber systems
  - Separate Joint Force operationally in time and space with ISR-strike, UW, Cyber, IAD systems
  - Achieve strategic objectives rapidly, before the Joint Force responds effectively
- **Return to Competition**
  - Reach negotiated settlement on favorable terms to adversary
  - Destabilize partners; occupy and defend any occupied areas
  - Foment insurgencies and reinforce with UW systems and operations
  - Extend regional influence; separate U.S. and Allies politically

** Source: MDB Concept 1.0*

US and partners Response: Compete continually. When required, win in war. Then return to competing.

Army Science Board

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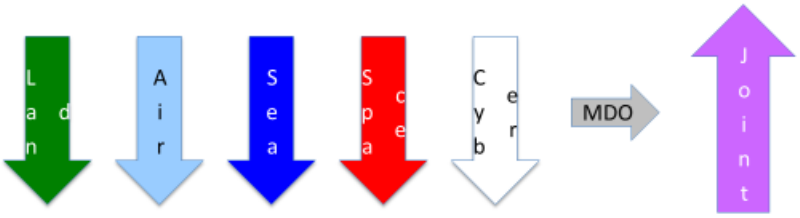
"Contested In All Domains"

- Contested in all domains = Relative power in individual domains is going down



- Need integrated (Joint) systems to achieve desired integrated effects at speed and scale to accomplish missions

Ensuring Victory on a Multi-Domain Battlefield

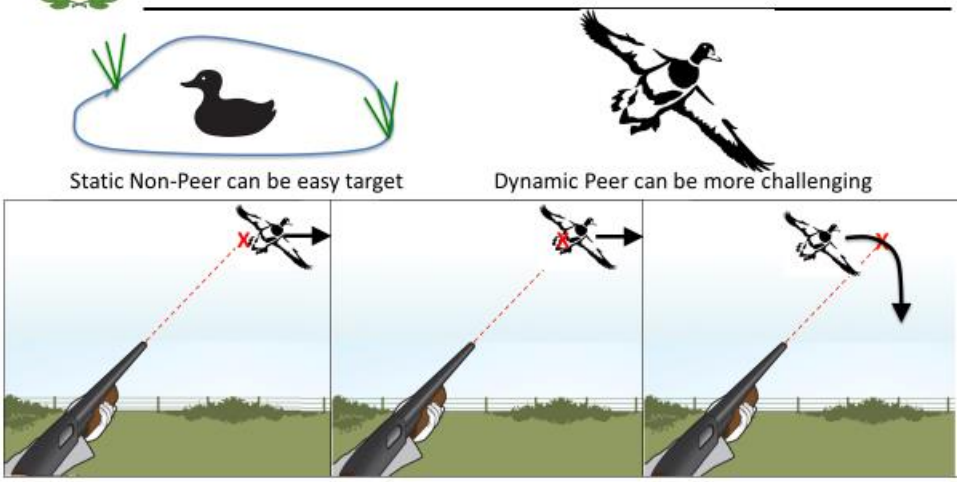
From 2017 MDB Study Report:

"The first finding addresses the need for new capabilities. **Using current capabilities in different ways will likely not defeat potential peer adversaries**."

1. Rapid advances and new disruptive capabilities, employed in a fully integrated Multi-Domain Battle (MDB) manner, are needed to ensure overmatch.
   - Potential peer adversary capabilities are advancing rapidly and will continue to do so.
   - A peer conflict is unlikely to be won by multi-domain integration of only existing and/or slowly evolving capabilities.

What is our planning strategy to ensure victory?

