Army Science Board
Fiscal Year 2017 Study

Multi-Domain Battle

Final Report
January 2018

Department of the Army
Office of the Deputy Under Secretary of the Army
Washington, DC 20310-0103

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DEPARTMENT OF THE ARMY
ARMY SCIENCE BOARD
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ARLINGTON, VA 22202

January 22, 2018

DUSA-ASB

MEMORANDUM FOR SECRETARY OF THE ARMY

SUBJECT: Final Report of the Army Science Board, "Multi-Domain Battle"

1. I'm pleased to forward the final report of the Army Science Board (ASB) study titled "Multi-Domain Battle." The purpose of the study was to assess how expanding and rebalancing focus on AirLand Battle to fight more effectively in all domains of warfare could enhance the Army's outcomes. The scope of the study included emerging operational environments or "battlefields," such as the electromagnetic spectrum, and cognitive elements in the human dimension.

2. For this effort, the ASB brought subject matter experts in Physics, Math, Electrical Engineering, Mechanical Engineering, Aerospace Engineering, Materials Science, Operations Analysis/Research, Nuclear Engineering, Public Administration and a variety of military operations and technologies, as well as former Army and Sister Service leaders. During its seven months together, the study team conducted over thirty visits and interviews among Army and DoD agencies, Federally Funded Research and Development Centers, Academe, and commercial industry.

3. From their work, the study team made several findings around the pace of disruptive, technological advances, methods for fully integrating MDB, key enabling technologies (cyber, autonomy, AI), and the need for increased speed from data collection to weapons employment. Based on these findings, the study team recommended the Army work within the Joint community to design a DoD-wide organizational construct for MDB, with deliberate plans for MDB modeling, exercise and experimentation. For the Army specifically, the study team recommended it develop a system-of-systems architecture to support integration across all domains. The team also advocated for the development of MUM-T capabilities, a multi-domain cyber/EW strategy, and alternative acquisition models to accelerate these efforts. The findings and recommendations were adopted by unanimous vote of the ASB on July 20, 2017.

4. I hereby endorse the findings and recommendations in this report.

Leonard W. Braverman
Chairman

TABLE OF CONTENTS

APPENDICIES

LIST OF FIGURES

EXECUTIVE SUMMARY

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.[1]

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.[2] 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.

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

[2] 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

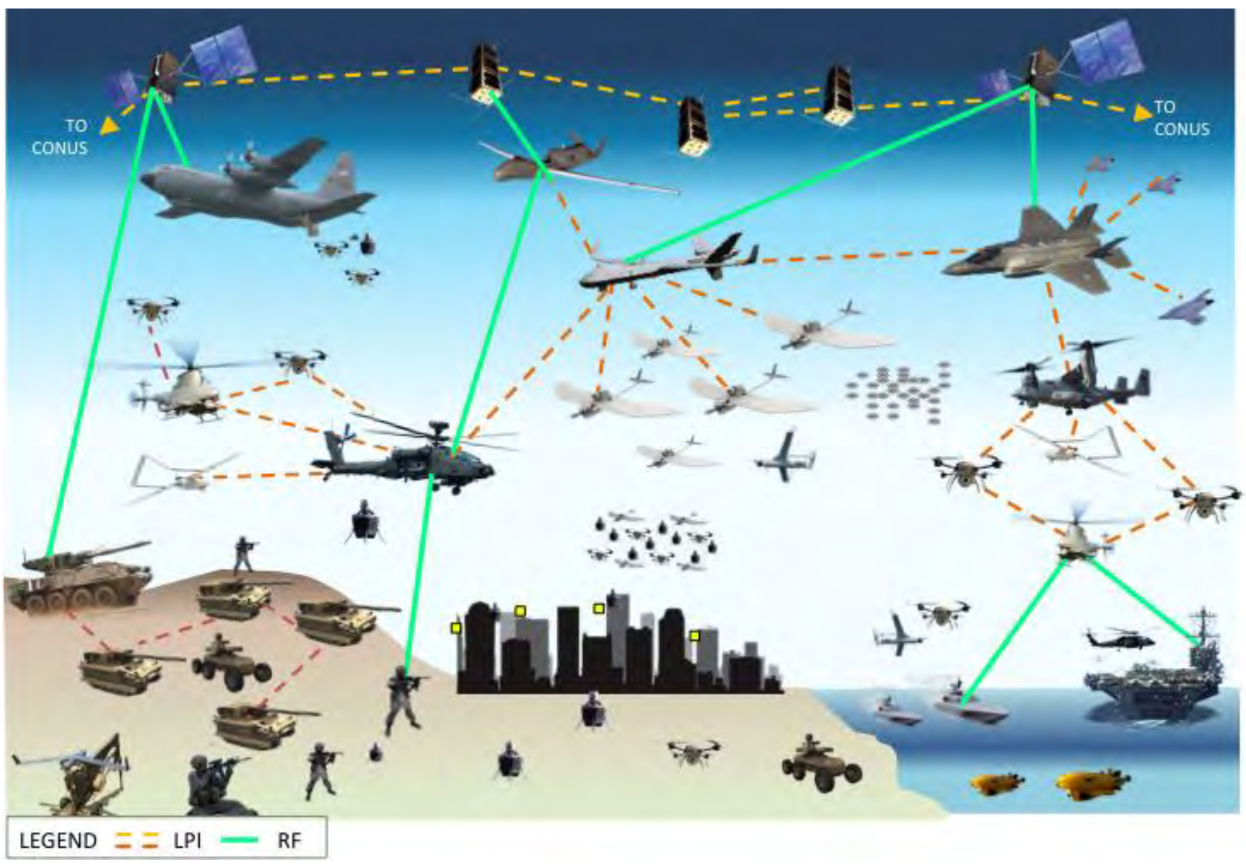

Figure E.1 Massively Distributed "Bots"

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

1. INTRODUCTION

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 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 MDB concept, the global operational environment, and technical concepts that could enable MDB. A comprehensive briefing describing the study in detail was completed and adopted by a unanimous vote of ASB members in July 2017.

1.1 TERMS OF REFERENCE

The Terms of Reference (TOR)[3] for the study state:

> 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 TOR specified nine tasks for the study team:[4]

a. What is different about the MDB concept? Why do we need a MDB concept?

b. What is the current baseline regarding MDB concept development within the Army and JIM?

[3] The TOR is reprinted at Appendix A
[4] See Appendix D for a precise mapping of these questions to the body of the report and summary of the study team’s responses to these questions.

c. What are the hurdles and impediments to effectively implementing MDB within the Army and across the JIM force?

d. What are the future opportunities presented by MDB?

e. How might MDB change the way the JIM force operates?

f. What are the potentially new roles, responsibilities, and relationships for the Land Component when executing MDB in an A2/AD environment?

g. What new learning demands emerge from the MDB concept? What kind of experimentation would be required to support these learning demands?

h. With regards to this experimentation, how could the Army rapidly transition the lessons learned in terms of new tactics, techniques, and procedures (TTP) and emerging technologies into approved concepts and rapidly fielded capabilities?

i. What emerging/cost-imposing technologies or novel mix of existing Army/JIM capabilities could significantly improve the Army's ability to shoot, move, communicate, and protect itself during ground combat operations in an A2/AD environment?

1.2 STUDY TEAM AND VISITS

The study team selected to address these tasks included ASB members with significant technical expertise and experience in a wide range of disciplines (see Appendix B):

- Armor/Anti-armor
- C4ISR
- Directed energy systems
- Electromagnetics
- Energy technology
- Aerospace Technology
- Integrated air defense
- Intelligence
- Missile defense
- Robotics
- Turbulence & Stochastic Systems
- Signal processing
- AI
- Surveillance systems
- Weapons systems
- Operations Analysis
- Systems Engineering
- Chemical Engineering
- Electrical Engineering
- Mechanical Engineering
- Nuclear Engineering
- Materials Science
- Physics

In addition, team members had significant operational experience covering all five domains, with retired flag officers (one Navy and one Air Force), a retired Army Colonel and a retired Army Lieutenant Colonel.

To obtain the information required to address the TOR tasks, members of the study team made over 30 visits to organizations involved in the development of the MDB concept, including:

Army

- U.S. Army Training and Doctrine Command (TRADOC), GEN Perkins
- U.S. Army Pacific (USARPAC,) GEN Brown
- U.S. Army Combined Arms Center (CAC), LTG Lundy
- U.S. Army Europe (USAREUR), LTG Hodges
- Army G-3/5/7, MG Hix
- Army Capabilities Integration Center (ARCIC), MG Dyess
- Maneuver Center of Excellence (MCOE), MG Wesley
- Cyber Center of Excellence (CCOE), MG Morrison
- Mission Command Center of Excellence (MCCOE)
- TRADOC Analysis Center (TRAC)
- TRADOC G-2 Intelligence Support Activity (TRISA)
- Center for Army Analysis (CAA)
- Army War College (AWC)
- Program Executive Office for Simulation, Training, and Instrumentation (PEO-STRI)
- National Cyber Range
- Communications-Electronics Research, Development and Engineering Center (CERDEC)

Other Services/ Joint/DoD

- Navy Joint Concept for Access and Maneuver in the Global Commons (JAM-GC)
- U.S. Marine Corps – Marine Corps Combat Development Command (MCCDC)
- U.S. Air Force - Headquarters, Director of Operations
- U.S. Air Force – PACAF Air and Space Operations Center
- Strategic Command (STRATCOM)
- Office of the Undersecretary of Defense (OUSD) Policy
- Defense Advanced Research Projects Agency (DARPA,) Dr. Walker & PMs

Other

- Institute for Defense Analyses (IDA)
- RAND
- National Defense University (NDU), Hammes
- Lexington Institute, Goure
- New America, Singer
- Industry

Lines of inquiry were established for each of the visitations (see Appendix C) to optimize data gathering.

1.3 BACKGROUND/OVERVIEW

Over the past 20 plus years, potential near-peer adversaries have extended the U.S. military's AirLand Battle integrated strategy to additional domains by investing in significantly advanced capabilities that are equal or superior to those of the U.S. As a result, it's no longer clear that the U.S. would achieve a desirable outcome in a conventional conflict (i.e., with acceptable conditional losses). What is clear is that the U.S. has a diminished ability to deter unwelcome adventures by its adversaries.

For the U.S. to regain its overmatch capabilities, it has to re-look at how it funds and implements its national security options to create a multi-domain strategy with each domain capability equal to or superior to our adversaries at the time and place necessary to achieve desired outcomes. The goal is to overwhelm the enemy and divert it from its preferred, advantageous course of action.

> 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.[5]

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.

Specifically, MDB transforms the usual kill chain of Find-Fix-Track-Target-Engage-Assess into a kill matrix across the five domains (Fig. 1.0). In the usual kill chain, all steps are in the same domain and may even be on the same platform. In a 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).

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

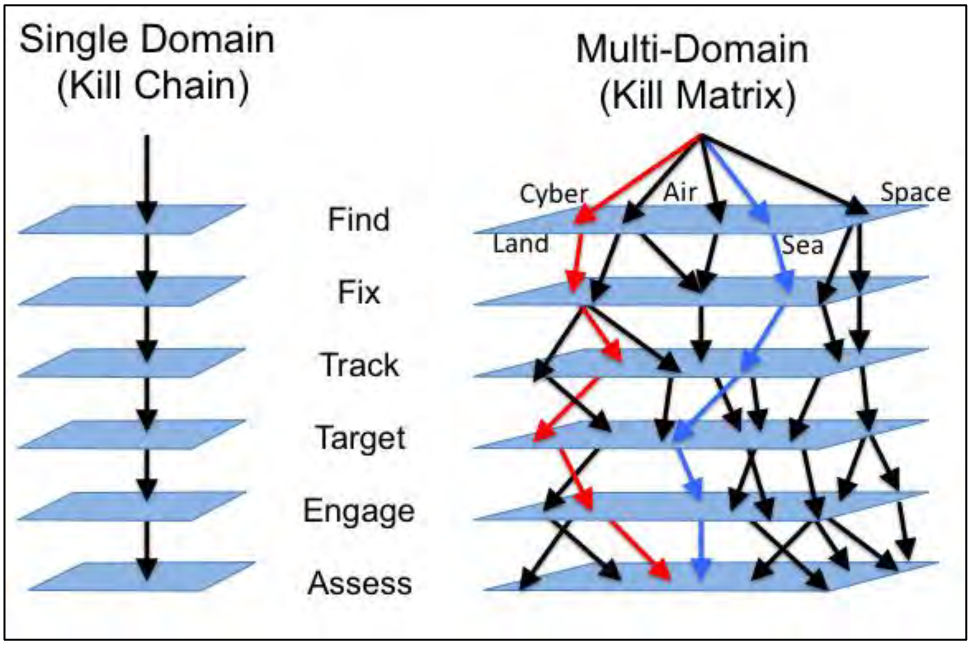

Figure 1.0 Increasing Operational Options

The study 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

The integration of capabilities and options across warfighting functions in the Army, other U.S. military Services, other organizations, and nations is key to optimizing MDB. Realistic experimentation, including operating in degraded environments, is also key to developing MDB. Lastly, greater speed in all aspects of the process is required.

1.4 WHAT IS MDB?

During its data gathering, the study team found there was no overarching understanding of what was meant by multi-domain. The situation was analogous to the fable of four blind men describing an elephant where one feels the tail, another a leg, another an ear, and the last the trunk. All gave accurate descriptions of the portion of the elephant they touched, but none provided an accurate description of the elephant.

To foster a common conception of MDB, the study team adopted an analogy to football, in large part because both the sport and military operations require strategies that provide multiple options, based upon what happens after contact with an adversary.

In football, imagine the domains are Ground, Air, Cyberspace (local ISR, communication, and jamming) and “Space” (overhead ISR). Historically, the offensive team in football used the ground to move the ball forward. The ground domain provided six options: the quarterback could run the ball forward or left or right laterally himself, trying to outflank the defense, or hand the ball off to another player to be run forward or left or right laterally.

Woody Hayes (Ohio State) was a Master of the ground domain, best known for his strategy to gain “3 yards and a cloud of dust” on every play. This was effective but took considerable time to move downfield, making it ineffective if a team was trying to come from behind in the score. When the rules changed to allow a quarterback to pass, it opened up the ground game, allowing the offensive team to score more quickly by exploiting the pass/air domain.

The use of the air domain provided multiple new options for the quarterback to throw the ball to a receiver downfield or behind him to someone who could run or make another pass. The pass greatly complicated things for the defense, and more than doubled the number of possible plays the offense could execute.

When there was no threat from the pass, the defense could jam the line of scrimmage and stop the run. Being forced to defend against the pass spread the defense and enabled the run (and vice versa). The defensive team now had a major dilemma since it had to contain the ground options in addition to the air options using the same number of people. It had to move fast to defeat the air option, but a significant number of the players had to remain heavy and strong enough to counter the ground option. This fractionated the defense into specialized sub-units that had to be prepared for multiple offensive options.

In the huddle, the quarterback would decide which of the options to use based upon previous plays and real-time inputs from his teammates. The offensive team would line up and the quarterback, using his eyes (local ISR) to see how the defense lined up, could “call an audible” (communications) to change the option to be used.

In recent years, the “space” (overhead ISR) domain began to be used in addition to local ISR, in that the coaches had people in or near the press boxes to get a synoptic, overhead view of both team formations that they could then wirelessly communicate to the players and coaches on the ground. The quarterback could then audible a change if necessary based on his local ISR and the instructions passed through a receiver in his helmet. If the offensive team was the visiting team, home team fans could counter the use of “space” by making noise and ”jamming” (cyberspace domain) the quarterback’s communications.

The team on defense uses the same domains (ground, cyberspace, etc.) to detect which option the offense is going to use and to deploy accordingly. However, the offense’s ability to make last-minute adjustments using local ISR and communications forced the defense to be uniformly good no matter what option the offense finally used. In other words, the team had to be trained and equipped to use whatever option presented as the best at the time. That’s the essence of MDB, because having multiple domains is necessary but not sufficient. MDB requires a fully integrated team capable of executing all options.

The football analogy translates to a synchronized military force exercising a full range of options in multiple domains as provided by the Services. The value of MDB won’t materialize if Service capabilities are siloed and linked through interoperability at the end of systems development rather than integrated from the beginning. In other words, full value will materialize if and only if the Services integrate their procurement of capability and train together to act as one. If the U.S. hasn’t adopted MDB and is forced to face an adversary with fully integrated forces, the outcome will be a high scoring game on the wrong side.

This isn’t a new concept and was promoted over 10 years ago by ADM Giambastiani who was then Supreme Allied Commander, Transformation, and commander of U.S. Joint Forces Command. In a speech entitled “Born Joint,” he said:

> “Jointness" is a term that is still not well understood—not only within the military but also within industry and by the public. And here I mean the BIG "J" in joint, which refers to a seamless integration of joint forces, interagencies and multinational/coalition partners.[6]

A recent article by the CG TRADOC confirms the need for integration, and the study team concurs that integration is key to leveraging advancing technology:

> Integrating space and cyberspace domains and the electromagnetic spectrum for how Army units and joint forces will fight is something the Department of Defense is just now beginning to understand. Multi-domain battle reintroduces the idea that converged cross-domain capabilities across DOTMLPF are an absolute prerequisite for success; this is how the concept frames integration. Finally, because of the role of new technology, from AI to robotics, multi-domain battle accounts for how the character of warfare on the future battlefield will be different.[7]

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[6] Edmund P. Giambastiani, *Born Joint*, speech given at AFCEA West, 5 Feb 2004, http://www.doncio.navy.mil/chips/ArticleDetails.aspx?ID=3317

[7] David G. Perkins. *Multi-Domain Battle – Driving Change to Win in the Future.* Military Review, July-August 2017.http://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/July-August-2017/Perkins-Multi-Domain-Battle/

2. MDB CONCEPT DEVELOPMENT

2.1 EVOLUTION FROM AIRLAND BATTLE

During the 2017 budget process, Deputy Secretary of Defense Robert Work challenged senior Army leaders to develop a concept for the future operational environment, similar to the way the AirLand Battle concept addressed the Cold War during the 1980s.[8] Though much of the previous strategy remained valid, new adversary threats called for a fundamental reevaluation of the Army's operational concept, because U.S. military ground forces couldn't rely on the kind of domain superiority that characterized the Coalition effort during Operation DESERT SHIELD/DESERT STORM.

General David Perkins, Commander of TRADOC, wrote that MDB was new but not unprecedented. He stressed that MDB proposed new combinations of capabilities and approaches while still building on the tradition of combined arms.[9] The study team concurs, for example, DESERT STORM built on AirLand Battle (two domains) and relied on space-based GPS systems for navigation in the hostile desert environment. Space-based sensors also provided remote sensing, weather, and communications. MDB is based on the idea that integrated Joint/multinational capabilities can be extended into and across all domains.

The developing MDB concept builds upon older operational concepts and ideas such as AirLand Battle 2000,[10] the Joint Operational Access Concept (JOAC),[11] and the Joint Concept for Integrated Campaigning (JCIC),[12] but it also introduces new ideas and unique interpretations. Whereas past concepts have called for "rolling back" an A2/AD network "so we can get the rest of the joint force in,"[13] MDB seeks to push ahead through weak points in the A2/AD zone — exploiting every avenue in the air, on the sea, on the land, and in cyberspace.

Because of his belief that the developing concept should be reviewed and critiqued across professional military communities, General Perkins officially debuted MDB as a developing TRADOC concept with the Marine Corps Combat Development Command. In early 2017, Army Chief of Staff General Mark Milley and Marine Commandant General Robert Neller jumpstarted

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[8] Sydney J. Freedberg Jr., *"DepSecDef Work Offers Dough For Army Multi-Domain Battle,"* Breaking Defense, October 4, 2016, http://breakingdefense.com/2016/10/depsecdef-work-offers-dough-for-army-multi-domain-battle/.

[9] David G. Perkins, *"Multi-Domain Battle: Joint Combined Arms Concept for the 21st Century,"* Association of the United States Army, November 14, 2016, https://www.ausa.org/articles/multi-domain-battle-joint-combined-arms-concept-21st-century.

[10] Headquarters U.S. Army Training and Doctrine Command, *AirLand Battle 2000,* 10 August 1982, DTIC a127471. http://www.dtic.mil/dtic/tr/fulltext/u2/a127471.pdf

[11] Joint Staff, *Joint Operational Access Concept (JOAC), Version 1.0,* 17 Jan 2012, https://www.defense.gov/Portals/1/Documents/pubs/JOAC_Jan%202012_Signed.pdf

[12] Joint Staff, Joint Concept for Integrated Campaigning, version 0.7, 13 April 2017, http://www.arcic.army.mil/App_Documents/SLTF/Joint_Concept_for_Integrated_Campaigning_Current.pdf

[13] op cit Freedberg.

formal work on the MDB concept[14] by approving it as a white paper for wide distribution and consideration. This signaled multi-service commitment to concept development and pursuit of multi-service DOTMLPF solutions.

MDB is an evolving concept within the U.S. Army and Marine Corps doctrine development communities (Fig. 2.0). It's not yet doctrine, as Army and Marine Corps senior leaders still have to officially approve the "1.0" concept. Once the concept is approved, work can begin on a detailed Multi-Service Concept. Informed by experiment, modeling, and exercises, an approved concept can provide the foundation for development of doctrine. Once doctrine is approved, training can begin, followed by operations, etc.