Potential Planning Strategies



Static Non-Peer can be easy target

Dynamic Peer can be more challenging

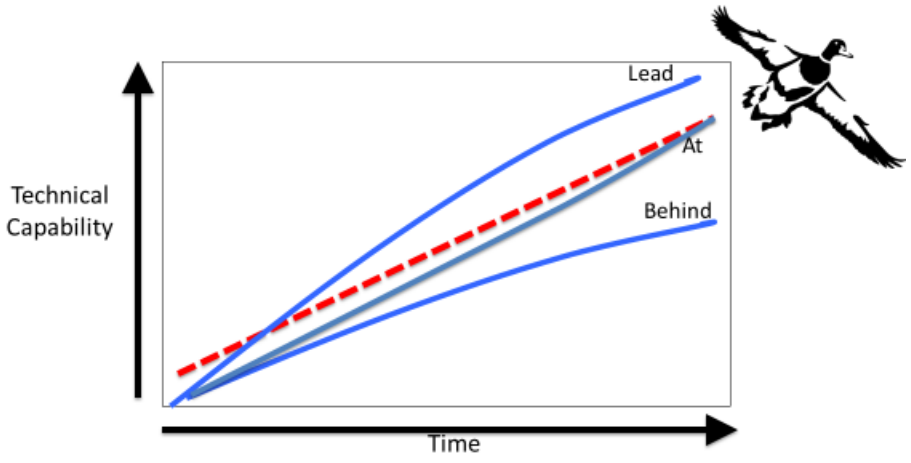
Design against demonstrated target capability, Inadequate

Design against possible current target capability, Marginal

Design against projected target capability, Success

Must lead the duck to defeat peer threat

Where Do We Aim?



Multinational View of Interoperability

Military Interoperability:
"The ability of military forces to train, exercise and operate effectively together in the execution of assigned missions and tasks."

In competition and conflict, we are more likely to be successful with Joint, Interagency, and Multinational partners.

Contributors to interoperability are:
- Standards
- Training & exercises
- Common military equipment
- "Need to share"
- Integrated planning with speed*

* Gen Townsend at LANPAC 2018

CD&E – Concept Development & Experimentation

Source: Col Andreas Henne, German Army, Chair NATO Helicopter Inter-Service Working Group (at Quad-A 2018)

Technology Critical to MDO – Conflict Phase

Operational Challenge	Near (Now-2025)	Mid (2026-2035)	Far (2036-2050)
Degraded/denied comms/networks; Pace of battle requires faster decision-making	Self-healing C4; Mission Command; Introduce commander's aids; Reduce CP size/signature; Data analytics; Small sats	Incorporate AI; Comm nodes available in multiple domains; Low probability of intercept	Small battle nets; Quantum communications
Survivable formations; Rapidly deployable expeditionary forces	MUM-T/Autonomy/AI for Wingman: Apache w/ Fire Scout/Shadow, ARCV (UGV, 7-15 ton)	Fleets of multi-domain robots (10:1), Comms: LPD, LPI, AJ	Swarms of multi-domain autonomous robots (100:1)
Anti-Access & Area Denial - Long Range Precision Fires out-ranged	Deploy (2x range of ATACMS); Submunition warhead/ISR	Hypersonic glide (>50% flight) range 500-1000 nm; Smart submunitions	Hypersonic propulsion; Low cost cruise missile; Rail gun w/ scram shell
Timely ISR data - Need to support long range precision fires	Targeting/fire control through UAS, space-based (LEO) SAR, EO/IR	Space-based MTI (LEO); Multi-domain fleets of robots	Ubiquitous ISR; Multi-domain swarms of autonomous robots
Counter-UAS (single/swarms)	"Iron Beam" on CAT 25-50 kW (UAS, rockets); Air-to-air UAS	Extend to RAM; Multi-domain fleets of robots	Multi-domain swarms of autonomous robots
Degraded/denied PNT	Miniaturized precision clock (CSAC); Digitized terrain map; Digitized compass/LRF; Celestial nav update	Precision INS on current GPS-guided munitions	Optimum mix of absolute and relative navigation

Technology Critical to MDO – Competition and Return to Competition Phases

Operational Challenge	Near (Now-2025)	Mid (2026-2035)	Far (2036-2050)
Map and influence the environment and people	Imbedded and Unattended sensors for Situation Assessments. Social Media Analytics with Controls. Monitor & Control the health of the Infrastucture (power, water, etc.)	AI at the Edge & Machine Learning for rapid fusion of Information. Advanced use of genetic markers to guide treatments for diseases	Thought Controlled Operations. Imbedded human sensors. Auto detection & treatment of illness's and diseases. Weather Control
Attract partners	Ensure common goals & values, Share common tools and assets. Move from need to know to need to share.	Advanced joint technology & concept development	Continue partnership agreements
Comms for military & civilian in urban terrain. Wide area Knowledge capture	Bridge connections to existing cell networks. LEO small sats for comms and SA.	Comms: LPD, LPI, AJ; Data to knowledge using AI	Quantum Communication
Low collateral damage weapons	Non-lethal weapons, HPM, cyber, etc.	More compact and rapidly deployable systems	Advanced concepts
Robotics and Autonomy	Control multiple ground and air unmanned systems	Increased levels of autonomy	Multi-function and autonomous