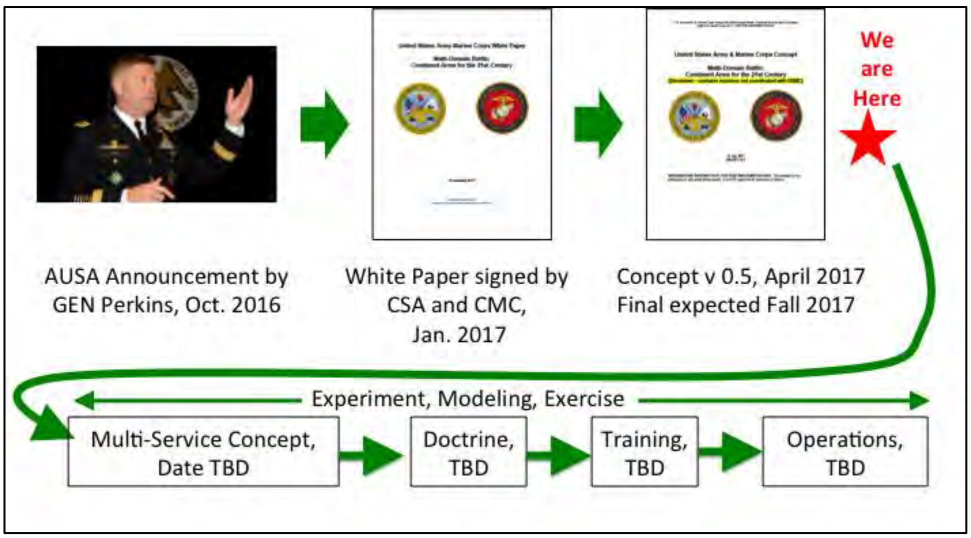

Figure 2.0 MDB Process from Concept to Operations

2.2 ARMY/USMC PROGRESS

In August 2017, the U.S. Army and Marine Corps released MDB concept draft version 0.7,[15] but as of this writing, the document remains "pre-decisional" and "not for distribution." Concurrently, General Brown and General Perkins described their views of MDB[16] as having the following characteristics:

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[14] Sean Kimmons, "Army, Marine Leaders Bring Multi-Domain Concept Closer To Reality," United States Army, January 27, 2017, https://www.army.mil/article/181271/army_marine_leaders_bring_multi_domain_concept_closer_to_reality.

[15] U.S. Army and U.S. Marine Corps, "*United States Army and Marine Corps Concept – Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040, Draft v0.70*," Director, Army Capabilities Integration Center and Deputy Commandant for Combat Development and Integration/Commanding General Marine Corps Combat Development Command, August 11, 2017. PRE-DECISIONAL,

[16] Brown, Robert B. and Perkins, David G., *Multi-Domain Battle: Tonight, Tomorrow, and Future Fight,* War on The Rocks, 18 August 2017. https://warontherocks.com/2017/08/multi-domain-battle-tonight-tomorrow-and-the-future-fight/

- Integration into joint and multinational forces is a prerequisite for victory.
- Battlefields are growing more complicated.
- Experimentation and adaptation are required to define the role of the multi-domain task force

Today the Army is an "integral and interdependent member of the joint force."[17] Systems and capabilities have been developed as interdependent programs of record managed by separate warfighting functions. To respond to emerging challenges, the Army, together with joint and multinational partners, must work toward converged and integrated solutions to achieve cross-domain effects, fires, and maneuver. DoD must evolve from a system defined by stovepipes and parochialism to an integrated force.

From pervasive information warfare in social media, to applying multi-functional and multi-domain military capabilities below the threshold of armed conflict, or the coupling of economic power with militia and irregular forces, warfare has become more complex. The U.S. Army Pacific is leading efforts to address these complexities by refining the ideas of MDB through experimentation and testing. The command has identified three near-term challenges: mindset, joint integration, and technology. To address these challenges, it's important to build partnerships with others around integrated systems, flexible C2, tailorable and scalable units, and flexible policy. The goal is technology that allows joint forces to be sensor and platform agnostic.

The resulting multi-domain task force will leverage capabilities including, but not limited to, long range fires, air and missile defense, EW, force protection, and sustainment to meet A2/AD challenges. The task force will balance offense (lethal and non-lethal) and defense. In addition, with the goal of more fully integrated comprehensive capabilities, the task force should integrate with organic, joint, interorganizational and multinational partners.

[17] Ibid

3. GLOBAL OPERATIONAL ENVIRONMENT

General David G. Perkins, CG TRADOC, provided a description of the current operational environment in March 2017:

- Adversaries, including super empowered individuals with access to weapons of mass effect (WME), cyber, space and nuclear/biological/chemical (NBC)
- Operations among populations in complex terrain including dense urban areas
- Contested in all domains, increased lethality, enabled by autonomy, robotics and AI, with the potential for overmatch
- Increased speed of human interaction, events and action, rapid proliferation of capabilities, constantly co-evolving
- Trans regional, hybrid strategies, regular, irregular, criminal, terrorists attacking our weakness, mitigating our advantage; Systems Warfare, Preclusion, Sanctuary, Isolation and Reflexive Control

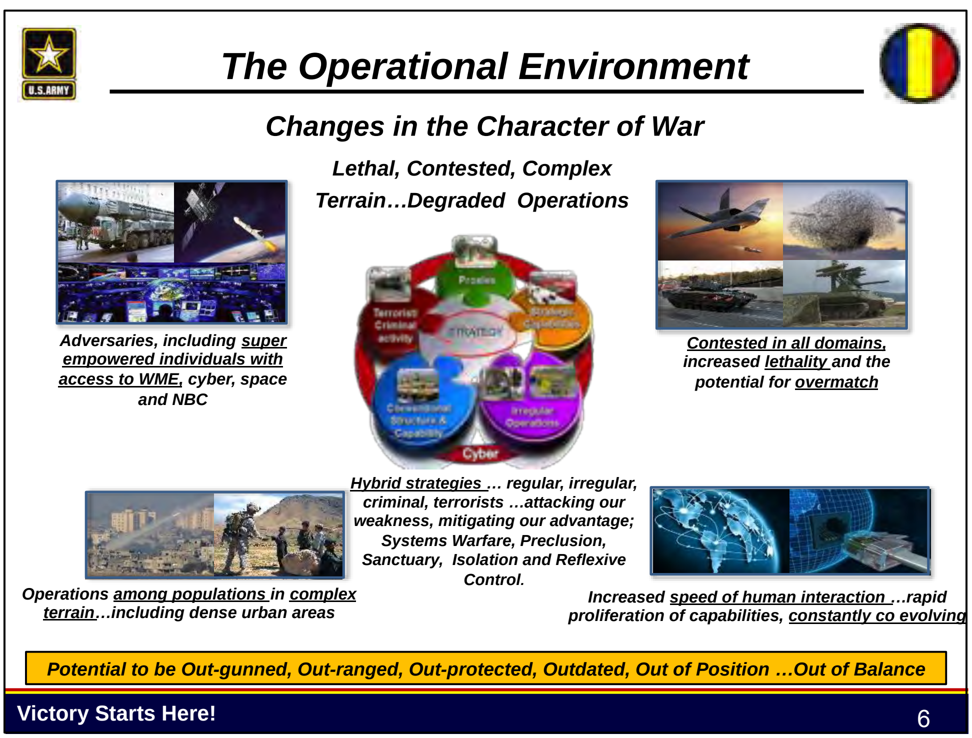

Figure 3.0 The Operational Environment as Described by GEN Perkins

3.1 THREATS

In a written statement to the House Armed Services Committee, Secretary of Defense Mattis[18] further defined the operational environment by identifying emerging threats in all domains:

- Space: persistent kinetic and non-kinetic attack against our satellites
- Air: proliferation of advanced integrated air defense networks and 5th-generation aircraft
- Maritime: long-range, land-based guided munitions battle networks are designed to attack our ships at increasingly longer ranges, and undersea assets are challenged by both Russia and China
- Land: long-range air-to-surface and surface-to-surface guided weapons, advanced armored vehicles and anti-tank weapons, and tactical EW systems
- Cyberspace: contested at the strategic, operational, and tactical levels of war.

The PACOM AOR, covers 36 countries in 16 time zones, contains over half the world's population—including 24 of the world's 36 megacities—and encompasses more than half the world's surface. The global economy relies on unimpeded access to sea-lanes in the area. The Indo-Asian-Pacific region includes some of the world's most intractable security challenges: an increasingly belligerent North Korea sharing its missile technology with Iran; China challenging international rules and norms; revanchist Russia active in the Pacific with a provocative military posture; a continuing nuclear-backed friction between India and Pakistan; growing activities by violent extremist networks in partner and ally nations; and political and diplomatic instability from changes in executive leadership of key regional allies and partners.[19]

To address these threats, PACOM and its Pacific partners are incorporating MDB concepts into regional exercises. At the AUSA Land Forces in the Pacific (LANPAC) conference held May 2017, the leadership of the Army, Navy, and Air Force component commands and the CG of the special operations forces in the Pacific, joined the Chief of Ground Staff, Japan and CG TRADOC on a panel to discuss MDB (Fig. 3.1). The panel discussed the challenges of MDB, including the capability to link targeting to fires across Services and within Services. They also identified the need to be able to train as if cyber authorities have been granted so that commanders are familiar with the capabilities available. In turn, the panel was encouraged by the level of experimentation with MDB concepts that's planned in PACOM.

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[18] James N. Mattis, *Written Statement for the Record to House Armed Services Committee*. 12 June 2017. http://docs.house.gov/meetings/AS/AS00/20170612/106090/HHRG-115-AS00-Bio-MattisJ-20170612.pdf

[19] Robert B. Brown. *At a Pacific Crossroads: U.S. Must Prepare for Present, Future Threats in Dynamic Region*. ARMY Magazine, 17 April 2017. https://www.ausa.org/articles/pacific-crossroads-us-must-prepare-present-future-threats-dynamic-region

Left to right: Maj. Gen. Yoo, CG SOCPAC; GEN O’Shaugnessy, CMDR PACAF; ADM Swift, CDR USPACFLT; GEN Brown, CG USARPAC; GEN Okabe, Chief Ground Staff Japan SDF; GEN Perkins, CG TRADOC

Figure 3.1 MDB Panel at LANPAC

In the EUCOM AOR, Russian aggression against Ukraine and its threat to the three Baltic republics of Estonia, Latvia, and Lithuania pose the greatest concern. Russian air defense capabilities pose a key challenge to U.S. and NATO forces. These capabilities fracture the paradigms of AirLand Battle and necessitate a new concept. In addition, Russian EW systems degrade communications and disrupt command and control. Cyber-attacks and the use of unmanned aerial systems for target acquisition further complicate operations. Additional details are provided in a classified annex to this report.

3.2 MDB RESPONSE TO THREAT

The MDB Operational View in Figure 3.2 illustrates and incorporates all five domains: land; air; maritime; space and cyberspace. It shows interactions between U.S. units (blue), Allies (green), and threat (red). Starting at the top: a U.S. satellite (space domain) images an adversary unit; the satellite communicates with a naval vessel (maritime domain) that delivers fire on the unit. The satellite is also in communication with an Army air mobile unit and Air Force strike aircraft. The Army air mobile unit and Marine Corps unit (land domain) are inserted behind threat elements. The Air Force aircraft (air domain) performs CAS missions in support of the land domain elements and air interdiction in the threat rear area. SOF elements have infiltrated into the rear area to acquire targets. A UAS on an ISR mission has located another adversary unit. An Army cavalry unit conducts EMS Recon (cyberspace domain) of the adversary’s frontal elements. Similarly, an Army air defense unit conducts offensive EW (e.g., jamming) against a threat unit (cyberspace domain). An Allied artillery unit is shown firing on a threat unit located by EMS Recon (land domain). One of the air defense units (land domain) engages a fixed wing aircraft and another one engages a threat ship. Armored elements act on intelligence assets and advance to attack threat ground units.

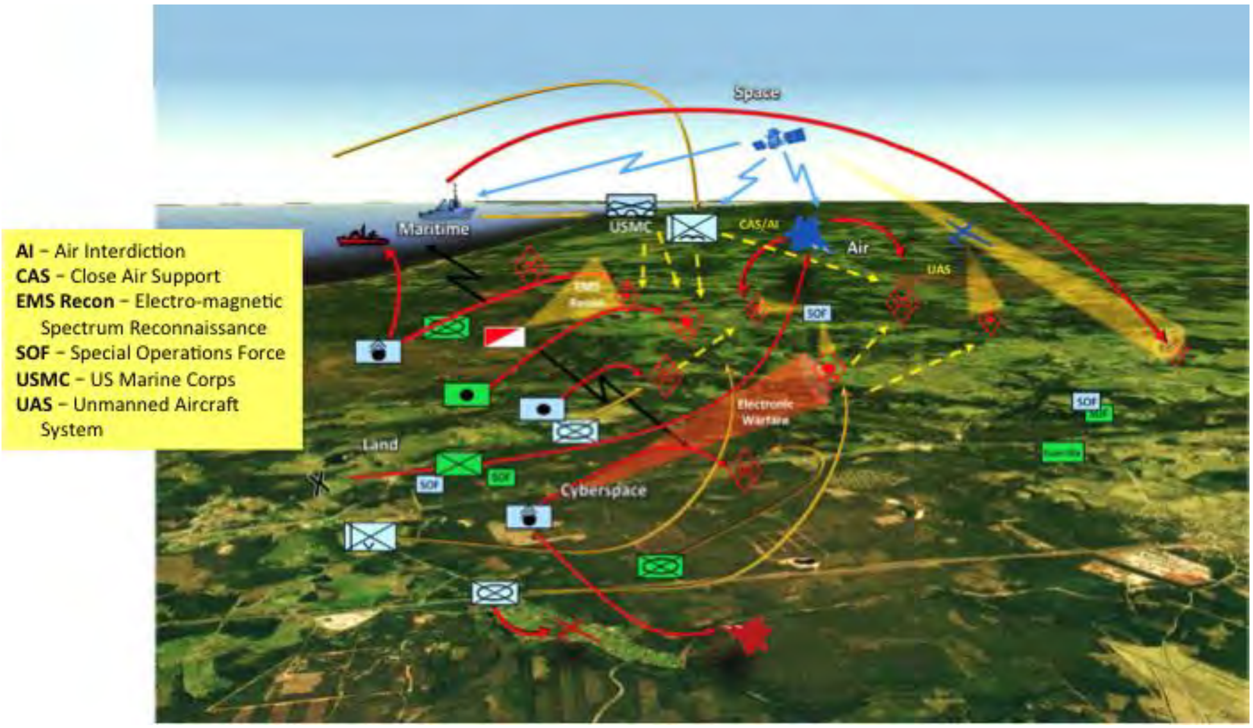

Figure 3.2 TRADOC MDB Concept: "Achieving Cross-Domain Synergy"[20]

GEN Perkins added the following on this operational view:

> This graphical representation is one of the first to depict the inherent integration and convergence of the future multi-domain battlefield. The scenario here shows joint forces achieving cross-domain synergy by applying the multi-domain battle concept.[21]

According to BG Huba Wass de Czege (USA Ret.), a principal designer of AirLand Battle:

> Today, the problem smart people in all of America's Armed Services are trying to solve is a newly evolved technical one, the threat to "freedom of maneuver" due to the broad

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[20]David G. Perkins, David G.. *Multi-Domain Battle – Driving Change to Win in the Future.* Military Review, July-August 2017.http://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/July-August-2017/Perkins-Multi-Domain-Battle/

[21]Ibid.

proliferation of Anti-Access and Area Denial (A2/AD) systems to potential adversaries--especially Russia, China, Iran, and North Korea.[22]

The study team found it useful to review recent studies on Russian advances in A2/AD systems to gain an understanding of the operational problems posed in EUCOM. Two classified studies were examined in detail and are discussed in the classified annex. RAND carried out an unclassified study in 2016[23, 24] that dealt with a range of Russian objectives, including to “regain its former security zone and inflict a strategic defeat on NATO.” The course of action Russia selected was a conventional, short warning attack by “peacekeepers” to seize the Baltic states. A key focus of this study was on Russian A2/AD and its role in accomplishing their strategic goals (Fig. 3.3).

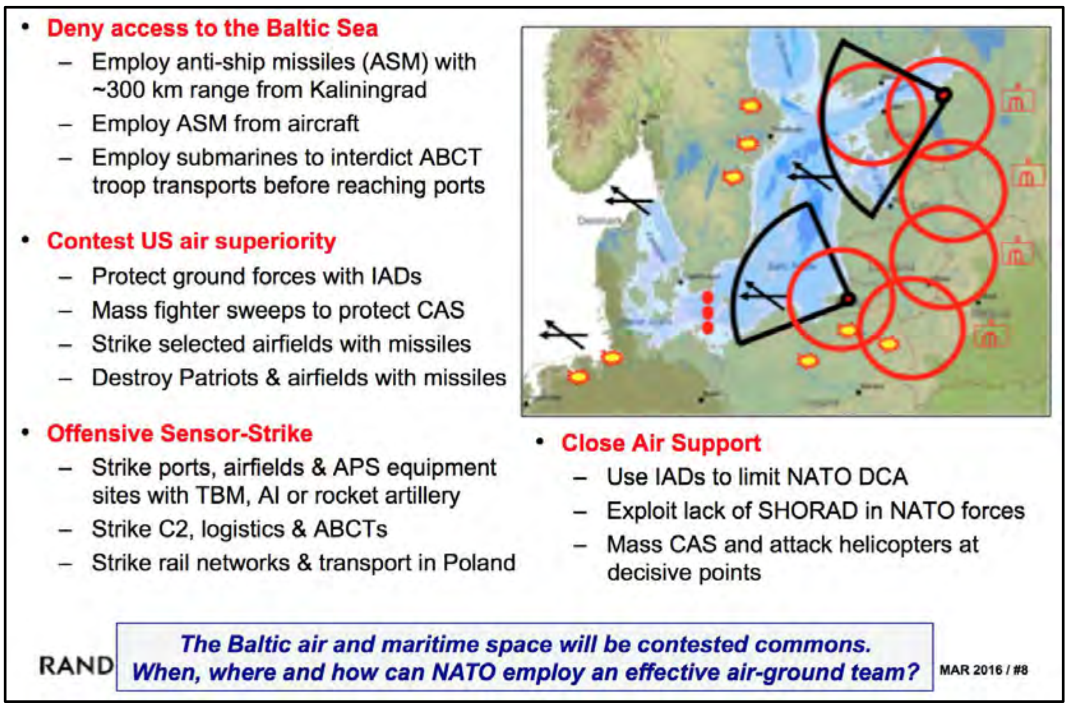

Figure 3.3 Russian A2/AD and Precision-Strike Capabilities[25]

To illustrate the relative capabilities of the various surface-to-surface missiles, air defenses, and artillery systems, RAND chose to compare key Russian systems with comparable U.S. systems. From the surface-to-surface missile perspective, the SS-26 Iskander missile with a range of 500 km outranges ATACMS 300 km capability. This range difference enables offensive strike against airfields, ports, and rail networks. The SA-21 (S-400) air defense system operational range of

[22] BG (Ret) Huba Wass de Czege, *AirLand Battle 2.0: Multidimensional Military Operations Beyond 20XX,* unpublished paper, Microsoft Word document, March 2017.
[23] David Shlapak and Michael Johnson, *Strengthening Deterrence in Europe*, Briefing, RAND Arroyo Center, March 2016, FOUO.
[24] David Shlapak and Michael Johnson, *Reinforcing Deterrence on NATO’s Eastern Flank.* RAND Research Report 1253, 2016. https://www.rand.org/pubs/research_reports/RR1253.html
[25] David Shlapak & Michael Johnson, *Strengthening Deterrence in Europe*, RAND Arroyo Center, March 2016

400 km outranges the Air Force HARM missile. This holds traditional close air support missions at risk. Russian rocket artillery offers tactical flexibility with the BM-30 Smerch range of 20–70 km and a variety of anti-tank munitions, plus the high firepower BM-21 Grad with 40 launch tubes for 122 mm rockets. Multiple launch rocket systems offers a variety of rocket types but counter battery targeting is problematic given range limitations of the Firefinder radar and the survivability of UAS. The effectiveness of U.S. cannon artillery has been degraded by the lack of a treaty compliant replacement for the DPICM munition, whereas Russia ignores treaty limitations (Fig. 3.4).

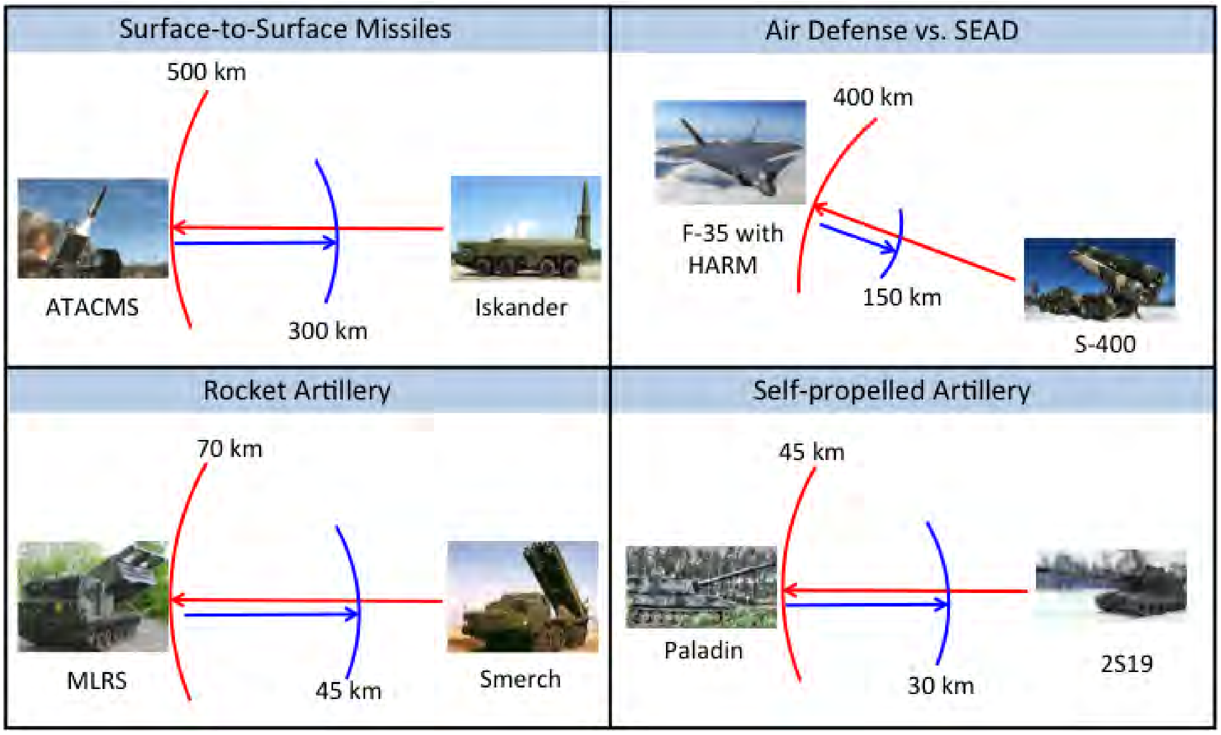

Figure 3.4 Relative Capabilities of Comparable Systems

RAND performed a qualitative assessment of the how these capabilities have evolved from Desert Storm to now (Fig. 3.5). To see how these changes played out, RAND also conducted a series of wargames to gauge the effect of Russian capabilities. In the first series, the Russians used 22–27 Brigade Tactical Groups (BTGs) with missions to seize the capitals of Latvia, Lithuania, and Estonia. The U.S. had deployed an Infantry Brigade Combat Team (IBCT) and NATO brigade to Latvia; an IBCT and Marine Expeditionary Unit (MEU) to Estonia; and a Stryker Brigade Combat Team (SBCT) to Lithuania. Additionally, an Armored Brigade Combat Team (ABCT) was deployed to Poland. In the second set of wargames, 3 additional ABCTs and 3 Field Artillery (FA) brigades were deployed to the Baltics. The Russian force was increased to 45 BTGs for this second wargame series.

Criteria	"ALB 1.5" (1991) Desert Storm	"ALB 2.0" (2016) Red Storm Rising
Vertical Escalation	None	Significant
Time Pressure	Low – attack at will	High – immediate defense
Air Domain	U.S. dominance	Overall Parity
Air Campaign	38 days before attack	Simultaneous defense
Maritime Domain	U.S. dominance	Deny U.S. access
Cyber Domain	U.S. dominance	Parity
C4ISR Systems	U.S. dominance	Parity
Artillery Counter-Fire	U.S. dominance	Russian dominance
Blue SEAD vs. Red ADA	U.S. dominance	Russian dominance
Red CAS vs. SHORAD	U.S. dominance	Russian dominance
Maneuver Systems	U.S. dominance	Parity - U.S. advantage
Casualties	Historic Lows	Bloody

RAND *How can the Joint force fight and win in this new environment?* AR 2016 / #30

Figure 3.5 Need for a New Concept and Capabilities[26]

The first series of wargames resulted in Russian forces, moving at approximately 5 mph, isolating Riga, Latvia and Tallinn, Estonia within 36-60 hours. Importantly, none of the Blue Teams participating in the wargame were able to prevent a Russian win. The overall assessment was that Russia has time to seize the Baltic States and establish a defense in depth. In the second set of wargames, with the additional U.S. ABCTs, Russia was still able to isolate Riga and Tallinn, but lacked the combat power for a quick assault. Both Russian and U.S. ground force losses where high, on the order of 33% for each side. The wargames indicated that shifting the U.S./NATO force posture in Europe was necessary but not sufficient. The U.S. and NATO needed a new operational concept and capabilities to counter Russian A2/AD.

There's a need for a new operational concept and capabilities to counter Russian A2/AD.

The study team examined how the MDB operational concept, coupled with advanced capabilities, could counter Russian A2/AD. It assessed two of the most potent Russian weapons systems in their A2/AD operations, the SS-26 and SA-400. The SS-26 Mach 6.2 missile has an operational range of 400-500 km with terminal precision of 5-7 meters. Warhead types include high explosive (HE) submunitions and a non-nuclear electro-magnetic pulse (EMP). When deployed to Kaliningrad, the SS-26 can hold airfields as far away as Berlin at risk. The S-400 air defense system has a range of 400 km and the missile has a velocity of Mach 5.9. When deployed to Kaliningrad, it can engage aircraft over a large portion of the Baltic Sea, as well as airfields around Warsaw, Poland.

[26] Ibid.

To counter these threats, the study team focused on how to destroy an SS-26 battalion, which was protected from U.S. air and missile assets by S-400 air defense systems (Fig. 3.6). The first task was to characterize and locate A2/AD assets using an electro-magnetic surveillance (EMS) reconnaissance team (cyberspace domain) that would be clandestinely inserted behind Russian lines. An air asset (e.g., UAS) (air domain) would be used to penetrate the initial layers of the Russian controlled airspace, stimulating Russian air defense surveillance and fire control radars and causing them to emit. This stimulation event would be timed with the passing of an electronic intelligence (ELINT) satellite (space domain) which would provide an approximate geo-location of the radar systems as well as communications links between systems. The locations would then be used to task an imaging intelligence (IMINT) satellite to image the region and locate the SS-26 and S-400 launchers.

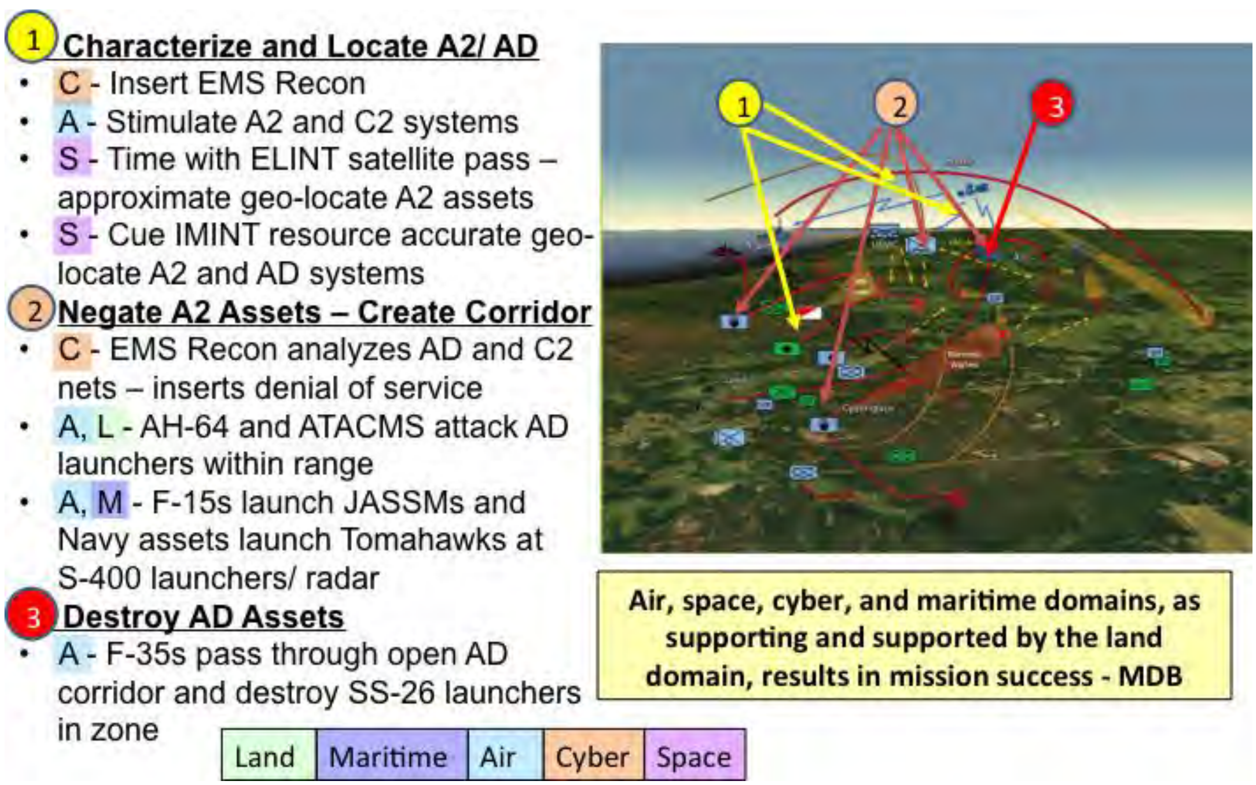

Figure 3.6 Elimination of Key A2/AD Assets through Application of MDB Operational Concept and New Capabilities

The next task would be to create a corridor back to the high value targets (HVTs)–the SS-26 and S-400. The EMS recon team would characterize the AD and C2 networks and insert denial of service software into these network computers causing them to shut down. During that period, the Army AH-64 (air domain) and ATACMS (land domain) would attack air defense launchers within their operational range along a specified corridor. Once the corridor was open, Air Force JASSMs and Navy Tomahawks would attack the S-400 launchers and associated command posts which are beyond the range of Army systems. With the critical air defense systems destroyed, the third task would be employment of the F-35s to pass through the open corridor and attack the SS-26s and other deep HVTs.

Mission success achieved through the MDB operational concept of employing air, space, cyberspace, and maritime domains—supporting and supported by the land domain.

It's important to recognize that the scenario represents one possible approach following the MDB operational concept. In this case, space assets were used proactively (space ELINT collection and subsequent cueing of space IMINT collection) in coordination with the stimulation of Russian air defense systems. The geolocation of A2/AD systems enabled subsequent targeting. Cyber was used to characterize key networks and, through this characterization, to insert denial of service software into the Russian network computers, effectively shutting the air defense systems down. Russian airspace could thus be penetrated.

If one of these or subsequent steps didn't happen as described, or if something went wrong, the scenario wouldn't work. Military planners must take into consideration the "what-if" scenarios, where certain aspects of an MDB operation don't go according to plan (Fig. 3.7).

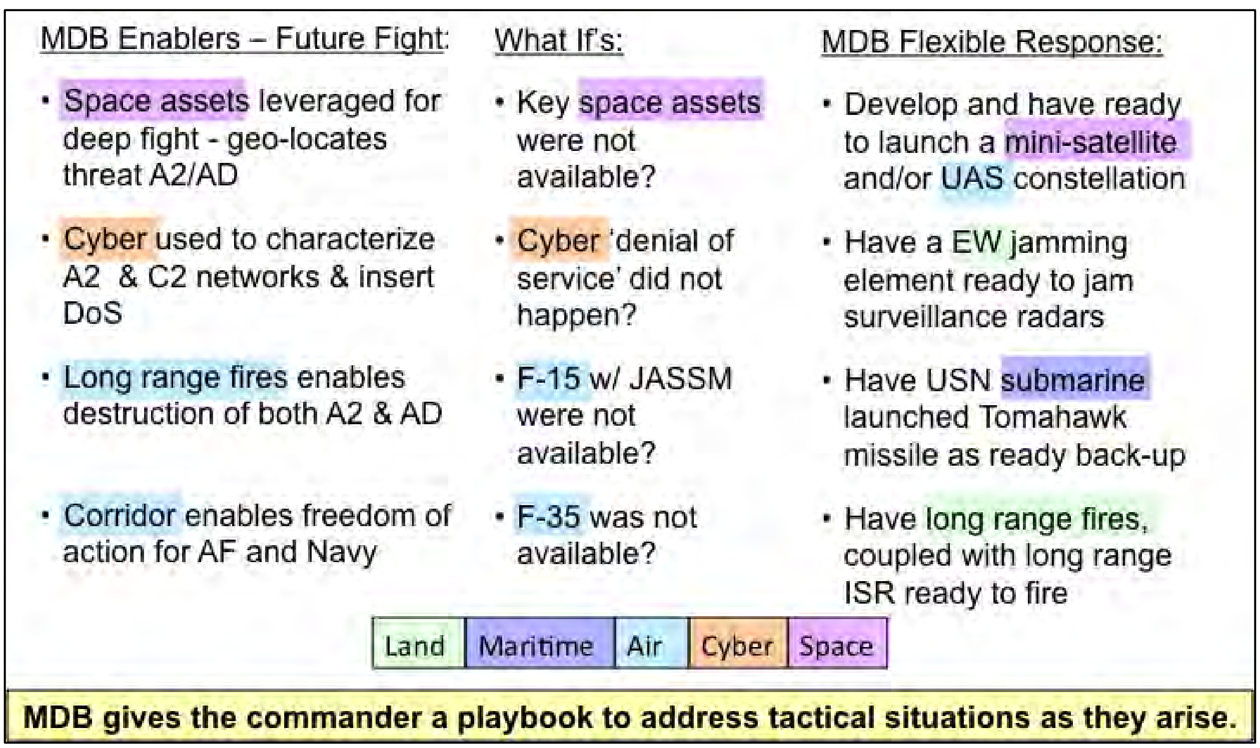

Figure 3.7 MDB Enablers and Flexible Response to "What-ifs"

For example, if space assets weren't available due to some Russian activity to destroy/negate space systems, it would be prudent for the U.S. to have mini-satellites ready to launch to reconstruct the space system constellation. Similarly, if the denial of service didn't happen as planned, high power EW jamming could render radars and communication networks inoperable. Submarines could launch Tomahawk missiles if Air Force assets were not available. For the deep fight, if F-35s were not available, and the Russian HVTs in the Baltic region were outside the range of ATACMS, then Army long range fires could be employed in this future fight.

The MDB operational concept provides multiple paths through the kill matrix, which gives the commander a playbook to address tactical situations as they arise.

MDB gives commanders a playbook to address unforeseen tactical situations as they arise.

3.3 GLOBAL COMMONS

The global commons–those areas that don't belong to any one state, such as the oceans, the atmosphere, and space–exist in and encompass all five DoD-recognized domains. The land portion is limited to Antarctica. Maritime and air commons are extensive and crucial to international commerce (movement of goods and people), and the specific boundaries of those commons are debated by the nation(s) claiming territorial waters or airspace. At this point, the space and cyberspace domains lie entirely within the commons. Setting Antarctica aside for now, there are challenges facing the U.S. military in each of the other commons and their corresponding domains:

- Maritime – Eighty-five per cent of all raw commodities and merchandise that move between nations are transported by sea, with a full three-quarters of that cargo transiting through international chokepoints such as a canal or a strait. Likewise, the U.S. military supply chain relies heavily on ocean transport. The 1982 United Nations Convention on the Law of the Sea (UNCLOS), and its follow-on treaties, delineate levels of sovereignty in littoral, offshore, and international waters. Access to these international waters has become threatened by piracy, conflicting territorial claims (e.g., in the South China Sea), and anti-access tactics that interfere with movement of vessels through straits. Furthermore, access to maritime transport is tightly linked to the availability of space and cyberspace assets for navigation and communication.[27]

- Air – A nation has sovereignty over its national airspace, defined as that over national land, some internal waters, archipelago waters and territorial seas. Thus, by definition, international airspace exists over international waters. Commercial air carriers transported more than two billion people on some 20 million flights in 2010. At the same time, a burgeoning air cargo industry now transports over 35 per cent by value of the world's manufactured exports. Access to international airspace has become challenged by the proliferation of surface-to-air missiles (SAMs) and advanced air-to-air

[27] Mark Barrett et al. *Assured Access to The Global Commons.* Supreme Allied Command Transformation, North Atlantic Treaty Organization, Norfolk, VA, April 2011, p4. http://www.act.nato.int/images/stories/events/2010/gc/aagc_finalreport.pdf

missiles. Cyber-attacks disrupting aviation command and control infrastructure are also a concern.[28]

- Space – No part of space falls under sovereign rule. The Outer Space Treaty of 1967 and its follow-on agreements assured access to and use of space for all who have the means to reach it. Over a thousand orbiting satellites collect, transmit and transfer data – telecommunications, meteorological imagery, surveillance, global positioning, and timing – which have both commercial and security applications. Control and launch facilities on the ground are crucial components of access to space, and threats to that access include kinetic damage to space assets on the ground, as well as those in orbit. Activities that disrupt the transmission or reception of satellite signals without direct physical damage to the components are also threats. Orbital debris also pose a threat to space assets and may make it difficult to distinguish intentional from unintentional damage. [29]

- Cyberspace – As it doesn't occupy a discrete physical location in the same manner as other commons/domains, cyber is the most unique common and domain. The vast amounts of digitized information traversing the electromagnetic spectrum constitute the cyber payload, and it's available to anyone with the technological means (a computer, a smart phone, etc.) to gain access. The infrastructure of cyberspace, however, depends upon physical nodes such as servers, terminals, wires and cables that comprise its infrastructure, all of which exist in nations that exert control and, in some cases, ownership over the cyber common and domain. Thus, access to cyberspace, and the security of the data it carries, are threatened by independent hackers, criminals, and state-sponsored actors. The forensics required to attribute an attack may take an extensive amount of time, if they can be accomplished at all.[30]

On 19 October 2016, Vice Chairman of the Joint Chiefs of Staff, General Paul Selva, USAF, signed the Joint Concept for Access and Maneuver in the Global Commons (JAM-GC), marking its approval as a joint operational concept.[31] The JAM-GC replaces the Air-Sea Battle concept, which mandated the integration of capabilities from all five warfighting domains, when operating in the face of comprehensive A2/AD threats.

3.4 RATE OF CHANGE OF TECHNOLOGY

The study team found that current MDB documents are overly conservative in their assessment of the pace of development and availability of new technology (e.g., availability of robotics,

[28] Ibid p14
[29] Ibid p22
[30] Ibid p38
[31] Michael E. Hutchens et al, *Joint Concept for Access and Maneuver in the Global Commons, A New Joint Operational Concept,* Joint Force Quarterly, NDU Press, 1st Quarter 2017, http://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-84/jfq-84_134-139_Hutchens-et-al.pdf?ver=2017-01-27-091816-550

autonomy, and AI). Technical advancements will enable greater operational opportunities and options than currently assumed in, e.g., the draft MDB concept document (as of Apr 2017). This is key, since rapid advances and new disruptive capabilities, employed in a fully integrated MDB manner, will be needed to ensure overmatch. The conservative estimate may result from the fact that, while the investment in S&T world-wide has increased at a significant pace, DoD is no longer a dominant contributor in technology acceleration. Moreover, the advantages in S&T personnel once enjoyed by DoD has eroded, as the science and engineering workforce has become globalized and more competitive.[32]

Multi-domain integration must advance beyond existing and/or slowly evolving capabilities.

A recent publication[33] points out that in 1960 the U.S. performed approximately 70% of the global R&D while the rest of the world combined performed 30%. By 2015 this had essentially been reversed. While U.S. expenditures have increased between 2000 and 2015, the U.S. share has significantly decreased (Fig. 3.8) largely because Chinese expenditures have increased dramatically. A 2014 article in Nature[34] shows China overtaking the U.S. in R&D spending by 2020. Potential peer adversary capabilities are advancing rapidly and will continue to do so. Therefore, a peer conflict is unlikely to be won by multi-domain integration of only existing and/or slowly evolving capabilities.

The study team identified several areas that are critical to MDB implementation and must be accelerated. These include:

- Manned-unmanned teaming
- Autonomy/AI
- Faster decision making
- Directed energy
- Intelligent systems
- Quantum effects

Integration of these areas must be accelerated on the U.S. side because significant advances are already being made in the global commercial sector and by our potential adversaries. Autonomy/AI and MUM-T technologies are moving especially quickly, as described in previous ASB studies[35] and their adoption is critical for MDB success to allow for faster decision making.

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[32] ASB FY 2013 “The Strategic Direction of Army Science and Technology;” p. 15.
[33] John F. Sargent, *Global Research and Development Expenditures: Fact Sheet,* Congressional Research Service 7-5700, 16 June 2017. https://www.hsdl.org/?abstract&did=801939
[34] Barbara Casassus, *China Predicted to Outspend U.S. on science by 2020*, Nature, 12 November 2014, http://www.nature.com/news/china-predicted-to-outspend-the-us-on-science-by-2020-1.16329
[35] Cf. FY 2015 “Army Science and Technology for Army Aviation 2025-2040,” and FY 2016 Robotic and Autonomous Systems-of-Systems Architecture," and "Future Armor/AntiArmor Competition."