Observations on Artificial Intelligence

- "The major challenge for the US is China," CNA analyst Larry Lewis said. "They are approaching the use of AI just like the US approached going to the moon in the sixties."
- From the Deputy Secretary of Defense Memorandum: "Establishment of the Joint Artificial Intelligence Center", June 27, 2018:

  "The 2018 National Defense Strategy (NDS) foresees that ongoing advances in artificial intelligence (AI) 'will change society and, ultimately, the character of war.' To preserve and expand our military advantage and enable business reform, we must pursue AI applications with boldness and alacrity while ensuring strong commitment to military ethics and AI safety. A new approach is required to increase the speed and agility with which we deliver AI-enabled capabilities and adapt our way of fighting."

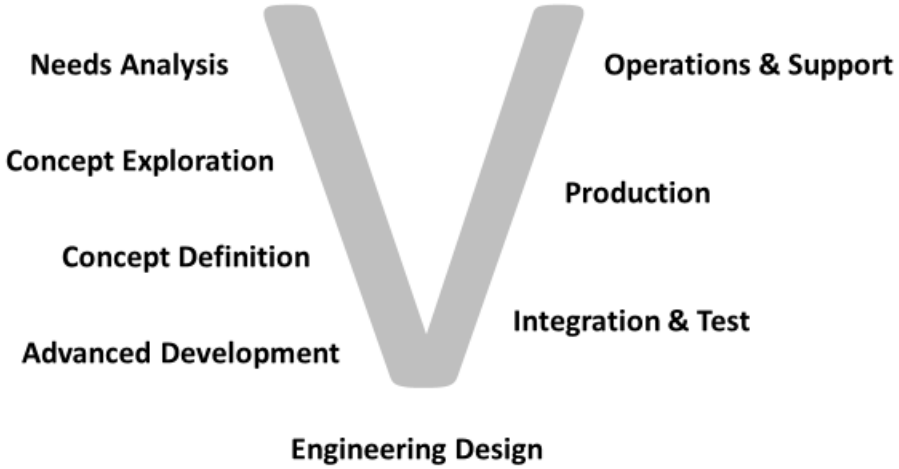
- OSD established a Joint Artificial Intelligence Center (JAIC) under the DoD CIO on June 27, 2018

Considerations on Architectures

- An MDO system of systems architecture for Conflict includes:
  - Manned-unmanned teaming, including AI
  - Autonomous systems with various levels of supervision
  - Assured, secure communications
  - A robust C4 architecture with, at a minimum, assured intermittent communications for mission command
  - A model-based system engineering (MBSE) approach
  - A model validation strategy utilizing experimentation and exercises
- An MDO system of systems architecture for Competition includes:
  - Details of the country/ city infrastructure
  - Comms, transportation, water, power, commerce, media/news, banking, etc.
  - Human behavior modeling with ability to test and measure results and effects is required
  - Modeling of the environment and the population
- A high/low mix of cost-effective technical and operational options could provide flexibility and agility throughout the competition continuum.
  - Formation of unmanned expendable/attritable vehicles with high-end manned vehicles allows new CONOPS and "system survivability"
  - Modular and multifunctional characteristics could lead to emergent behavior

System of Systems Engineering

Nested Set of Analyses: System, Subsystem, Component, …



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The Problem: Dense Urban Environment

"Army *will* operate in large cities and megacities; Our potential adversaries will intentionally choose to go to cities." **Gen Townsend**, LANPAC 2018

- Experience from Mosul:
  - C2 systems didn't work well
  - Targeting systems could not keep up with the changes to the urban terrain.
  - Range of our sensors was degraded
  - Range and effectiveness of our weapons are degraded

MDO and DUE:

- Dense Urban Environment (DUE) operations is an inherently multi-domain environment that compresses physical and temporal spaces, compounds obstacles and demands simultaneous execution of innumerable tasks.
- No single military service or Army unit is capable of unilaterally operating in DUE during competition or conflict.