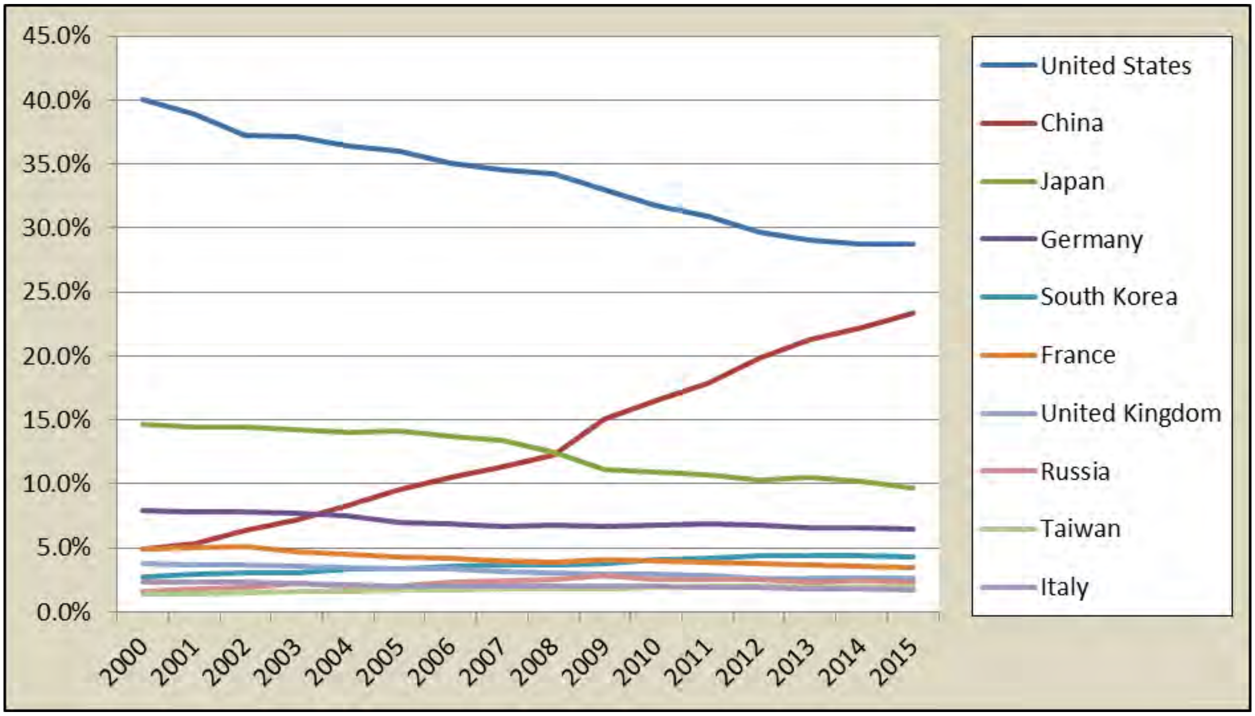

Figure 3.8 Share of Global R&D of Selected Countries, 2000-2015[36]

Other examples include:

- Successful U.S. proof-of-concept experiments in hypersonic and boost-glide propulsion demonstrating the potential for greater range and speed has motivated adversaries to move forward with major investments of their own.

- The same can be said for quantum computing and cryptography. The U.S. showed what could be done early on, and based on those successes, the Chinese have made major steps forward and are now outpacing the U.S. with patents (Fig. 3.9). The recent experiments by the Chinese demonstrating quantum communications from space to significant distances underwater[37] provide them with secure (i.e., potentially un-hackable) means of communication which could pose a challenge for the U.S.

It's critical that the U.S. accelerate efforts in low probability of intercept communications, especially at local levels, to enable multi-function capabilities (e.g. situational awareness, EW, and strike) as commanders' intents become manifested at lower bandwidth and more decision making is pushed down to the local level for implementation of MUM-T. Adversaries will not allow communications for everything all the time.

[36] Global Research and Development Expenditures: Fact Sheet, June 2017

[37] Davide Castelvecchi, China's Quantum Satellite Clears Major Hurdle on Way to Ultrasecure communications, Nature, 15 June 2017. http://www.nature.com/news/china-s-quantum-satellite-clears-major-hurdle-on-way-to-ultrasecure-communications-1.22142

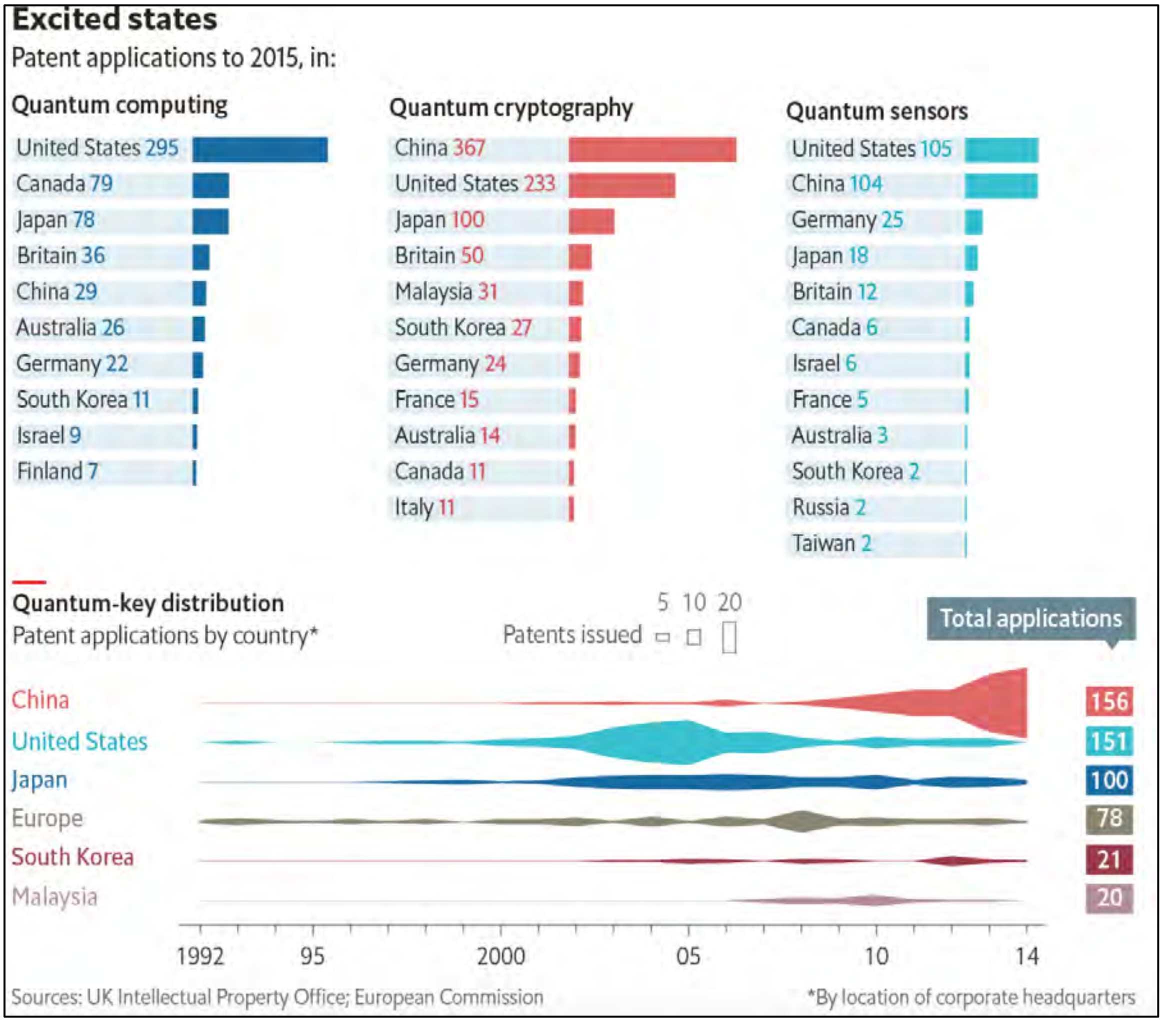

Figure 3.9 Quantum Technology Patents[38]

Cyber capabilities, both threats and opportunities, continue to evolve rapidly, and the use of cyber in the early contested phases of conflict has been demonstrated by adversaries to be an effective tool. It's imperative that our efforts in defensive and offensive cyber accelerate.

[38] The Economist, 9 Mar 2017.

4. ATTRIBUTES OF A 21ST CENTURY SYSTEM OF SYSTEMS

4.1 INCREASED OPERATIONAL OPTIONS

One of the key characteristics needed in a modern system of systems military architecture is a high degree of flexibility, which allows adapting to changing battlefield conditions. Flexibility may yield less surety than an individually threaded system of systems capability would provide, but it will yield greater operational options. For example, adversary systems which change or cycle rapidly due to, e.g., the use of easily refreshed software, make it difficult to assess the level of capability to be faced when the conflict begins. Thus, having additional options mitigates the risk.

Operational options present dilemmas to the adversary in preparation for and during the conflict. Following an ongoing measure/countermeasure cycle, the adversary will prepare counters to new U.S. system of systems capabilities, choosing appropriate elements of the kill chain to disrupt. If options exist to circumvent these weak links, the countermeasure problem for the adversary becomes much more significant. Either all possible options for a given link must be countered, or the adversary must choose to defeat an alternative link, one likely more inherently difficult to counter. Clearly, there's a large win for the U.S. if multiple existing capability options can be "wired" together in novel ways that force the creation of entirely new adversary defensive capabilities. Similarly, there's a potential significant win if a new path is developed without the knowledge of the opponent, such that it emerges as an unexpected capability at the time of the conflict.

Warfighting capabilities are often depicted as "kill chains" (Fig. 4.0), which show the multi-step process by which an integrated capability achieves its desired function. For example, the USAF has adopted the F2T2EA (Find, Fix, Track, Target, Engage, Assess) kill chain to describe many of their system of system weapon employment capabilities. An alternative construct which provides the flexibility of greater operational options can be visualized as system of systems matrix or "kill matrix." At each step of the progression, there are multiple paths which represent either differing concepts of employment for sensor or weapon system capabilities or entirely different system capabilities. The strategy in this flexible use of operational options is to create paths unknown to the adversary (and therefore not countered by adversary planning, material capabilities, or training), or to force the opponent to spread resources in preparing counters to many potential options (limiting the effectiveness of all the counters).

As a strong enabler of the kill matrix, MDB allows the linking of capabilities across all warfighting domains, and hence provides the potential for creating many more options and posing this larger set of dilemmas to the adversary. Flexibility in their application further allows the opportunity to adjust on the fly between potential system-of-system connections as the conflict progresses, identifying and exploiting kill matrix paths that are weakly defended by the adversary.

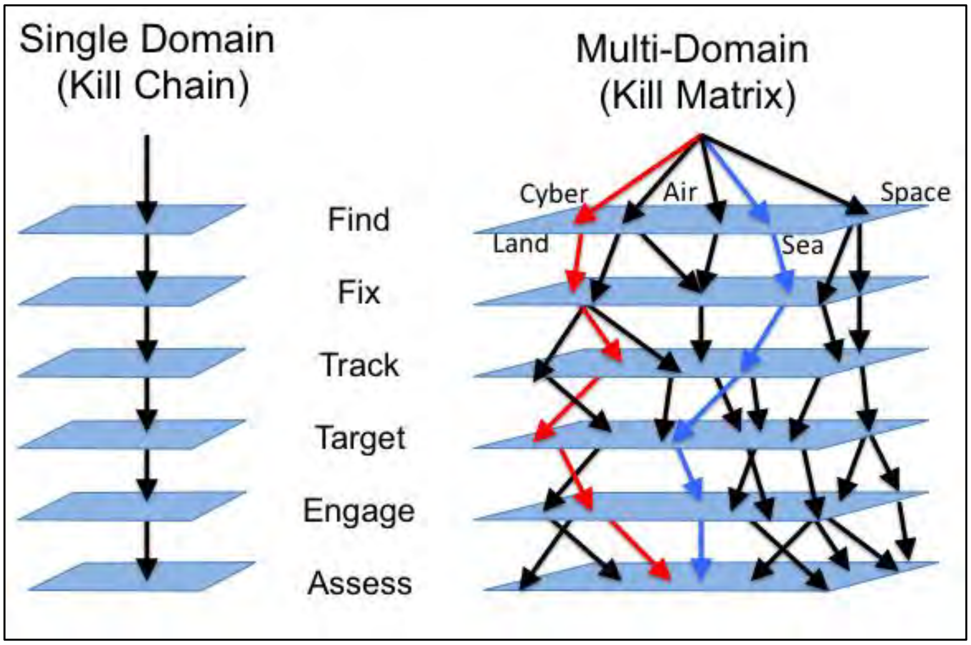

Figure 4.0 Kill Chain vs. Kill Matrix Constructs

The armor/anti-armor competition illustrates the flexibility offered by MDB. Traditionally, armor/anti-armor was a land domain challenge: the threat to be countered lived fully in the land domain (ground platform to ground platform), and the solution to the challenge was to employ land domain forces (armor, artillery, etc.). This solution relied upon superior numbers, superior systems capabilities, or some combination of the two. The ability to muster those advantages was limited by resources and by the restricted creativity imposed by the boundaries of the "land systems" box.

Applying MDB concepts to armor/anti-armor, Airland Battle expanded "the box" and allowed greater system of systems design space. Air-based capabilities presented very different solutions, in which airborne ISR detected the position of adversary armor formations, identified individual targets, handed those positions to an air based strike capability (e.g., Apache or A-10), which engaged the land-based targets. The air domain ability to affect the land domain posed a new dilemma for the adversary. Well-developed counters against U.S. land capabilities were useless in combatting this system of systems approach, and adversaries were compelled to develop air defense capabilities. Furthermore, the threat from U.S. land forces hadn't diminished, so the adversary needed to consider defenses to both possible kill chains, dividing resources which might otherwise have been focused in the land domain.

Furthering MDB concepts beyond Airland Battle, the following hypothetical kill chain could present further dilemmas for the adversary in armor/anti-armor:

- Open source intelligence (e.g., blog reporting from the civilian population) identifies large armor movements through a region

- Novel small satellite ISR (e.g., leveraging recent commercial satellite advancements) cues to the region and detects and identifies specific armor movements
- Sea based assets off the coast of the region cue to launch a cruise missile strike
- Cruise missiles attack the armor column directly or target critical lines of communication (LOC) vulnerabilities to slow or halt adversary advance.

The kill chain now combines multiple warfighting domains to accomplish the counter-land objective. The “find”, “fix”, and “track” elements of the kill chain are accomplished using the cyberspace and space domains. The “target” element is done by a maritime domain asset, and the “engage” element is done by an air domain weapon.

While this multiple kill domain approach could present significant new dilemmas for the adversary, the real power comes in the ability to further substitute elements and create the multiple options of the full kill matrix construct. For example, instead of using space-based assets for the “fix” and “track” functions, land forces could alternatively launch small, attritable UAVs, which could provide the needed stand-in ISR, even in the presence of formidable air defenses. Alternately, the engagement could be accomplished via weapon delivery from an airborne platform (e.g., rotary or fixed wing), or the cruise missile might be replaced by a land-based weapon.

The key to using MDB to develop these operational options is to create new dilemmas for the adversary which are costlier to defeat than to implement, or which are protected and held in reserve until the conflict. The multi-domain employment of existing system capabilities and the creation of new system capabilities can be used to generate these new options. In either case, capabilities need to be evaluated from the perspective of how difficult it will be for the adversary to anticipate and counter all the kill matrix opportunities they present.

4.2 INTEGRATION

The initial task in implementing MDB is to integrate capabilities and associated infrastructure across and within the Services. Unlike integration activities in the past that focused on single systems, MDB integration must involve virtually all major systems in the U.S. inventory inside and outside DoD. The study team recognized a JIM approach is required to address all levels of engagement, from peacetime through warfare. In the past, shaping the battlefield principally involved intelligence and maneuver, but the modern concepts of ambiguous warfare require appropriate U.S. government agencies in all Departments to engage in a given conflict or theater.

Relative to this level of integration, a pressing problem is that of command, control, and communications (C3). Current mission-focused C3 systems will need to evolve to include well-defined interfaces that allow them to integrate with each other and higher-level systems. The descriptions of these interfaces will require clear functional, physical, electrical, network, and cyber definitions to ensure interoperability and ease of integration under degraded conditions. Communications could represent special problems for U.S. forces because of the need for high bandwidth, reliable and secure data transfer at all levels, and the expectation to perform in harsh and contested environments.

Full connectivity between all levels of the force seems like a reasonable objective. The prevalent view presented during study team visits was that only essential communications (e.g., mission command/commander's intent) between appropriate elements would be required. A difficulty with that view is that what is essential and what are appropriate changes as the conflict evolves. The introduction of coalition and civilian partners into the mix increases the challenge because of the need for tiered security in the communications channels.

Recently, terminals allowing for ground forces to use the U.S. Navy's Mobile User Objective System satellite constellation[39] were evaluated at the annual Army Network Integration Evaluation 17.2. The terminals allow for voice and data transfer between individual Soldiers or between forward deployed and CONUS units and can extend throughout the force, enabling effective call for fires and unit coordination among other functions, thereby offering one means to begin solving the Army's communications problems.

Another example of the kind of integration that needs to occur for the future force involves the theater air and missile defense (AMD) systems. Currently, there are at least three systems involved in AMD: Command and Control, Battle Management, and Communications (C2BMC);[40] Integrated Air and Missile Defense Battle Command System (IBCS);[41] and Indirect Fire Protection Capability (IFPC).[42] C2BMC has been developed by the Missile Defense Agency for ballistic missile defense and is used with Terminal High Altitude Area Defense (THAAD), Patriot and the Aegis system. IBCS is under development by the Army for ballistic missile and air defense. IFPC is currently used by the Army for short-range air defense (SHORAD), including defense against rockets, artillery, and mortars (RAM). The connections between these systems are tenuous at best and their respective developments have been conducted with limited regard for shared capabilities or interfaces. The future development of each of these systems should include, at a minimum, track sharing, and ideally, blue force tracking as well. Another desired capability would be an integrated theater air picture that's available to all the systems, planners, and users. As a future enhancement, this air picture should be shared with U.S. Navy, Marines, and Air Force systems with their data integrated as well. A similar capability that

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[39] Stew Magnuson, *Army One Step Closer to On-the-Move Satellite Comms,* National Defense, Aug 2017, http://www.nationaldefensemagazine.org/articles/2017/8/11/army-one-step-closer-to-on-the-move-satellite-comms, accessed 15 Aug 2017

[40] Missile Defense Agency website, *Ballistic Missile Defense System: C2BMC*, https://www.mda.mil/system/c2bmc.html, accessed 29 Aug 2017

[41] Northrup Grumman website, *Capabilities: Integrated Air and Missile Defense Battle Command System (IBCS)*, http://www.northropgrumman.com/Capabilities/IBCS/Pages/default.aspx, accessed 29 Aug 2017

[42] U.S. Army Acquisition Support Center website, *Indirect Fire Protection Capability Increment 2 – Intercept Block 1*, http://asc.army.mil/web/portfolio-item/ms-ifpc_inc_2-i/, accessed 29 Aug 2017

focuses on the land or surface picture would be just as useful. Once common air and surface pictures are available for situational awareness, it can be extended to support fire control quality tracks in a networked fire control system similar to the Cooperative Engagement Capability.[43] This would allow for adaptive weapons target pairing in an any-sensor/any-shooter structure for the maximum flexibility in responding to the threat.

Previous ASB studies have emphasized the need for the Army to re-kindle and extend its EW capability. Beyond electronic support measures to provide intelligence data and jamming systems for asset protection, EW elements can also be applied for passive precision geo-location to support the air and ground picture, and to provide direct fire control quality target data. For example, three drones equipped with Advanced Tactical Target Tracking (AT3)[44] capability could be deployed far forward of the force to identify, track, and geo-locate threat radars with advertised accuracies of 50 meters in less than 10 seconds. This data could be used to initialize long range surface to surface missiles that could then eliminate those radars and reduce the anti-access threat. The data could also be provided to other air assets or used by intelligence units to help maintain the electronic order of battle.

Analysis plays a key role in the successful integration of systems of systems. Because of the complexity, tools associated with model based systems engineering (MBSE) should be considered for the design of the systems, development of their requirements, and definition of the interfaces. The artifacts of the MBSE process can then serve as the basis for model and simulation development to support analysis. These models need to be verified by independent agents and then validated against real world, and where possible, physical experiments and tests. The lessons learned during the experiments and tests can then be fed back into the design for iterative improvements over the life of the systems under a “build a little, test a little” construct.

4.3 SPEED

When thinking about speed as it relates to MDB, there are at least two types–strategic and tactical. Strategically, the increased reliance on CONUS-based forces makes it difficult, if not impossible, to deliver substantial U.S. forces to a location of conflict in less than weeks or months. The tyranny of distance is a driving element to how the U.S. plans its military deployments. Alternatives to the traditional methods of delivering forces need to be developed to offset excessive deployment times. These alternatives need to make use of non-traditional forces, such as coalition partners who may already be in theater. Furthermore, U.S. capabilities that offer essential and available “immediate” support need to be used prior to the arrival of more lethal capabilities. For example, cyber presents a potential first choice for combatant commanders to deliver timely effects on an adversary. Understanding how and to whom cyber

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[43] U.S. Navy website, *Fact File – Cooperative Engagement Capability*, http://www.navy.mil/navydata/fact_display.asp?cid=2100&tid=325&ct=2, accessed 29 Aug 2017

[44] Stephen Welby, *Networked Targeting Technology,* DARPA Special Projects Office, http://archive.darpa.mil/DARPATech2000/Presentations/spo_pdf/3WelbyNetworkedTargetingB&W.pdf, accessed 29 Aug 2017

is applied and what effect it will have requires intelligence work and perhaps a new manner of preparing the battlefield. Once the uncertainties are managed cyber will become an effective, ever-evolving tool in the commander's arsenal. Cyber represents the fastest means to achieve an objective and will grow in its importance, which means its effects need to be understood as part of the broad suite of offensive effects available to the U.S. Army.

Tactical speed depends heavily on communications, maneuver, and the delivery of effects. Conventional modern warfare moves rapidly, limited only by the ability to sustain the force logistically. The Army has done that well in the past, once it's been deployed, but there's little experience in how to do so in an A2/AD environment. Given the range of potential adversary air defense systems, there may not be air superiority for U.S. forces in some theaters, especially at the onset of combat operations. This means that maneuver forces will need local air defense systems that travel with them and engage the full range of threats (ballistic missiles, surface to surface missiles, RAM, as well as fixed wing and rotary wing air threats) while on the move. Mobile air defense presents a significant challenge to a joint force because of the potential for friendly fire incidents with coalition air assets, which is why comprehensive blue force tracking is so important for the Joint force.

In an A2/AD environment, longer range supersonic surface to surface weapons are essential to help compensate for denied operational areas. Their use, however, still requires highly accurate and timely targeting data. Drones equipped with electronic support measure systems were discussed earlier as one means to obtain that targeting data. Another way may be to have tactical satellites that may be launched on an as-needed basis into low earth orbit to provide essential targeting data within hours of launch. If small enough and cheap enough, these may be useful for small unit support in theater without the burden of a national command asset.

In addition to strategic and tactical speed, there will also be a need for increased speed in decision-making. As threats increase, the amount of data increases, the operational tempo increases, and the number of unmanned systems increases, optimized human-machine systems will become increasingly important to future combat operations. Decision-making aids should help commanders operate effectively, perhaps based on inadequate information.

There's also a need for administrative speed in the areas of technology advancement, data collection and analysis, decision-making, and the acquisition process.

For U.S. forces to address future threats, advanced capabilities should be developed as soon as possible. Techniques should be developed to collect data and analyze it quickly to anticipate adversary actions and inform appropriate responses. Finally, once these capabilities become available, they should be provided to the forces in numbers sufficient to address the threat.

5. TRENDS IN TECHNICAL OPTIONS AND OPPORTUNITIES

The study team examined and synthesized past ASB studies, current S&T efforts, meetings with key leaders and organizations, and a review of policies and doctrine to identify MDB-relevant trends in technology options and opportunities.

5.1 TECHNOLOGY OPTIONS

Operationalizing MDB will require Integration across multiple domains, multiple Services, and multiple functions over extended geographic regions and extended time. That integration will require operation in a degraded/denied communications and network environment as well as faster decision-making capabilities. There are technologies to address those challenges (Fig. 5.0; top row).

Operational Challenge	Near (Now-2025)	Mid (2026-2035)	Far (2036-2050)
Degraded/denied comms/networks; Pace of battle requires faster decision-making	Self-forming networks (w/ 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)	Swarms of multi-domain autonomous robots (100:1)
A2/AD - Long-Range 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 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

Figure 5.0 Examples of Technology Critical to MDB

For example, in the near term (now-2025) U.S. forces could begin to rely on mission command (the exercise of authority and direction by the commander using mission orders to enable disciplined initiative within the commander's intent)[45] to minimize the amount of information

[45] Headquarters Department of the Army, *ADP 6-0. Mission Command*, Army Doctrine Publication, 12 March 2014. http://usacac.army.mil/sites/default/files/misc/doctrine/CDG/cdg_resources/manuals/adp/adp6_0_new.pdf

that must be transmitted when communications are degraded, thereby reducing the operational impact of degraded communications. The tactic, combined with self-forming networks and other technologies would begin to lessen the impact of degraded communications. Similarly, in the midterm (2026-2035), low probability of intercept communications could provide secure short-range communications to enable formations of unmanned vehicles to provide multifunctional capability, including real-time updating of the battlefield environment. The subsequent rows in Fig. 5.0 identify technologies to address the remaining challenges shown in the first column.

5.2 RELEVANT ASB STUDIES

The study team found 11 prior ASB studies that had relevancy to MDB (Fig. 5.1).

2013

- Army Science and Technology (S&T) Essential Core Competencies (**S&T**)

2014

- Decisive Army Strategic and Expeditionary Maneuver (**Maneuver**)
- Army Air and Missile Defense Electronic Warfare Assessment (**EW**)

2015

- Army Cyber at the Tactical Edge (**Cyber**)
- Human Interaction and Behavioral Enhancement (**Social Media**)
- Future of Army Aviation (**Aviation**)

2016

- Future Armor/Anti-Armor Competition (**Armor**)
- Countering Enemy Indirect Fires, Target Acquisition Using Unmanned Aerial Systems, and Offensive Cyber/Electronic Warfare Capabilities (**C-IDF**)
- Robotic and Autonomous Systems-of-Systems Architecture (**RAS**)
- The Military Benefits and Risks of the Internet of Things (**IoT**)
- Disruptive Innovative Concepts for the Future Army **(Integration)**

Figure 5.1 Previous ASB Studies Provide Insights for MDB

The 2013 “Army S&T Essential Core Competencies” study identified twelve needed Army S&T core competencies, with the first two considered essential to the entire acquisition community:

- Systems Engineering and Integration (SE&I)
- Advanced Prototyping and Experimentation in Operational Environments

The need for these core competencies (as applied to specific technical areas) was also cited in numerous subsequent studies, and they’re key to operationalizing MDB.

The 2014 “Decisive Army Strategic and Expeditionary Maneuver” study provides insight into the challenges of maneuver in an A2/AD environment and explores the challenges inherent in a

CONUS-based force. For example, that study team recommended developing the business case to exploit commercial assets for transportation, acquisition of supplies, and communications.

The 2014 “Army Air and Missile Defense Electronic Warfare Assessment” study was classified, but one pertinent unclassified recommendation was that the Army should ensure training for battalion and brigade staff for operating in an EW environment.

The 2015 “Army Cyber at the Tactical Edge” study was also classified. A key recommendation involved the Army developing a risk framework to allow the application of offensive techniques at all echelons.

Particularly relevant to pre-conflict stages of MDB, the 2015 “Human Interaction and Behavioral Enhancement” study examined the role of social media in modern conflict.

The 2015 “Army Science and Technology for Army Aviation 2025-2040” study recommended that the Army conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/unmanned systems (MUM-T), future vertical lift performance characteristics, higher levels of autonomy, precision, navigation and timing (PNT) in denied GPS environments, attritable unmanned aerial system assets, and enhanced lethality of directed energy weapons.

The 2016 “Future Armor/Anti-Armor Competition” study recommended developing lightweight armed unmanned aerial and ground platforms to serve as surveillance and weapons assets. It also recommended improved survivability (using active protection system) and lethality (using advanced guns such as Raven) for existing armored fighting vehicles.

The 2016 “Countering Enemy Indirect Fires, Target Acquisition Using Unmanned Aerial Systems, and Offensive Cyber/Electronic Warfare Capabilities” study recommended developing unmanned aerial and ground vehicle-delivery systems for kinetic and non-kinetic effects. The study also recommended developing long-range missiles to counter integrated air defense systems (IADS). In addition, the study recommended improving survivability by using deception and reducing the signature of tactical operations centers.

The 2016 “Robotic and Autonomous Systems-of-Systems Architecture” study encouraged the Army to establish a RAS-focused Campaign of Learning for evaluating operational utility of RAS and developing RAS CONOPS and TTPs. The campaign was to include simulation, prototyping, limited fielding, experiments & warfighting assessments. The study included a test and evaluation approach to develop trust in autonomous systems. It recommended development of a modular-payload unmanned aerial vehicle for counter-IADS that included ISR, SIGINT, EW, and weapons payloads. The study also called for developing an attritable robotic ground counter-armor capability.

The 2016 “The Military Benefits and Risks of the Internet of Things” study recommended developing risk mitigation for inclusion of IoT in military operations and platforms (Blue IoT). The study also recommended that the Army support research programs to explore exploitation of adversary IoT (Red IoT). The study also discussed opportunities to use IoT to shape the environment in the competition stages prior to conflict.

Lastly, the 2016 “Disruptive Innovative Concepts for the Future Army” study recommended that the Army appoint a GO/SES reporting to the CSA, with authority to lead MUM-T and establish an experimentation architecture that integrates analysis and field experiments.

The technical analyses that led to these recommendations informed the current MDB study. For each of these prior studies at least one member of the MDB team was a study participant.

6. CONSTRUCTS AND PATH FORWARD

6.1 MASSIVELY DISTRIBUTED "BOTS"

The study team's vision of future engagements (Fig. 6.0), which leverages technology advances in all domains and operationalizes MDB in theater, includes the following technologies:

- 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 is on supervised autonomy, with the potential deployment of many robotic elements.

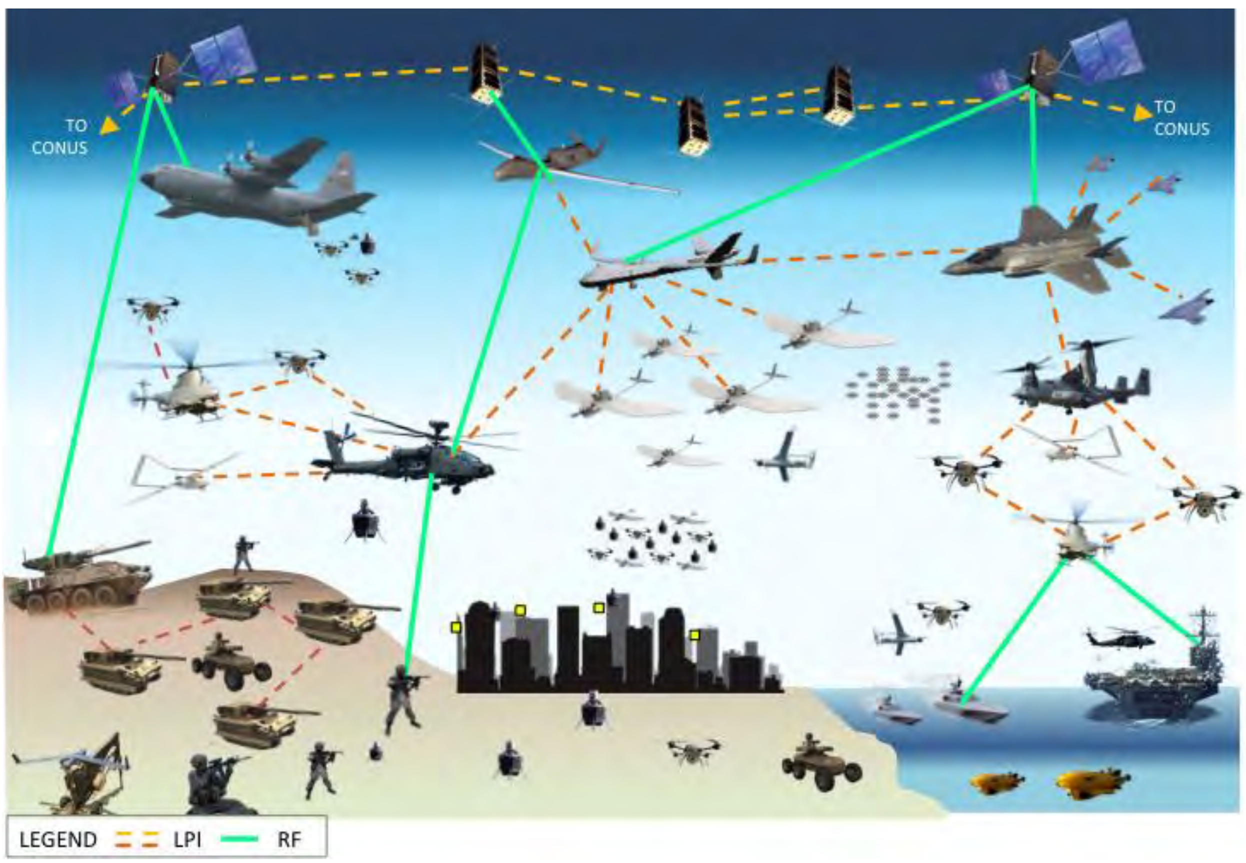


Figure 6.0 Example: Massively Distributed "Bots"

Across the top of the illustration are satellites, including many small satellites (e.g. integrated cubesats) in the middle, which provide data links to the master air and ground platforms in each formation, as well as back to CONUS. The satellites can also provide navigation and ISR capabilities.

On the right is a formation led by an F-35 that communicates with the Marine Corps Osprey and Predator as well as to its unmanned team members. The Osprey in turn communicates with a formation of unmanned assets including a rotary wing Fire Scout. The Fire Scout communicates with manned and unmanned naval vehicles.

The Predator is linked to other fixed-wing UAVs as well as the Apache, F-35 and Global Hawk. The Apache is linked to numerous UAVs, both fixed-wing and rotary wing.

The C-130 in the upper left is deploying various ground and air assets as directed by satellite communications.

On the lower left are the ground forces, including a Stryker lead vehicle, UGV lethal and ISR vehicles, UGV mules, and dismounted troops. These forces are linked to the Apache overhead.

In the urban area the small yellow boxes represent sensors distributed throughout the city.

The communications links shown are a mix of RF and low probability of intercept links. Although the figure depicts numerous links, there are substantially more in order to enable full integration of capabilities across multiple domains, multiple Services, and multiple functions over extended geographical area and time.

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.

The vision includes supervised autonomy of unmanned platforms. Currently, there appears to be resistance within several areas of the Army to the use of autonomous systems, but potential adversaries do not appear to share that reluctance. A campaign of learning to explore the limitations and advantages of autonomy must be undertaken to raise awareness and to establish appropriate conditions for its use. Over time, as trust in autonomy is built, the degree of autonomy will increase. Also, over time, the number of unmanned platforms will increase by factors of 10, 100, and eventually 1,000.

6.2 ANALYSES AND REALISTIC EXPERIMENTATION

While a qualitative case has been made by the Army and Marine Corps for a multi-domain approach, comprehensive, detailed, integrated modeling, simulations, analyses, and validation have not been performed in this study, and capability gaps for MDB are not well understood. In fact, the current version of the Army-Marine Corps MDB Doctrinal Concept list of issues requiring further study includes the need to identify the capabilities needed to deter and defeat adversaries.

A key function of an operational MDB system will be the ability to effectively control the transitions between data/information sharing, decisions, people and assets in a rapid, complex and dynamic environment. Realistic experimentation and training will be essential to determine how the global team interacts and performs in MDB.

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. This need for iterative analysis and experimentation has been recommended in numerous previous ASB studies.

There's a tendency, for good reason, to focus on exercises and training in preparing troops to use current capabilities. The incremental, "experimental" introduction of current threat capabilities, such as degraded communications and cyber, could be useful to inform MDB evolution. In today's exercises and training events, insufficient examples were found of exercises and training based on realistic threats that stress current concepts and technologies (e.g., degraded communications/networks & GPS, cyber effects, advanced A2/AD, UAS utilization, long-range fire effects). There's a role for experimentation that isn't focused on training to explore operations in these stressing environments.

Simulations to examine Joint and partner operations are also limited. The study team found each Service tends to fund development of modeling and simulation of its systems without incorporating the added complexity of the multi-Service perspective.

The study team therefore recommends that the Army perform MDB modeling and simulation, exercises and 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.

The Army needs to develop holistic MDB approaches based on the analyses and experimentation described above. They should include high/low mixes of collaborative manned/unmanned systems, higher levels of autonomy, PNT in denied GPS environments, attritable unmanned assets, and the enhanced lethality of directed energy. They should also:

- Expeditiously develop CONOPS & operational architectures for the most promising concepts
- Determine which elements of the concept are valuable under what conditions
- Identify MDB requirements

These approaches will require the Army to develop a system of systems architecture to achieve an integrated solution across all domains for an effective implementation of MDB. This architecture should include all the elements depicted (Fig. 6.0):

- Manned-unmanned teaming
- Autonomous systems with various levels of supervision
- A robust C4 architecture with, at a minimum, assured intermittent communications for mission command

The architecture should also include:

- An MBSE approach
- A model validation strategy utilizing experimentation and exercises

6.3 OPTIMIZING THE HUMAN-MACHINE SYSTEM

Consider the multiple elements and required functionality of an MDB system, the complexity is significantly larger than any system of systems that the U.S and its Allies have fielded to date; mainly because all the existing systems (as well as some new ones) will need to be integrated into a new MDB architecture. The result will be the most complex system ever developed by the military, because it will be an integrated system of many systems, operating in a dynamic environment (though some operations in degraded environments will rely on more local, possibly allowing for “simpler” connectivity requirements). Greater complexity drives the need for enhanced autonomy, AI, decision tools, human performance and the optimization of the human-machine systems. The requirements for additional technologies and capabilities will be discovered through analysis and learning experimentation.

MDB will place new demands on Soldiers and members of other Services. A fully automated MDB systems is highly unlikely in the near term. Therefore, coordinated, good decision-makers at all levels will be mandatory across the network of people and domains. Soldiers’ and other Service members’ backgrounds, prior training, communication skills/methods, ability to adapt to complex environments, ability to team across joint and international boundaries, etc. will be critical to MDB success. Much of the required training and shaping should start now and will evolve as the MDB system evolves.

The role of people will change as the level and broader application of autonomy is implemented to include high levels of knowledge of any sophisticated systems, adversary capabilities and the ability to apply judgment and cognition attributes to an optimized human-machine system. The acceptance and, more importantly, the trust in fully autonomous and AI systems will take time, training and experimentation. A natural first step will be the implementation and acceptance of semi-autonomous sub-systems which the Army is doing now. Hands-on-training with the actual equipment in realistic environments will help to develop the levels of confidence necessary for future systems. The required rapid response times and decision cycles in the complex MDB environment will demand acceptance and trust in eventual fully autonomous systems.

The Operational Challenges posed by peer and near–peer competitors from now through 2050 will require the development of new, critical technologies and capabilities in degraded/ denied communications and networks; dynamic and rapid decision making; survivability; A2/AD: time critical ISR data (with resulting actionable INFORMATION); counter-UAS (single/swarms/distributed bots/etc.); and degraded/denied PNT. Deception and misinformation techniques will also be an important factor in the Operational Challenge. This can be realized in many forms such as active/passive equipment and network communications via Social Media and bot traffic (e.g., machine-to-machine interactions).

This is just a partial list of operational challenges the Army will face and it's clear that the workload will be far too demanding. Autonomy, AI, and big data management systems will be required to support the dynamic and rapid decision making necessary in any future MDB architecture.

Our peer competitors will also have these systems. How well they're integrated and how robust they make them will be important for a successful mission. Continuous advancement in technologies and capabilities must be a part of the MDB system going forward.

The increased speed and complexity inherent in MDB operations will impose burdens on Soldiers and civilians. Advances in AI-supported decision aids will enable personnel to react at the required speed.

7. OBSERVATIONS

In summary, the character of warfare has already changed, and even greater changes will occur at an accelerating pace in the coming years. The global environment will continue to be characterized by increasing complexity, uncertainty, ambiguity and rapid developments in technology and society.

The features of MDB include:

- More operational options
- Greater integration
- Realistic experimentation
- Greater speed

Multi-domain operations have been conducted for years in various forms, primarily against non-peer competitors with little contested in the global commons. MDB presents an opportunity to overcome the potential advantages of peer competitors by leveraging, synchronizing and integrating JIM entities. Long-term success will depend on several factors:

- The emergence of MDB architectural concepts
- Clarification of the specific operational problems MDB can solve
- Consensus on the value MDB brings to bear on pressing security challenges

Extensive activity is ongoing to advance the MDB concept:

- Development of a Multi-Service concept is scheduled to begin early FY18 (Other Services have begun exploration of multi-domain operations).
- The Defense Science Board (DSB) has just begun a Multi-Domain Effects (MDE) study.

The DSB MDE task force was briefed on this study in September 20217 and the sense was concurrence with the ASB analysis and study results. The DSB will likely pursue multi-domain issues such as policy, regulations, and authorities which are complementary to the ASB efforts.