ASB studied Dense Urban Ops in 2017

Three Block War

- In the mid 1990s, USMC General Charles ***Krulak*** offered the concept of the "***three block war***" as a metaphor to describe the demands of the modern battlespace.
- Soldiers and Marines may be confronted by the entire spectrum of tactical challenges in the span of a few hours and within the space of three contiguous city blocks: ***humanitarian aid, full scale military action, and peacekeeping operations***.
- "The individual will be the most conspicuous symbol of American foreign policy and will potentially influence not only the immediate tactical situation, but the operational and strategic levels as well. His actions, therefore, will directly impact the outcome of the larger operation; and he will become -- ***the Strategic Corporal***."

"Three Block War" Laboratory can contribute to necessary cultural change

MDO in Dense Urban Environment Objectives

Competition Objective #1: Stay in competition: Avoid moving into conflict

- Dept. of State will often lead. MDO benefits can only be effective with fully Integrating interagency capabilities and multinational collaboration.
- Understand and exploit the operating environment
- Create options; Provide extra time for diplomacy
- Address political, economic, food, energy, shelter, info, and security concerns

Competition Objective #2: Establish conditions for success in conflict should it occur

- Map the terrain, understand the environment, build relationships
- Add resiliency to organic networks by exploiting local networks
- Prepare the force; utilize synthetic training and rehearsals

Conflict Objective: Win the battle without losing the war; Return to Competition

- Knowledge: Address the C2 challenge
- Speed: Tighten Observe, Orient, Decide, Act (OODA) Loop
- Range: Make up for loss of weapon range advantage through increased operational reach using other domains

How Can MDO Make A Difference Across the Competition Continuum?

Stalingrad | Mosul | Aleppo | MDO

Create more knowledge

- Push it to the "Strategic Corporal"
  - Pull from universally available sensors, add micro-UAVs and robots
  - Use AI and machine learning to convert data to knowledge
  - Use activity-based intelligence to improve decision-making
- Increase sharing of assets & knowledge to enable collaboration with partners
- Increase speed and effectiveness of C4ISR at every echelon

Create more options for action

- Improved interactions with community (relationships, cyber, IO, social media)
- Improved weapons: Dial an effect, improved infantry weapons, soldier lethality

What's New: MDO improves odds of succeeding without destroying the city

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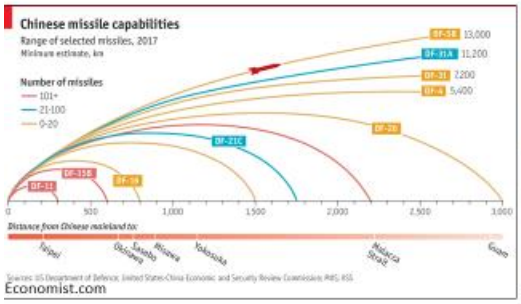
EUCOM Challenges: Long Range Precision Fires

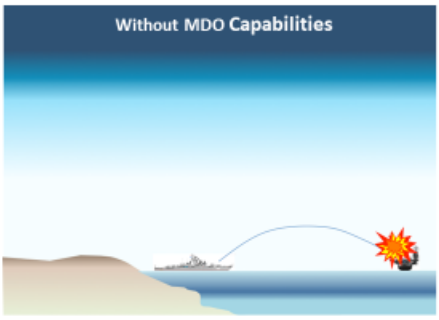
- Russian indirect fire systems (MRLs, artillery, missiles) outrange U.S. systems.
- New Russian long range SSC-8 cruise missile enables attack at ranges ≥ 2,000 km
- Advanced IADS capabilities provide important Anti-access and Area Denial advantage that inhibit attack of enemy forces and supporting assets from combat aircraft

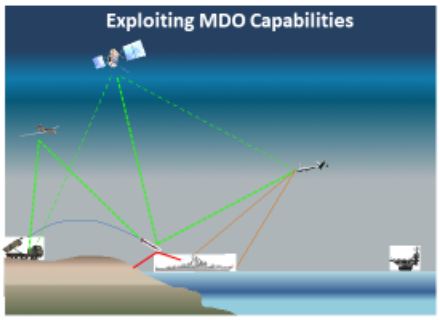
PACOM Challenges: Long Range Precision Fires

- Chinese missile capabilities continue to increase in range and integration.
- China is advancing its anti-access and area denial capabilities. The idea is first to push the US Navy beyond the "first island chain" and ultimately make it too dangerous for it to operate within the "second island chain".