The key attributes of MDB (Fig. 7.0) include challenges, both external, presented by peer competitors (A2/AD, range of fires, the tyranny of time and distance, and degraded networks) and internal, which are often the result of administrative stovepipes (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 decreased sustainment burden will be key to enable deployment and maneuver.

Several technology options have been identified based on data available from previous ASB studies. These will support an improved battlefield outcome–to win–based on more operational options and overmatch.

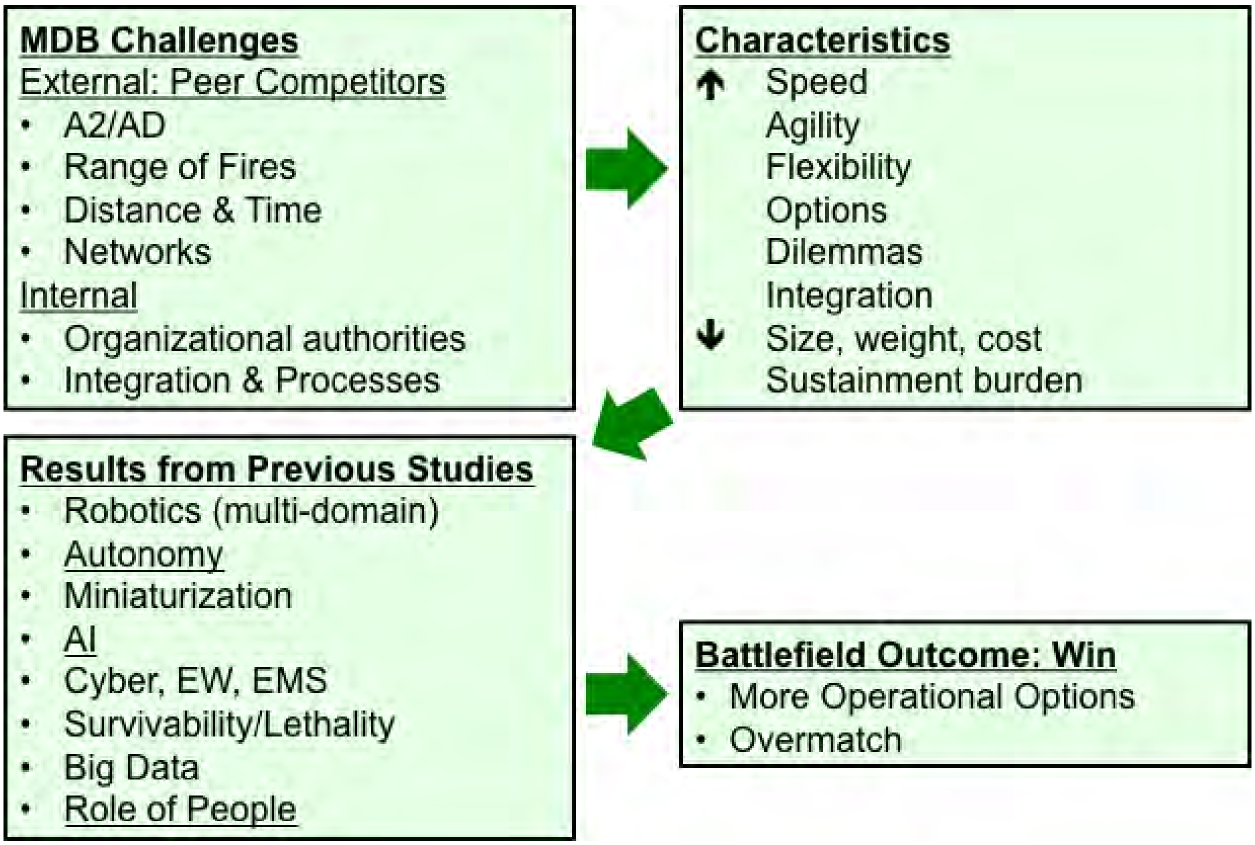


Figure 7.0 MDB Attributes

8. FINDINGS

Over the course of its investigation, the study team developed eight findings.

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.

The second finding points out that the Army is assuming a slower pace of technology development than is warranted. This assumption is shown in draft concept 0.5, the most recent available at the time of the study, but has been removed in later drafts.

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).

The third finding identifies the need for integrated analyses and experimentation to provide a solid foundation for MDB. Exercises and training too often are based on a non-stressing threat.

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).

The fourth finding points out that extending the Army-Marine Corps concept to include JIM may require new processes. Integrated development of capabilities will be difficult in stove-piped processes.

4. It is unclear to ASB how existing organizations and processes will support integrated development of MDB CONOPS and doctrine to their full potential.

The fifth finding addresses the importance of integrated command, control, communications and computers (C4) to achieve the full potential of MDB. New enabling technologies will be needed.

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.

The sixth finding points out the rapidly changing nature of cyber. It is recognized that many cyber techniques are "perishable," which imposes constraints on training and experimentation. Policy considerations governing use of cyber, partially driven by perishability, are also an issue.

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.

The seventh finding points out the importance of autonomy, AI and big data to realizing the potential of MDB. Over time, as trust in autonomy is built, the degree of autonomy will increase. This will enable use of autonomy in expanding roles within the Army. As autonomy increases, the role of people will likely shift to supervising formations of systems rather than controlling individual systems.

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.

The final finding emphasizes the importance of speed to adapt to rapidly changing scenarios and take advantage of windows of opportunity as they are presented. This includes speed of deployment to reach the area of potential conflict before tensions escalate.

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

9. RECOMMENDATIONS

Based on its findings, the study team developed seven recommendations.

The first recommendation recognizes the need to have DoD-wide involvement in development of the MDB concept. It also supports development and acquisition of integrated, not interoperable, systems.

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.

The second recommendation supports joint modeling, exercises and experimentation to define system constructs to support MDB. It also calls for basing CONOPS, architectures and requirements on the modeling, 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.

The third recommendation calls for developing a system of systems architecture to achieve an integrated solution.

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

The fourth recommendation supports developing and fielding MUM-T capabilities, including payload packages. Initial focus should be on the land domain.

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.

The fifth recommendation calls for developing and fielding a high/low mix of capabilities in near, mid, and far term. Specific technologies identified include, but are not limited to unmanned systems, longer range high velocity fires, and C4 networks to control formations of unmanned systems.

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

The sixth recommendation calls for and integrated multi-domain cyber/EW strategy.

6. CYBER COE in collaboration with Joint counterparts: Develop an integrated Multi-Domain Cyber/EW Strategy to support MDB development

The final recommendation calls for alternative acquisition approaches to accelerate system development, experimentation, and integration to operationalize MDB.

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.

10. CONCLUSIONS AND NEXT STEPS

The MDB concept depends upon inherently JIM operations. The study team focused on the technical challenges and opportunities for the Army, operating primarily in the conflict phases of operations. A proposed follow-on study by the ASB will explore the JIM aspects of the evolving MDB concept and the opportunities and challenges associated with pre-conflict and post-conflict campaigns.

The contextual framework for this study is that the character of warfare has already changed and that even greater changes will occur, at an accelerating pace, in the coming years. The global environment will continue to be characterized by increasing complexity, uncertainty/ ambiguity and advancements in technology and society. This view of the future drives the need for a new concept.

The study team identified several themes and ideas important to developing and operationalizing the MDB concept, many of which were integral to several previous ASB studies, including:

- 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

As the threats increase, the amount of data increases, the operational tempo increases, and the number of unmanned systems increases, optimized human-machine systems will become critical to future combat operations. The future will see more reliance on autonomy and AI. The role of people will need to change as the level and broader application of autonomy is implemented–not every Soldier (or platform) will need the same skills and/or equipment.

Based on these themes and ideas, the study team developed a vision of future engagements that leverage technology advances in all domains to enable MDB operations, while recognizing that potential adversaries will continue to rapidly advance their capabilities. Key technologies include, but aren't limited to:

- MUM-T (use of unmanned systems performing various functions including C4ISR,

lethality, deception, logistics, etc.)
- Robotics, autonomy, AI, and decision-making tools
- Self-forming modular C4 networks

The vision includes a system-of-systems architecture of massively distributed “bots” that could increase operational options, provide greater speed, agility and flexibility, and enable effective integration of operations in contested environments. This construct provides a high/low mix of assets with robust/resilient characteristics in degraded environments. The model also 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. The potential for emergent capabilities may include approaches for enhanced adaptability to deal with changes on the battlefield. Having more options should produce improved battlefield outcomes and enable winning in contested and dynamic environments.

The study team’s findings and recommendations supported the evolving MDB concept to address rapidly evolving peer challenges as well as the enabling technology and operational opportunities available to the Army to counter those challenges. The integration and optimized contributions from the JIM players are critically important for future success.

10.1 LINKS TO OTHER 2017 STUDIES

There were three other studies completed by the ASB in July 2017:

- Character of Future Warfare
- Experimentation
- Dense Urban Operations

The Character of Future Warfare study also recommended investing in MUM-T ground vehicles, commercial network capability for Army participation in MDB, and increased lethality.

The Experimentation study emphasized the importance of experimentation in technology development.

The Dense Urban Operations study highlighted issues that MDB will face in urban environments.

10.2 STUDY PHASE II

To explore JIM contributions to MDB more completely, a second year of study is recommended. Several ongoing activities should support an integrated JIM construct:

- The next version of TRADOC’s Army-Marine Corps MDB Doctrinal Concept is expected in

September 2017
- The Air Force is studying MDB C2 and will explore broader MDB operations next year
- The Navy will explore MDB as an extension of Air-Sea Battle and JAM-GC next year
- The DSB study on "Multi-Domain Effects" is beginning and, based on a meeting where the ASB results were shared, the DSB will likely expand upon the work in this study

Moreover, the current version of the Army-Marine Corps MDB Doctrinal Concept includes a 4-page list of issues needing further study.

Finally, in addition to the follow-on 2018 MDB study, and to realize the potential of the evolving MDB concept, the study team recommends a campaign of learning based on realistic experimentation in which threats and scenarios include degraded communications, complex environments, and cyber/EW.

APPENDIX A: TERMS OF REFERENCE

SECRETARY OF THE ARMY
WASHINGTON
FEB 2 2 2017

Dr. James Tegnelia
Chairman, Army Science Board
2530 Crystal Drive, Suite 7098
Arlington, VA 22202

Dear Dr. Tegnelia:

I request the Army Science Board (ASB) conduct a study entitled "Multi-Domain Battle." The objective of the study is to assess how expanding and re-balancing the Army's focus on AirLand Battle (ALB) to fighting more effectively in all five Department of Defense (DoD)-recognized military warfighting domains (henceforth referred to simply as "domains," which include land, air, sea (maritime), space, and cyberspace, as well as operational environments which could emerge as more important "battlefields," such as the electromagnetic spectrum (EMS) and cognitive) could significantly enhance tactical, operational, and strategic outcomes. A corollary objective is to assess potential combat efficiencies and synergies gained by better leveraging, synchronizing, and integrating joint, interorganizational, and multinational (JIM) capabilities across all present and future domains.

Currently, each service places primary focus on operations in specific domains: the Navy in the maritime, the Air Force in the air and space, the Marine Corps in the maritime and land, and the Army on land, while all the services operate in the cyberspace domain. However, in practice, each service possesses organic assets that operate in all five domains. In addition, Joint Publication (JP) 3.0, "Joint Operations," identifies joint functions as (1) command and control, (2) intelligence, (3) fires, (4) movement and maneuver, (5) protection, and (5) sustainment. Each service provides forces to perform these functions. Joint doctrine focuses on Joint operations in which forces from multiple Services, employing service-unique capabilities, contribute to the successful accomplishment of military operations.

For example, in the 1970s, to address the challenges of defeating a numerically superior Soviet adversary, the U.S. Army developed the ALB concept. ALB emphasized coordinating closely between land and air forces to attack the enemy across the full depth of the battlefield and to seize the initiative through early offensive action to bring about the conclusion of battle on U.S. terms. This concept proved effective during the Cold War years.

Today however, 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.

As a result, the Army and its Joint Force partners have recently developed and crafted the Joint Operational Access Concept (JOAC), the Joint Concept for Entry Operations, the Joint Concept for Access and Maneuver in the Global Commons, the Planner's Guide for Cross-Domain Synergy in Joint Operations, the Army Operating Concept, the Army white paper on Joint Cross-Domain Fires and Maneuver, and the Army-Marine Corps white paper on Multi-Domain Battle (MDB): Combined Arms for the 21st Century (draft).

Specifically, the JOAC proposes employing cross-domain synergy – the complementary versus merely additive employment of capabilities in different domains such that each enhances the effectiveness and compensates for the vulnerabilities of the others – to establish superiority in some combination of domains that will provide the freedom of action required by the mission. Similarly, the Army-Marine Corps white paper on MDB emphasizes the need to achieve cross-domain synergy through coordinated, simultaneous actions across contested spaces. The Army-Marine Corps MDB concept consists of cross-domain operations that create temporary windows of localized control across multiple domains, allowing the Joint Force to seize, retain, and exploit the initiative in order to defeat the enemy.

This study will seek to expand on these past efforts; shape, reinforce, and amplify the development of the Army-Marine Corps MDB concept; and further explore opportunities to better leverage, synchronize, and integrate JIM capabilities across all existing and potential future domains in order to enhance combat efficiencies and synergies; impose multiple, simultaneous dilemmas on our adversaries; degrade enemy capabilities; enable close-combat overmatch; and counter enemy A2/AD strategies.

The study team's tasks shall include, but not be limited to, determining (from a technology/capability-based point of view) the following:

a. What is different about the MDB concept? Why do we need a MDB concept?

b. What is the current baseline regarding MDB concept development within the Army and JIM?

c. What are the hurdles and impediments to effectively implementing MDB within the Army and across the JIM force?

d. What are the future opportunities presented by MDB?

e. How might MDB change the way the JIM force operates?

f. What are the potentially new roles, responsibilities, and relationships for the Land Component when executing MDB in an A2/AD environment?

g. What new learning demands emerge from the MDB concept? What kind of experimentation would be required to support these learning demands?

h. With regards to this experimentation, how could the Army rapidly transition the lessons learned in terms of new tactics, techniques, and procedures (TTP) and emerging technologies into approved concepts and rapidly fielded capabilities?

i. What emerging/cost-imposing technologies or novel mix of existing Army/JIM capabilities could significantly improve the Army's ability to shoot, move, communicate, and protect itself during ground combat operations in an A2/AD environment?

To the extent possible, the study team's recommendations should not require changes in either Title 10 or the Goldwater Nichols Act, and they should recognize the Army's S&T budget is unlikely to increase dramatically over the next 10 years.

CG, TRADOC is the sponsor of this effort and will assist the study team in accessing classified information up to Top Secret and including Sensitive Compartmented Information and Special Access Programs.

A briefing and report with findings and recommendations will be provided by September 30, 2017 to the Secretary of the Army and Army Chief of Staff. The study will operate in accordance with the Federal Advisory Committee Act and Department of Defense 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.

Sincerely,

Robert M. Speer
Acting

APPENDIX B: STUDY TEAM MEMBERS

Maj Gen (Ret) Ron Sega, PhD – Chair

Mark Glauser, PhD – Vice-Chair

Bob Atkins, PhD	COL (Ret) Susan Myers, PhD
Nancy Chesser, PhD	Bill Snowden, PhD
Bob Douglas, PhD	LTC (Ret) Buck Tanner, PhD
Bill Guyton	Tony Tether, PhD
RADM (Ret) Grant Hollett	Joe Theobald, PhD

Red Team Advisor

Jeff Isaacson, PhD

Study Managers

MAJ Chris Ellis, ARCIC
MAJ Marco Lyons, TRADOC

Tech Writer/Editor

Mark Swiatek

APPENDIX C: VISITATIONS AND INTERVIEW LINES OF INQUIRY

US Army Training and Doctrine Command (TRADOC)/15-16 March 2017/ FT Eustis, VA
ASB provided TOR to TRADOC.
ASB Team Members engaged with BG Odom, MG Dyess, and GEN Perkins about various aspects of MDB and the initial guidance on how the study should proceed and additional site visits.
Discussed the issues of the MDB White Paper with Joint Army Concepts Division (JACD) Director, COL Runey.
Received an Operational Environment briefing from TRADOC G-2, Mr. Schmidt.
Received a briefing on the top 20 critical gaps from Capability Needs Analysis, Mr. Burris.

US Army Maneuver Center of Excellence (MCoE)/29 March 2017/ FT Benning, GA
ASB provided TOR to MCoE.
ASB Team Members engaged with MG Wesley and discussed procurement and organizational challenges with MDB.
Received briefing on the Army Functional Concept: Movement and Maneuver.
Discussed MUM/T and AI with semi-independent operations.

National Capital Region/ 12-13 April 2017/ Washington D.C.
ASB provided TOR to guest speakers.
ASB Team Members received an updated Future Operational Environment brief from TRADOC G-2.
Discussed technological solutions to gaps in MDB with HQDA, MG Hix.
Discussed projects currently pursued by DARPA.
Met and discussed various aspects of MDB, both technological and challenges of the Operational Environment, with: T. X. Hammes (author), IDA, Service Planners, and the Lexington Institute.

US Army Cyber Center of Excellence/ 04 May 2017/ FT Gordon, GA
ASB provided TOR to CCoE.
ASB Team Members met with and discussed the roles and capabilities of cyber in the MDB environment with MG Morrison and his staff. Additionally, what challenges existed in training both defensive and offensive cyber during CTC rotations and what policy challenges exist.

Unified Quest Workshop/10-11 May 2017/ Carlisle, PA
ASB members attended a workshop on Unified Quest, including observing numerous working groups.

AUSA- Institute of Land Warfare/ 11 May 2017/ Arlington, VA
ASB Team Members listened to GEN Perkins give an overview of MDB and the similarities to and differences from Air Land Battle, the process of moving from concept to doctrine, and the challenges of the changing character of warfare.

USARPAC LANPAC Conference/ 22-25 May 2017/ Honolulu, HI

ASB Team Members listened to several panels hosted by GEN Brown and AUSA. The topics covered on day one: Perspectives on Land Force and Joint Force Roles and Opportunities (Chaired by GEN Brown), Status/Assessment of the Theater (Chaired by MG Pasquarette), and Preventing Crisis While Preparing for War (Chaired by LTG Volesky).
Day two topics covered: Access to, Operations in and Influence of Non-Traditional Domains (Chaired by BG Thoms), Joint and Multinational Sustainment of the Force (Chaired by MG Davidson), and Empowering the Team: Total Force Integration (Chaired by BG Curda).
Day three topics covered: Empowering the Team: Leveraging Leadership and Mission Command to Maximize the Human Dimension (Chaired by LTG Vandal) and Empowering the Team: Innovation and Experimentation in Partnership with Industry and Partner Nations (Chaired by Dr. Roper).
The MDB Study Members also received briefings at Hickam Air Force Base from Maj Gen Dillon, Brig Gen Gainey, and Col Blomme. Additionally, the members also received an MDB briefing from LTC Lakey at FT Shafter. The members also discussed MDB topics with GEN Ham and how AUSA is looking into MDB.

<u>National Capital Region II/ 30 May-01 June 2017/ Washington D.C.</u>
ASB provided TOR to guest speakers.
On day one: ASB Team Members met with LTC Phillips (OUSD-P) to Discuss Wargaming, Experimentation, and Research and Development. The Members also discussed past ASB Studies Briefs with MG Hix, and conducted a teleconference with Dr. Bonin, USAWC to discuss MDB Organizations.
On the second day: Members had a meeting with RAND (Dr. Predd) to discuss the USARPAC Study. They also met with Lockheed Martin Center for Innovation to discuss C4ISR. USASOC DCS G-9 conducted a VTC to discuss the Human Dimension and how PH 0-II can have an impact on MDB. The day concluded with a discussion on MDB with Mr. Singer, author of Ghost Fleet.
On day three: Met and teleconferenced with RDECOM CERDEC. The day concluded with a discussion and overview of DARPA Programs that focus on MDB with Acting Director, Dr. Walker. At the conclusion of the discussion, the Members were invited to receive more in depth briefings at DARPA.

<u>National Capital Region III/ 20-21 June 2017/ Washington D.C.</u>
ASB provided TOR to guest speakers.
This visit brought Joint Partners into the MDB discussion.
On day one: ASB Team Members attended an Institute of Land Warfare breakfast hosted by AUSA, the guest speaker was LTG Hodges, Commanding General US Army Europe. The Members discussed MDB with CAPT Michael E. Hutchens, USN, DCNO N3N5. The Members attended a VTC with Maj. Gen. Bussiere, Commander, Eighth Air Force (Air Forces Strategic) and Joint Functional Component Commander for Global Strike. The Study had lunch with ADM (Ret) James O. Ellis, President's Intelligence Advisory Board and asked for his views and challenges with MDB. The day concluded with a discussion on the challenges of MDB with Col. Pietrucha, USAF.
On day two: Met with Brig. Gen. B. Chance Saltzman, Director of Future Operations, Deputy Chief of Staff for Operations, Headquarters U.S Air Force to discuss how the Air Force is

approaching MDB. Members discussed gaps and challenges MDB presents with HQDA G-3/5/7. The "Oklahoma "Chart was also reviewed. The day concluded with a SVTC with Joint Concepts Division, Future Joint Force Development, Joint Staff J-7.

US Army Combined Arms Center / 27-28 June 2017/ FT Leavenworth, KS

ASB provided TOR to guest speakers.

On day one: ASB Team Members attended a Scenario 7 Combat Modeling Results Brief conducted by TRAC (TRADOC). Members had office calls with the Deputy Commanding General, CAC, Mr. Brown, the Deputy of CAC-T, Mr. Johnson, and with the Deputy Director, MCCoE, Mr. Jordan.

On day two: Met with COL Berryman and his staff from MCCoE Battle Lab to discuss modeling and experimentation for MDB and the challenges of including Multinational Partners. Members met with TRADOC G-2 Intelligence Support Activity (TRISA)/ATHENA (TRADOC) for small group meeting. The day concluded with an overview and discussion of Red Teaming hosted by Mr. Rotkoff.

PEO STRI / 06 July 2017/ Orlando, FL

ASB provided TOR to guest speaker.

Met with Mr. Miller, Director of the Cyber Arena, to discuss how the Cyberspace Domain is modeled and trained. Additionally, he gave details on how cyber teams can conduct both defensive and offensive scenarios on a closed network.

APPENDIX D: TOR MAPPING

The TOR specified nine tasks for the study team. These are presented below together with references to where each issue is discussed in the report and a summary of results.

a. What is different about the MDB concept? Why do we need a MDB concept?

The MDB concept expands on current DoD concepts to include domains traditionally considered to be included in the global commons – specifically space and cyberspace. The MDB concept is needed to explore the ramifications of the speed, complexity, and integration required to successfully accomplish future engagements. (See Sections 1 through 6 above.)

b. What is the current baseline regarding MDB concept development within the Army and JIM?

MDB is a developing concept within the U.S. Army and Marine Corps doctrine development communities. It is not presently doctrine, and Army and Marine Corps senior leaders still have to officially approve the final concept. (See Section 2)

c. What are the hurdles and impediments to effectively implementing MDB within the Army and across the JIM force?

Weapons, C4ISR, EW, platforms, and other systems are not integrated within Services or across Services. Fully operational MDB will require the capability to pass information among platforms to permit coordination of activities. Interoperability is not sufficient, full integration of systems beginning at the design phase is needed. Additional impediments are presented by silos within the Services and across Services that inhibit integration and coordination of capabilities. (See Section 4.2)

d. What are the future opportunities presented by MDB?

MDB provides the opportunity to consider numerous options, independent of where they reside, to defeat the adversary. (See Section 4.1.)

e. How might MDB change the way the JIM force operates?

As MDB is operationalized, integration of capabilities across the JIM force means no organization operates in isolation. Each organization can pass off information to a second organization that is better positioned to act on the information. (See Section 4.2)

f. What are the potentially new roles, responsibilities, and relationships for the Land Component when executing MDB in an A2/AD environment?

The Land Component will face an expanding role as roles and responsibilities blur under MDB. It will not be necessary for each component to be able to use all capabilities in all situations. Rather each can rely on the others to provide support when needed. This will require coordination among components to ensure at least one component will be able to provide the required capability. (See Section 4.2)

g. What new learning demands emerge from the MDB concept? What kind of experimentation would be required to support these learning demands?

In the future the increased speed and complexity of operations will require new techniques at the man-machine interface. Soldiers and civilians will need to be able to make decisions faster. (See Sections6.2 and 6.3)

Development of new capabilities will require a campaign of learning to inform development. As the level of autonomy and AI is increased in MUM-T systems, such a campaign of learning can also help to build the trust needed operationalize those capabilities. (See Sections 6.2 and 6.3)

Iterative analysis and experimentation will inform both learning and experimentation to optimize system capabilities.

h. With regards to this experimentation, how could the Army rapidly transition the lessons learned in terms of new tactics, techniques, and procedures (TTP) and emerging technologies into approved concepts and rapidly fielded capabilities?

ASB recommends that 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. TRADOC can then use knowledge gained in those efforts to inform development of new capabilities and concepts to employ them. See Section 9)

i. What emerging/cost-imposing technologies or novel mix of existing Army/JIM capabilities could significantly improve the Army's ability to shoot, move, communicate, and protect itself during ground combat operations in an A2/AD environment?

Autonomy, AI, and MUM-T enable new tactics based on formations of unmanned platforms led by manned platforms. (See Section 6.1)

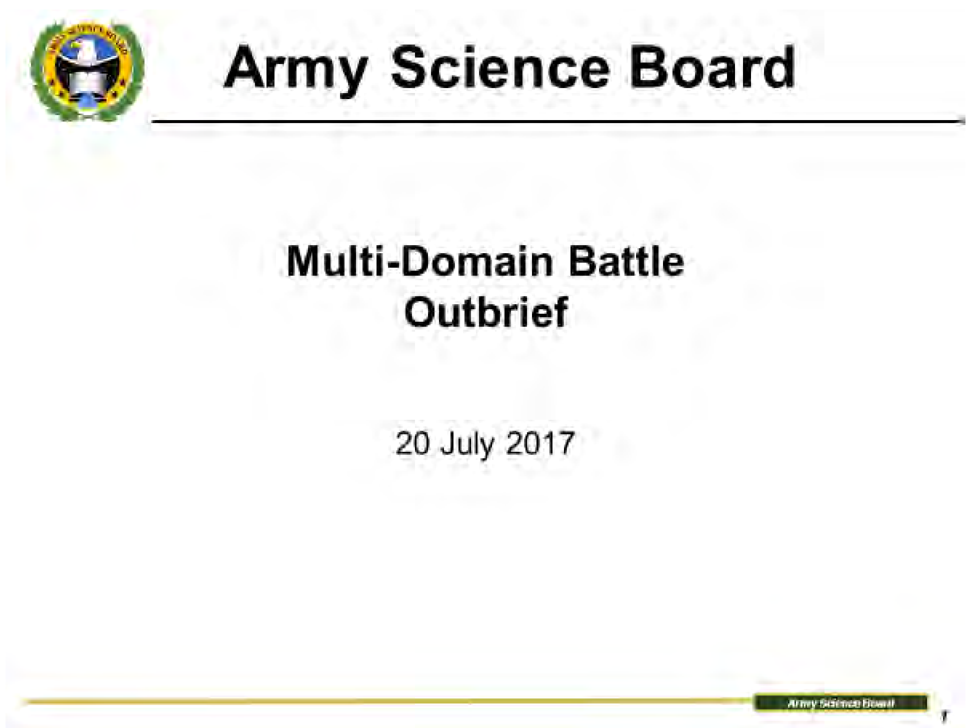
C4 options to enable integration are also key. (See Section 4.2)

APPENDIX E: ASB APPROVED BRIEFING WITH FINDINGS & RECOMMENDATIONS

The following briefing was presented by Dr. Ronald Sega, Study Chair, to the ASB in plenary session at the Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering, U.C. Irvine, on 20 July 2017.

By unanimous vote, the ASB approved and adopted the findings and recommendations made by the study team.

Classified material and material marked as for official use only (FOUO) has been removed.



Agenda

- Introduction
  - TOR
  - Members
  - Visits
  - Background
- MDB Description
- MDB in PACOM
- MDB in EUCOM
- Observations
- Findings & Recommendations

Army Science Board 2

Terms of Reference - Objectives

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

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

TOR signed by SA on 2/22/17
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Army Science Board 3

Terms of Reference - Tasks

a. What is different about the MDB concept? Why do we need a MDB concept?
b. What is the current baseline regarding MDB concept development within the Army and JIM?
c. What are the hurdles and impediments to effectively implementing MDB within the Army and across the JIM force?
d. What are the future opportunities presented by MDB
e. How might MDB change the way the JIM force operates?
f. What are the potentially new roles, responsibilities, and relationships for the Land Component when executing MDB in an A2/AD environment?
g. What new learning demands emerge from the MDB concept? What kind of experimentation would be required to support these learning demands?
h. With regards to this experimentation, how could the Army rapidly transition the lessons learned in terms of new tactics, techniques, and procedures (TTP) and emerging technologies into approved concepts and rapidly fielded capabilities?
i. What emerging/cost-imposing technologies or novel mix of existing Army/JIM capabilities could significantly improve the Army's ability to shoot, move, communicate, and protect itself during ground combat operations in an A2/AD environment?

Army Science Board 4

Team Members & Visits (partial list)

Study Team

- Maj Gen (Ret) Ron Sega, PhD – Chair
- Mark Glauser, PhD – Vice
- Bob Atkins, PhD
- Nancy Chesser, PhD
- Bob Douglas, PhD
- Bill Guyton
- RADM (Ret) Grant Hollett
- COL (Ret) Susan Myers, PhD
- Bill Snowden, PhD
- LTC (Ret) Buck Tanner, PhD
- Tony Tether, PhD
- Joe Theobald, PhD
- Jeff Isaacson, PhD – Red Tm

Study Managers:

- MAJ Chris Ellis, ARCIC
- MAJ Marco Lyons, TRADOC

Visits: Army

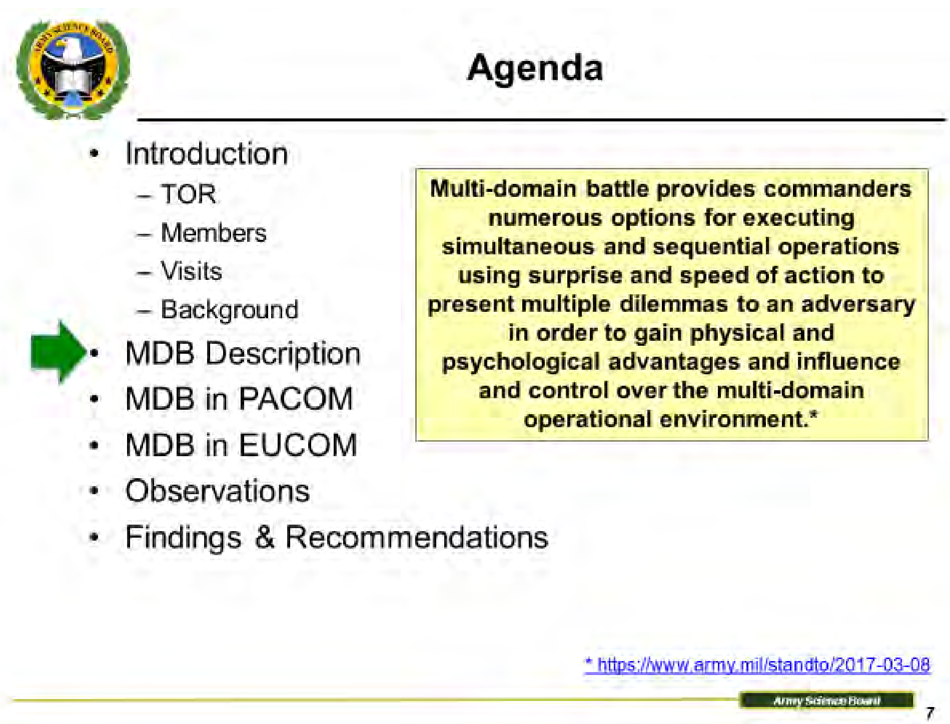
- TRADOC, GEN Perkins
- ARPAC, GEN Brown
- CAC, LTG Lundy
- USAREUR, LTG Hodges
- Army G3/5/7, MG Hix
- ARCIC, MG Dyess
- Maneuver COE, MG Wesley
- Cyber COE, MG Morrison
- Mission Command COE
- TRAC
- TRISA
- Center for Army Analysis
- Army War College, Freier
- PEO-STRI
- National Cyber Range
- CERDEC

Visits: Other

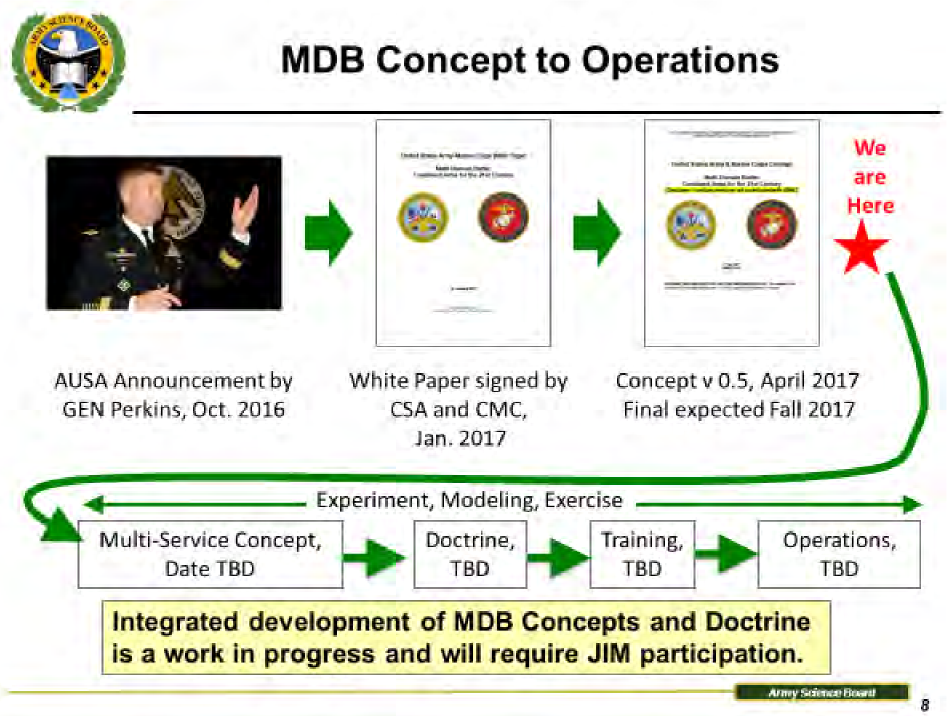
- STRATCOM
- OUSD Policy
- Navy JAM-GC
- USMC - MCCDC
- USAF - USAF HQ, Dir Operations
- DARPA, Dr. Walker & PMs
- IDA
- Rand (USARPAC study)
- NDU, Hammes
- Lexington Institute, Goure
- New America, Singer
- Industry

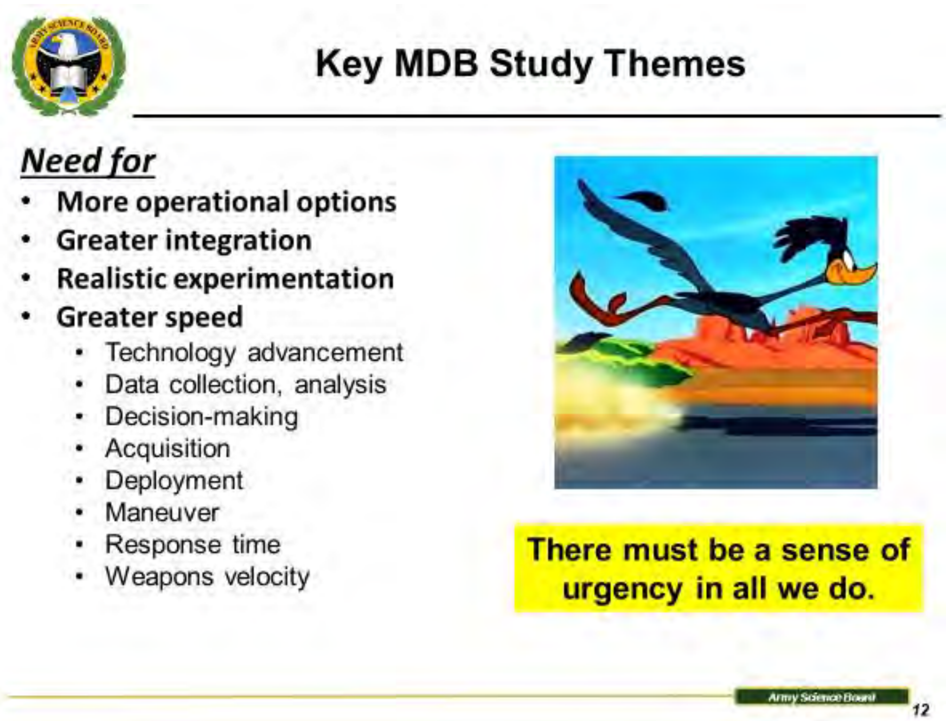
Army Science Board 5

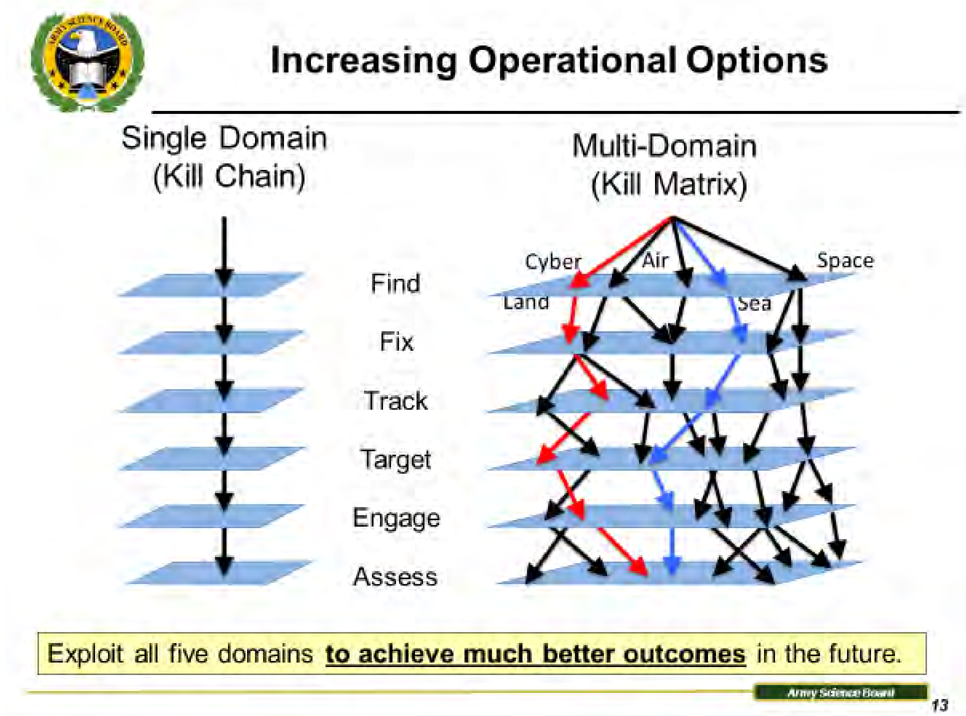
U.S. ARMY
The Operational Environment
Changes in the Character of War
Lethal, Contested, Complex
Terrain…Degraded Operations
Adversaries, including super empowered individuals with access to WME, cyber, space and NBC
Proxies
Terrorist/ Criminal activity
STRATEGY
Strategic Capabilities
Conventional Structure & Capability
Irregular Operations
Cyber
Contested in all domains, increased lethality and the potential for overmatch
Hybrid strategies … regular, irregular, criminal, terrorists …attacking our weakness, mitigating our advantage; Systems Warfare, Preclusion, Sanctuary, Isolation and Reflexive Control.
Operations among populations in complex terrain…including dense urban areas
Increased speed of human interaction …rapid proliferation of capabilities, constantly co evolving
Potential to be Out-gunned, Out-ranged, Out-protected, Outdated, Out of Position …Out of Balance
Victory Starts Here!
6

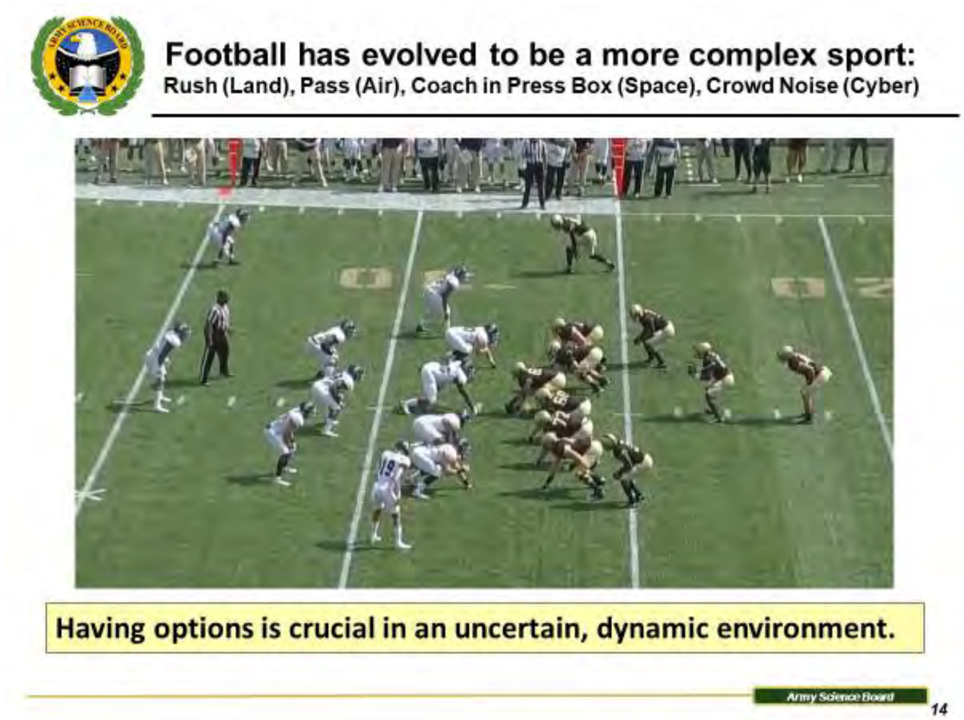


Agenda
• Introduction
– TOR
– Members
– Visits
– Background
• MDB Description
• MDB in PACOM
• MDB in EUCOM
• Observations
• Findings & Recommendations
Multi-domain battle provides commanders numerous options for executing simultaneous and sequential operations using surprise and speed of action to present multiple dilemmas to an adversary in order to gain physical and psychological advantages and influence and control over the multi-domain operational environment.*
* https://www.army.mil/standto/2017-03-08
Army Science Board
7


MDB Concept to Operations
We are Here
AUSA Announcement by GEN Perkins, Oct. 2016
White Paper signed by CSA and CMC, Jan. 2017
Concept v 0.5, April 2017
Final expected Fall 2017
Experiment, Modeling, Exercise
Multi-Service Concept, Date TBD
Doctrine, TBD
Training, TBD
Operations, TBD
Integrated development of MDB Concepts and Doctrine is a work in progress and will require JIM participation.
Army Science Board
8


Key MDB 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.
Army Science Board
12


Increasing Operational Options
Single Domain
(Kill Chain)
Multi-Domain
(Kill Matrix)
Find
Fix
Track
Target
Engage
Assess
Cyber
Air
Space
Land
Sea
Exploit all five domains to achieve much better outcomes in the future.
Army Science Board
13


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.
Army Science Board
14

MDB Study Considerations

Context:

- Exploiting capabilities in multiple domains is not without precedent (e.g., Desert Storm – AirLand Battle plus "First Space War").
- MDB will enable innovative ways to integrate overall capabilities.
- MDB is based on the idea that integrated Joint/multinational capabilities can be extended into and across all domains, which can currently be contested by the adversary.