Impact of MDO: Long Range Precision Fires





- Very limited situational awareness (SA)
- High-value asset vulnerable to enemy attack from extended ranges
- Single Domain: Maritime
- Russia and China are marching to increasingly longer ranges with multi-domain targeting strategies.

- Space, airborne, and ground assets, coupled with secure comms, provide large area SA and enable effective targeting and updates
- LRPF from Multiple Domains: Air, Ground, and Maritime

Long Range Precision Fires

- Gen (Ret) Perkins, former CG of TRADOC, when asked his opinion of Long Range Precision Fires said " We have always wanted this capability but have never been able to figure out how to target." (AUSA Dinner Aug 2017).
- Red advantages can be offset by coordinated exploitation of Joint Interagency and Multinational capabilities in multiple domains.
  - MDO using aviation and space assets could mitigate this shortfall by being able to provide a location for the targets using network capability.
  - MDO could also provide updated targeting information to the munition enroute to its target and receive sensor information from the munition to communicate SA to the rear (e.g., BDA, other targeting opportunities).
- A Long Range Precision Fires munition is under development:
  - Neither the sensors, nor the network from ground/air assets to the munition and from the munition to the rear are currently included.
- Other considerations for a long range precision fire system capability:
  - Cyber-hardened weapon systems
  - Decision-making under Uncertainty (AI Applications)

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General Observations

- Command relationships across the whole of government during Joint, Interagency, Multinational operations are not clear.
- The principles of agility, flexibility, adaptability, and speed should be integral components of all Joint and Service doctrine.
- In competition prior to conflict we have the ability to collect and analyze extensive data in all domains and take advantage of "perfect" communications when available.
- Services are working on their own multi-domain concepts:
  - Army – Multi-Domain Operations
  - Air Force – Multi-Domain Command and Control
  - Navy & Marine Corps – Littoral Operations in Contested Environment
- COCOMs are focused on daily operations and exercises out to 3 years.
- Cyber Quest 2018 sponsored by Cyber COE involved Army and Marine Corps operators (hope to add AF next year) and liaisons from Germany, Netherlands, UK, Australia, Belgium, Norway.
- There are single-Service exercises that add other Services at later stages:
  - AF 2018 Title 10 Global Engagement Wargame and Red Flag 18-1

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Findings and Recommendations Topics

Joint	1. Joint by Design
	2. System of Systems Approach
	3. Modeling and Experimentation
Examples	4. Dense Urban Environment
	5. Long Range Precision Fires
Technology	6. CSA Priorities and MDO
	7. Information Operations and Cyber Electromagnetic Activities
	8. Counter-UAS and Air and Missile Defense
People	9. Optimized Human-Machine Systems
	10. Defense Culture and MDO

1. Joint, Interagency, and Multinational by Design

Findings:

- ***Army MDO must be Joint, Interagency, and Multinational by Design***.
- Single Service-developed multi-domain concepts are not sufficient for a fully integrated Joint MDO concept.
- There is a limited set of DoD joint experiments and exercises with time horizons beyond 3 years.
- The most successful experiments and exercises are Jointly planned and executed. Single-Service exercises that include other Services are a step in the right direction.
- There is a history of interagency reluctance to participate in military exercises.

Recommendation:

- CJCS: Develop and resource a coherent organizational construct with Joint, Interagency, and Multinational partners to develop multi-domain concepts and doctrine, and evaluate them in realistic, integrated experimentation and exercises, particularly for the mid and long term.

2. System of Systems Approach

Findings:

- ***MDO requires a system of systems approach.***
- The system of systems approach would expand the range of options critical to successful multi-domain operations in a contested environment (multi-functional "subsystems" and emergent behavior).
- There is no system of systems architecture for multi-domain operations in Conflict or Competition.