Geographic emphasis:

- Pacific and Europe feature:
  - A2/AD
  - Cyber/Networks
  - Megacities
- Pacific has more Navy involvement; Europe more Army

Army Science Board 15

Agenda

- Introduction
  - TOR
  - Members
  - Visits
  - Background
- MDB Description
- MDB in PACOM
- MDB in EUCOM
- Observations
- Findings & Recommendations

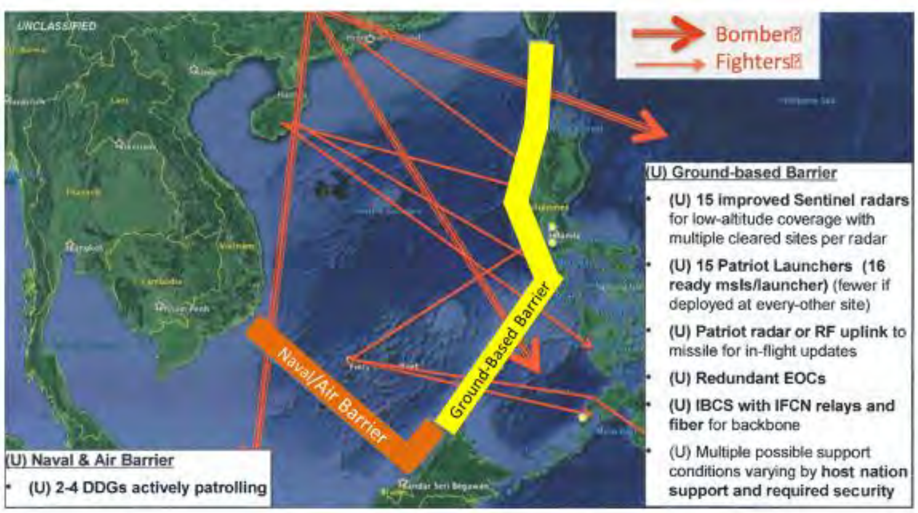
Army Science Board 16

China's Zones of Emerging Geo-Strategic Dominance

- **Assuring military dominance in the "First Island Chain"**
- **Gaining military dominance in the "Second Island Chain"**

Source: Peter Wilson at Joint Staff World Order Futures Seminar,
Applied Physics Laboratory, Dec 2016

A "Barrier Defense" Could Significantly Complicate Adversary Plans



RAND 18

PACOM Efforts in MDB

Maj. Gen. Yoo, CG SOCPAC | GEN O'Shaugnessy, CMDR PACAF | ADM Swift, CDR USPACFLT | GEN Brown, CG USARPAC | GEN Okabe, Chief Ground Staff Japan SDF | GEN Perkins, CG TRADOC

- **All Services** are participating in MDB exercises in **PACOM**
- Pacific partners are also participating (e.g., Japanese anti-ship from land will play)

Army Science Board 19

Allied View

"Unilateral action has gone the way of the dodo."

Brigadier Paul M Nothard, Commander 17th Combat Service Support Brigade, Australian Army, in presentation at LANPAC Symposium May 2017

MDB way forward is Joint, Interorganizational and Multinational

Army Science Board 20

Agenda

- Introduction
  - TOR
  - Members
  - Visits
  - Background
- MDB Description
- MDB in PACOM
- MDB in EUCOM
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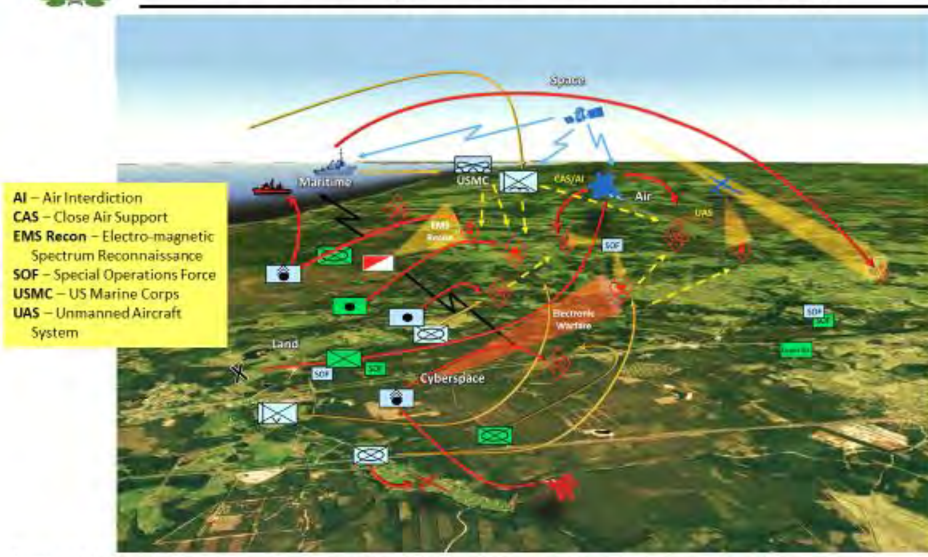
Army Science Board 21

TRADOC MDB Concept: *"Achieving Cross-Domain Synergy"*



Source: Multi-Domain Battle, Driving Change to Win in the Future, GEN Perkins, Military Review Jul-Aug 2017

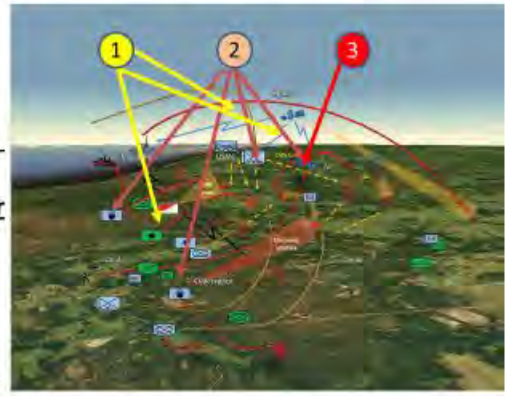
Army Science Board 22

ASB Example Mission: Destroy SS-26 Protected by S-400

1 Characterize and Locate A2/ AD
- C - Insert EMS Recon
- A - Stimulate A2 and C2 systems
- S - Time with ELINT satellite pass – approximate geo-locate A2 assets
- S - Cue IMINT resource accurate geo-locate A2 and AD systems

2 Negate A2 Assets – Create Corridor
- C - EMS Recon analyzes AD and C2 nets – inserts denial of service
- A, L - AH-64 and ATACMS attack AD launchers within range
- A, M - F-15s launch JASSMs and Navy assets launch Tomahawks at S-400 launchers/ radar

3 Destroy AD Assets
- A - F-35s pass through open AD corridor and destroy SS-26 launchers in zone



Air, space, cyber, and maritime domains, as supporting and supported by the land domain, results in mission success - MDB

Land	Maritime	Air	Cyber	Space

Army Science Board 26

Observations Regarding MDB Example

MDB Enablers – Future Fight:	What If's:	MDB Flexible Response:
• Space assets leveraged for deep fight - geo-locates threat A2/AD	• Key space assets were not available?	• Develop and have ready to launch a mini-satellite and/or UAS constellation
• Cyber used to characterize A2 & C2 networks & insert DoS	• Cyber 'denial of service' did not happen?	• Have a EW jamming element ready to jam surveillance radars
• Long range fires enables destruction of both A2 & AD	• F-15 w/ JASSM were not available?	• Have USN submarine launched Tomahawk missile as ready back-up
• Corridor enables freedom of action for AF and Navy	• F-35 was not available?	• Have long range fires, coupled with long range ISR ready to fire

MDB gives the commander a playbook to address tactical situations as they arise.

Land	Maritime	Air	Cyber	Space

Army Science Board 27

Agenda

- Introduction
  - TOR
  - Members
  - Visits
  - Background
- MDB Description
- MDB in PACOM
- MDB in EUCOM
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- Findings & Recommendations

Army Science Board 28

Study Observations

- 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 **rate of change of technology and society.**
- Key MDB study themes are need for: more **operational options,** greater **integration,** realistic **experimentation** and greater **speed.**
- Multi-domain operations have been conducted for years in various forms, primarily against non-peer competitors with **little contesting in the global commons**.
- MDB presents an opportunity to overcome the advantages of peer competitors by **leveraging, synchronizing and integrating** Joint, Interorganizational, and Multinational (**JIM**) entities.
  - Long-term success will depend on several factors:
    - The emergence of MDB architectural concepts
    - Clarification of the specific operational problems MDB can solve
    - Consensus on the value MDB brings to bear on pressing security challenges
- Extensive activity is ongoing to advance the MDB concept.
  - **Multi-Service** concept to begin early FY18 (Other Services have begun exploration of multi-domain operations)
  - **DSB** is beginning a Multi-Domain Effects study
- **Previous ASB studies** provide insight to MDB.

Army Science Board 29

MDB Attributes

MDB Challenges

External: Peer Competitors
- A2/AD
- Range of Fires
- Distance & Time
- Networks

Internal
- Organizational authorities
- Integration & Processes

Characteristics

↑ Speed
Agility
Flexibility
Options
Dilemmas
Integration

↓ Size, weight, cost
Sustainment burden

Results from Previous Studies
- Robotics (multi-domain)
- Autonomy
- Miniaturization
- AI
- Cyber, EW, EMS
- Survivability/Lethality
- Big Data
- Role of People

Battlefield Outcome: Win
- More Operational Options
- Overmatch

Army Science Board 30

Previous ASB Studies that Provide Insights

2013
- Army Science and Technology (S&T) Essential Core Competencies (**S&T**)

2014
- Decisive Army Strategic and Expeditionary Maneuver (**Maneuver**)
- Army Air and Missile Defense Electronic Warfare Assessment (**EW**)

2015
- Future of Army Aviation (**Aviation**)
- Army Cyber at the Tactical Edge (**Cyber**)
- Human Interaction and Behavioral Enhancement (**Social Media**)

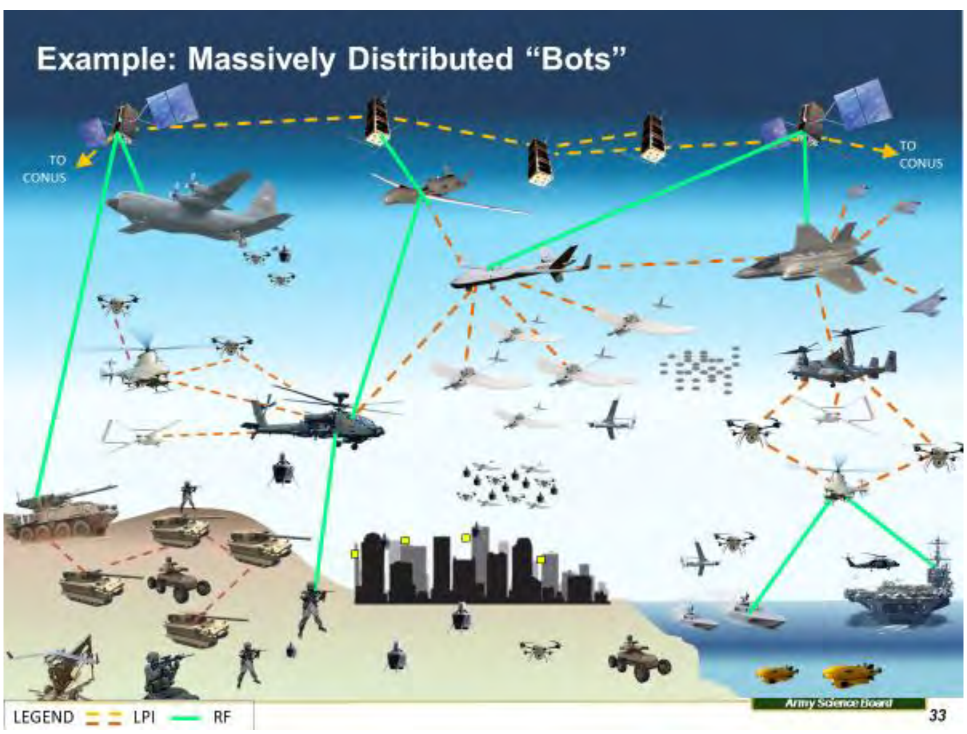
2016
- Future Armor/Anti-Armor Competition (**Armor**)
- Countering Enemy Indirect Fires, Target Acquisition Using Unmanned Aerial Systems, and Offensive Cyber/Electronic Warfare Capabilities (**C-IDF**)
- Robotic and Autonomous Systems-of-Systems Architecture (**RAS**)
- The Military Benefits and Risks of the Internet of Things (**IoT**)
- Disruptive Innovative Concepts for the Future Army **(Integration)**

Army Science Board 31

Examples of Technology Critical to MDB

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)	Swarms of multi-domain autonomous robots (100:1)
A2/AD - Long-Range 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 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

Army Science Board 32



The Massively Distributed "Bots" Construct

- Leverages technology advances in all domains
  - MUM-T (unmanned systems performing various functions including C4ISR, lethality, deception, logistics, etc.)
  - Autonomy, AI, and decision-making tools
  - Self-forming modular C4 networks
- Increases operational options
  - Greater speed, agility and flexibility
  - Integration of operations in the contested environment
  - High/low mix with robust characteristics in degraded environments
- Enables winning in a contested and dynamic environment through improved battlefield outcomes

Army Science Board 34

Agenda

- Introduction
  - TOR
  - Members
  - Visits
  - Background
- MDB Description
- MDB in PACOM
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- ➡ Findings & Recommendations

Army Science Board 35

Findings (1 of 4)

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).

Army Science Board 36

Findings (2 of 4)

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).

Army Science Board 37

Findings (3 of 4)

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.

Army Science Board 38

Findings (4 of 4)

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

Army Science Board 39

Recommendations (1 of 3)

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.

Army Science Board 40

Recommendations (2 of 3)

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.

Army Science Board 41

Recommendations (3 of 3)

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.

Army Science Board 42

ASB MDB QED

Army Science Board 43

APPENDIX F: GLOSSARY OF TERMS, ABBREVIATIONS AND ACRONYMS

A2	Anti-Access
A2/AD	Anti-Access/Area Denial
ABCT	Armored Brigade Combat Team
AD	Air Defense or Area Denial
ADA	Air Defense Artillery
AI	Artificial Intelligence
AMD	Air and Missile Defense
AOR	Area of Responsibility
APS	Active Protect System
ARCIC	Army Capabilities Integration Center (part of TRADOC)
ARCV	Armed Robotic Combat Vehicle
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASB	Army Science Board
ASM	Anti-ship missile
ATACMS	Army Tactical Missile System
AUSA	Association of the U.S. Army
AWC	Army War College (Carlisle, PA)
BCT	Brigade Combat Team
BG	Brigadier General (1-star)
BTG	Brigade Tactical Group
C-IDF	Countering Indirect Fires
C2	Command and Control
C2BMC	Command and Control, Battle Management, and Communications
C3	Command, Control, Communications
C4	Command, Control, Communications, Computers
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CAA	Center for Army Analysis
CAC	Combined Arms Center (Ft Leavenworth)
CAS	Close Air Support
CCOE	Cyber Center of Excellence (Ft Gordon)
CERDEC	Communications-Electronics Research, Development and Engineering Center
CG	Commanding General
CMC	Commandant of the Marine Corps
COE	Center of Excellence
COL	Colonel (Army)
CONOPS	Concept of Operations
CONUS	Continental United States
CP	Command Post
CSA	Chief of Staff of the Army
CSAC	Chip Scale Atomic Clock
CTC	Combat Training Center

DARPA	Defense Advanced Research Projects Agency
DE	Directed Energy (RF or Laser)
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership & Education, Personnel, Facilities
DPICM	Dual Purpose Improved Conventional Munition
DSB	Defense Science Board
ELINT	Electronic Intelligence
EMP	Electromagnetic Pulse
EMS	electromagnetic spectrum
EO/IR	Electro-Optic/Infrared
EUCOM	Europe Command
EW	Electronic Warfare
FA	Field Artllery
GC	Global Commons
GEN	General (4-star)
GO	General Officer
GPS	Global Positioning System
HARM	High-Speed Anti-Radiation Missile
HE	High Explosive
HQDA	headquarters Department of the Army
HVT	High Value Target
IAD	Integrated Air Defense
IADS	Integrated Air Defense System
IBCS	Integrated Air and Missile Defense Battle Command System
IBCT	Infantry Brigade Combat Team
IDA	Institute for Defense Analyses
IFPC	Indirect Fire Protection Capability
IMINT	Imaging Intelligence
INS	Inertial Navigation System
IoT	Internet of Things
ISR	Intelligence, Surveillance, and Reconnaissance
JACD	Joint and Army Concepts Division (TRADOC)
JAM-GC	Joint Concept for Access and Maneuver in the Global Commons
JASSM	Joint Air-to-Surface Standoff Missile (AGM-158)
JCEO	Joint Concept for Entry Operations
JCIC	Joint Concept for Integrated Campaigning
JCS	Joint Chiefs of Staff
JIM	Joint, Interorganizational and Multinational (or Interagency)
JOAC	Joint Operational Access Concept
LANPAC	Land Forces in the Pacific (AUSA conference)
LEO	Low Earth Orbit
LOC	Lines of Communication
LPI	Low Probability of Intercept

LRF	Laser Range Finder
LTC	Lieutenant Colonel (Army)
LTG	Lieutenant General (3-star)
MBSE	Model-based System Engineering
MCCDC	Marine Corps Combat Development Command
MCCOE	Mission Command Center of Excellence (Ft Leavenworth)
MCOE	Maneuver Center of Excellence (Ft Benning)
MDB	Multi-Domain Battle
MEU	Marine Expeditionary Unit
MG	Major General (2-star)
MLRS	Multiple Launch Rocket System
MTI	Moving Target Indicator
MUM-T	Manned-Unmanned Teaming
NATO	North Atlantic Treaty Organization
NBC	Nuclear/Biological/Chemical
NDU	National Defense University
OE	Operational Environment
OODA	Observe-Orient-Decide-Act
OUSD-P	Office of the Undersecretary of Defense - Policy
PACAF	Pacific Air Forces (USAF)
PACOM	Pacific Command
PEO-STRI	Program Executive Office for Simulation, Training, and Instrumentation
PM	Program Manager
PNT	Positioning, Navigation, and Timing
R&D	Research and Development
RAM	Rocket, Artillery, and Mortar
RAS	Robotic and Autonomous Systems
RDECOM	Research, Development, and Engineering Command (Army)
RF	Radio Frequency
S&T	Science and Technology
SA	Situational Awareness
SAM	Surface-to-Air Missile
SBCT	Stryker Brigade Combat Team
SEAD	Suppression of Enemy Air Defense
SES	Senior Executive Service
SIGINT	Signals Intelligence
SOF	Special Operations Force
STRATCOM	Strategic Command
TBM	Theater Ballistic Missile
TOR	Terms of Reference
TRAC	TRADOC Analysis Center
TRADOC	Training and Doctrine Command (Army)
TRISA	TRADOC G-2 Intelligence Support Activity
TTP	Tactics, Techniques, and Procedures

UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
USAREUR	U.S. Army Europe
USARPAC	U.S. Army Pacific
USASOC	U.S. Army Special Operations Command
WME	Weapons of Mass Effect

APPENDIX G: BIBLIOGRAPHY

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