Recommendations:

- CG AFC: Develop a system of systems architecture of options for multi-domain operations in conflict and competition.
- SA: Establish a Systems Engineering CFT to integrate the other CFTs to facilitate more rapid advance of multi-domain capabilities and support requirements development.

3. Modeling and Experimentation

Findings:

- ***Modeling and experiments should inform MDO development.***
- The Services do not have sufficient Joint, Interagency, and Multinational involvement in their models and experiments, nor do they fully exploit common advanced tools and technology.

Recommendations:

- CJCS and USDR&E: Develop and deploy to the Services, Joint models and experiments using common advanced tools and technology.
- CG AFC: Conduct multi-domain modeling, experimentation, exercises, and analyses of system of systems concepts that address capability gaps in realistic mid to far term threat environments.
  - Develop holistic approaches that include high/low mixes of collaborative manned/unmanned systems, higher levels of autonomy, PNT in degraded environments, attritable unmanned assets and enhanced Directed Energy.
  - As appropriate, leverage AI and machine learning.
  - Expeditiously develop and validate systems architectures and CONOPS.

4. Dense Urban Environment

Findings:

- ***MDO is critical to success in the Dense Urban Environment.***
- Army MDO conceptual thinking properly recognizes Dense Urban Environment (DUE) operations as an inherently multi-domain environment that compresses physical and temporal spaces, compounds obstacles and demands simultaneous execution of innumerable tasks.
- The benefits of robotics, autonomy, AI, and big data analysis are *essential* for DUE situational awareness, effective decision making and adequate operational reach. Realization of these benefits can only be achieved with interagency integration.
- The "Three Block War" syndrome tests the limits of the human psyche which can, to some extent, be overcome through training.

Recommendations:

- CG AFC: Evaluate and adjust the Army's robotics, autonomy, AI and big data analysis programs to address Army capability shortfalls in DUE.
- CG AFC: Create a **"Three Block War" laboratory** to investigate advanced technologies and concepts.
- CG TRADOC: Evaluate and adjust the Army's training programs to be commensurate with the complexity and probability of DUE engagements.

5. Long Range Precision Fires

Findings:

- ***Long Range Precision Fires and MDO are interdependent.***
- The Long Range Precision Fires (LRPF) and Network CFTs are developing systems that have significant issues and shortfalls:
  1. The Network CFT is not currently recommending network options that link the aviation and space assets to the LRPF Command and Control Center and the LRPF munition in flight.
  2. The LRPF CFT is not currently recommending a munition that has the capability to receive position updates of target location in flight.

Recommendations:

- CG AFC: Design and develop a maneuvering Long Range Precision Fires system that includes the network, sensing, and targeting required to make it effective.
- CG AFC: Design and develop a maneuvering munition for the Long Range Precision Fires System with the capability to receive commands in flight and to transmit SA and location information back to the LRPF Command and Control system.

6. CSA Priorities and MDO

Findings:

- ***CSA priorities*** *(Long Range Precision Fires, Next Generation Combat Vehicle, Future Vertical Lift, Networks, Air & Missile Defense, and Soldier Lethality)* ***are necessary but not sufficient for successful execution of MDO in all of its phases***
  - Examples: Rapidly deployable expeditionary forces, enhanced wide-area and local-area situational awareness, precision targeting, systems interoperability, environmental mapping, social network access and exploitation, non-lethal and low collateral damage weapons (both kinetic and non-kinetic)
- To permit evolution of technologies, systems need to be able to accommodate integration into Army, Joint, and multinational formations.
- High/low mix provides possible entry points for multinational partners.
- Low cost unmanned systems could provide flexible, agile, attritable and/or expendable system options, but they must be compatible with higher end systems.

Recommendations:

- CG AFC: Develop a high/low mix of capabilities and options for near/mid/far-term multi-domain applications that provide more versatile, less exquisite systems for growing threats.
- CG AFC: Aggressively pursue research and development with potentially disruptive technical and operational options in areas such as autonomy, AI, decision theory, quantum technology, and hypersonics.

7. Information Operations (IO) and Cyber Electromagnetic Activities (CEMA)

Finding:

- Information Operations (***IO***) **and** Cyber Electromagnetic Activities (***CEMA***) ***are essential for MDO*** and will be contested in both conflict and competition. Current capabilities are not fully integrated.
- Adversaries are exploiting rapidly evolving and proliferating IO and cyber technologies.
- Multi-domain operations require innovative approaches to the integration of cyber operations, enabling maneuver across domains and creating dilemmas for the enemy.

Recommendation:

- CYBER COE: Develop an integrated Multi-domain IO/CEMA Strategy that is responsive to the rapidly evolving MDO environment.

8. Counter-UAS and Air and Missile Defense

Finding:

- ***Counter-UAS and Air and Missile Defense are critical to MDO***
- Controlling multiple unmanned systems has been demonstrated and is being deployed around the world. This is both a threat and an opportunity.
- Within the next year there could be 10X drones in such configurations and the numbers will continue to grow even more rapidly going forward.
- Developing UAS formations for offensive and defensive applications has tremendous potential.

Recommendation:

- CG AFC: Develop cost-effective Counter-UAS and air & missile defense options based on MUM-T, Robotics and Autonomous Systems, AI, electronic warfare, and directed energy to support MDO.
- CG AFC: Develop and test UAS technologies and concepts for offensive and defensive capabilities using more advanced ranges such as the "Three Block War" laboratory.

9. Optimized Human-Machine Systems

Findings:

- ***The development and use of AI, machine learning, and autonomous systems are accelerating, including in military applications such as MUM-T and C4ISR.***
- The massive amounts of data being produced in multiple domains can only be processed in relevant time scales by using advanced data analytics, machine learning and artificial intelligence.
- The speed needed to recognize, discriminate, target, and decide is moving beyond human capacity, driving the need for automation and/or optimized human-machine systems. Speed and accuracy trades must be undertaken and understood.
- Optimized human-machine system experimentation can improve understanding of technical performance and the value to the relevant CONOPS and support the culture change needed to operate in this high-speed environment.
- MDO effectiveness requires optimized human-machine systems.

Recommendation:

- ASA(ALT) and CG AFC: Develop and field optimized human-machine systems, which include trusted autonomy, AI and machine learning in operations, planning, wargaming, experimentation, acquisition, business processes, etc.

10. Defense Culture and MDO

Finding:

- ***Defense culture must be changed to embrace Joint, Interagency, and Multinational and advanced concepts for MDO to succeed in the mid-to-long term.***
- "Jointness" has not advanced to a level to enable MDO.
- Changing the culture requires a change in training and education.
- While changes to training and education must occur at all levels, there must be particular focus on mid-level Service leadership.
- Successful MDO requires alignment of incentives and measures of success (example, promotion and assignments).

Recommendation:

- CG TRADOC: Develop Tactics, Techniques, and Procedures (TTPs) for MDO and establish a realistic training and education program that supports the cultural change to embrace Joint and advanced concepts necessary for success in multi-domain operations. Develop an MDO curriculum across professional military education.

MDO 2018 Study Themes

Need for

- **More operational options**
- **Greater integration**
- **Realistic experimentation**
- **Greater speed**
  - Technology advancement
  - Data collection, analysis
  - Decision-making
  - Acquisition
  - Deployment
  - Maneuver
  - Response time
  - Weapons velocity

There must be a greater sense of urgency in all we do.*

**** includes Joint, Interagency, and Multinational partners***

QUESTIONS?

APPENDIX G. GLOSSARY OF TERMS, ABBREVIATIONS, AND ACRONYMS

AFC	Army Futures Command
AFMC	Air Force Materiel Command
AFRICOM	Africa Command
AI	Artificial Intelligence
AJ	Anti-Jam
AMRDEC	Aviation and Missile Research, Development, and Engineering Center
APS	Active Protection System (SK/HK/CE = Soft kill, Hard kill, chemical energy)
ARCIC	Army Capabilities Integration Center (part of TRADOC)
ARCV	Armed Robotic Combat Vehicle
ARSTRAT	Army Forces Strategic Command
ASA(ALT)	Assistant Secretary of the Army (Acquisition, Logistics and Technology)
ASB	Army Science Board
ATACMS	Army Tactical Missile System
AUSA	Association of the US Army
BDA	Battle Damage Assessment
C-UAS	Counter Unmanned Aerial System
C2	Command and Control
C4	Command, Control, Communications, Computers
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CCOE	Cyber Center of Excellence (Ft Gordon)
CEMA	Cyber electromagnetic activities
CFT	Cross-Functional Team
CG	Commanding General
CIA	Central Intelligence Agency
CIO	Chief Information Officer
CJCS	Chairman Joint Chiefs of Staff
COCOMs	Combatant Commands
COE	Center of Excellence
CNA	Center for Naval Analysis
COL	Colonel
CONOPS	Concept of Operations
CONUS	Continental US
CP	Command Post
CSA	Chief of Staff of the Army
CSAC	Chip Scale Atomic Clock
DAMO	Department of the Army Military Operations
DARPA	Defense Advanced Research Project Agency
DE	Directed Energy (RF or Laser)
DIA	Defense Intelligence Agency
DoD	Department of Defense
DOS	Department of State

DSB	Defense Science Board
DUE	Dense Urban Environment
EMS	Electromagnetic Spectrum
EO	Electro-optic
EUCOM	European Command
GPS	Global Positioning System
HCM	Hypersonic Cruise Missile
HPM	High Power Microwave
HQDA	Headquarters Department of the Army
I&W	Indications & Warning
IADS	Integrated Air Defense System
JAIC	Joint Artificial Intelligence Center
IAM	Individual Assault Munition
IEO	Information Environment Operations
INS	Inertial Navigation System
IO	Information Operations
IR	Infrared
ISIS	Islamic State of Iraq and Syria
ISR	Intelligence, Surveillance, and Reconnaissance
JAM-GC	Joint Concept for Access and Maneuver in the Global Commons
JATO	Jet Assisted Take Off
JCIC	Joint Concept for Integrated Campaigning
JFCOM	Joint Forces Command (formed 1999, disestablished 2011)
JIM	Joint, Interagency and Multinational (or Interorganizational)
JOE	Joint Operating Environment
KE	Kinetic Energy (Rod)
KEM	Kinetic Energy Missile
LANPAC	Land Forces Pacific (AUSA Conference)
LEO	Low Earth Orbit
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LRASM	Long Range Anti-Ship Missile
LRF	Laser Rangefinder
LRPF	Long Range Precision Fires
MALD	Miniature Air-Launched Decoy
MBSE	Model-based System Engineering
MDA	Missile Defense Agency
MDB	Multi-Domain Battle
MDO	Multi-Domain Operations
MPF	Mobile Protected Firepower
MRL	Mobile Rocket Launcher
MSIC	Missile and Space Intelligence Center (Huntsville, AL)
MTI	Moving Target Indicator
MUM-T	Manned-Unmanned Teaming

NASAMS	Norwegian Advanced Surface to Air Missile System
NASIC	National Air and Space Intelligence Center (Dayton, OH)
NATO	North Atlantic Treaty Organization
NDS	National Defense Strategy
NGA	National Geospatial-Intelligence Agency
NGCV	Next Generation Combat Vehicle
NGIC	National Ground Intelligence Center (Charlottesville, VA)
NRO	National Reconnaissance Office (Chantilly, VA)
NSA	National Security Agency (Ft Meade, MD)
OODA	Observe-Orient-Decide-Act
OE	Operating Environment
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
PACAF	Pacific Air Forces
PACOM	Pacific Command
PD EC&P	Principal Deputy, Emerging Capability and Prototyping
PNT	Positioning, Navigation and Timing
RAM	Rocket, Artillery, Mortar
RF	Radio Frequency
S&T	Science & Technology
SA	Secretary of the Army
SA	Situational Awareness
SAR	Synthetic Aperture Radar
SMDC	Space and Missile Defense Command
SOF	Special Operations Force
STRATCOM	Strategic Command
TCM	TRADOC Capability Manager
TOR	Terms of Reference
TRADOC	Training and Doctrine Command
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
USAID	US Agency for International Development
USARPAC	US Army Pacific
USDR&E	Under Secretary of Defense for Research and Engineering

APPENDIX H. BIBLIOGRAPHY

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