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EXPLOITING ARTIFICIAL INTELLIGENCE AND AUTONOMOUS SYSTEMS TO IMPLEMENT DECISION-CENTRIC OPERATIONS

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Executive Summary

The United States is increasingly engaged in a long-term competition with the People's Republic of China (PRC) and the Russian Federation—a competition in which U.S. defense leaders and experts argue the U.S. military is falling behind technologically and operationally.[1] To regain its advantage, the Department of Defense (DoD) is pursuing new defense strategies and operational concepts designed to improve U.S. military capability by realigning defense posture and better integrating actions between air, land, sea, space, and cyberspace domains.[2] Implementation of these new approaches has led the U.S. government to increase DoD research and development (R&D) spending to levels not seen since the Second World War, accounting for inflation.[3]

Despite these efforts, the U.S. military may be unable to gain and maintain superiority over its great power competitors by simply using improved versions of today's forces to conduct modest variations on existing tactics. The capabilities DoD developed to help win the Cold War—including stealth aircraft, precision weapons, and long-range communications networks—have proliferated to other militaries. Potential adversaries have likewise observed U.S. operations during post-Cold War conflicts in Kosovo, Iraq, and Afghanistan and adapted their operational concepts accordingly.[4] As a result, U.S. military leaders acknowledge any future advantage U.S. forces gain under these circumstances may be narrow and fleeting.[5] Moreover, sustaining an advantage using only better versions of today's capabilities and tactics will be increasingly costly.

1 Paul Sonne and Shane Harris, "U.S. Military Edge Has Eroded to 'A Dangerous Degree,' Study for Congress Finds," *The Washington Post*, November 14, 2018.

2 Sydney J. Freedberg Jr., "Services Debate Multi-Domain: 'Battle' Or 'Operations'," *Breaking Defense,* April 10, 2018.

3 David Vergun, "DOD Leaders Make Case to Congress for Budget Request," *DoD News Service*, March 12, 2019, available at https://www.defense.gov/explore/story/Article/1782973/dod-leaders-make-case-to-congress-for-budget-request/.

4 David Ochmanek, RAND Corporation, "Restoring the Power Projection Capabilities of the U.S. Armed Forces," testimony to the Senate Armed Services Committee, February 16, 2017, available at https://www.rand.org/pubs/testimonies/CT464.html.

5 John Richardson, *A Design for Maintaining Maritime Superiority* (Washington, DC: U.S. Navy, 2018), p. 17, available at https://www.navy.mil/navydata/people/cno/Richardson/Resource/Design_2.0.pdf.

The Need for a New Warfighting Approach

Instead of competing with other great powers using capabilities and operational concepts that have already proliferated to adversaries, the U.S. military should consider new approaches to warfare that could lead to a prolonged advantage. During the Cold War, for example, the United States was able to combine prominent emerging technologies with new operational concepts to overcome the numerical superiority of Soviet forces, first with nuclear weapons and later with precision weapons and stealth.[6]

Today, the most significant operational challenges facing U.S. forces include the long-range sensor and precision weapons networks fielded by the Chinese and Russian militaries. China's People's Liberation Army (PLA) employs these capabilities as part of a comprehensive system of systems (SoS) designed to attack perceived vulnerabilities in U.S. and allied forces. The PLA and Russian Armed Forces complement their long-range precision weapons and sensors with proxy and paramilitary forces, which they use to enact "gray zone" tactics to gain territory and influence by contesting disputed territories or destabilizing neighboring countries.[7]

Countering the Chinese or Russian operational approaches will require that U.S. and allied militaries improve their ability to survive and pursue their objectives at various levels of escalation. Today, the most effective U.S. force packages combine multi-mission units and platforms into relatively large formations such as Army Brigade Combat Teams (BCT), Marine Expeditionary Units (MEU), or Navy Carrier Strike Groups (CSG). These units are vulnerable due to their size and aggregation, which constrains their operational flexibility and increases their detectability. Moreover, the size of these force packages risks unduly escalating a confrontation and could make the U.S. deployed force posture fiscally unsustainable.[8]

Although new DoD concepts such as Distributed Maritime Operations (DMO), Multidomain Operations (MDO), and Expeditionary Advanced Base Operations (EABO) emphasize more distributed formations, DoD's investments still prioritize relatively small numbers of multi-mission platforms and troop formations that lack the numbers or decision support tools to enable distributed operations.[9] U.S. force packages also tend to aggregate multi-mission units so they can provide mutually supporting defenses, coordinate large volumes of offensive fires, and gain sustainment and management efficiencies.

6 Robert Martinage, *Toward a New Offset Strategy: Exploiting U.S. Long-Term Advantages to Restore U.S. Global Power Projection Capability* (Washington, DC: Center for Strategic and Budgetary Assessments, 2014), pp. 5–16.

7 James Mattis, *Summary of the 2018 National Defense Strategy of the United States of America* (Washington, DC: DoD, 2018), p. 7, available at https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

8 The escalation and dynamics imposed by Chinese and Russian militaries' combination of long-range precision weapons with gray zone tactics are described in more detail in Bryan Clark, Mark Gunzinger, and Jesse Sloman, *Winning in the Gray Zone: Using Electromagnetic Warfare to Regain Escalation Dominance* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

9 The FY 2020 DoD budget does not significantly increase the number of units.

The design of U.S. military units reflects an attrition-centric view of warfare in which the goal is achieving victory by destroying enough of the enemy that it can no longer fight. For example, the U.S. military's operations during the last two decades have increasingly relied on killing or capturing terrorists and insurgents rather than denying enemies the benefits of their aggression.[10] To better address the operational challenges presented by great power competitors, this study proposes that DoD embrace a new theory of victory and operational concepts that focus on making faster and better decisions than adversaries, rather than attrition.

Instead of destroying an adversary's forces until it can no longer fight or succeed, a decision-centric approach to warfare would impose multiple dilemmas on an enemy to prevent it from achieving its objectives. Classical maneuver warfare, for example, is designed to *dislocate* an enemy's offensive operations through delay or degradation and *disrupt* its centers of gravity, such as sustainment or command and control (C2).[11] This can be viewed as attacking the cohesion of an adversary battle network.[12]

The current U.S. military would be constrained in its ability to execute decision-centric and maneuver warfare. Because of their cost, multi-mission platforms are not numerous enough to achieve sufficient distribution or diversity of presentations to impose multiple operational dilemmas on a great power adversary. This cost and scarcity also require that multi-mission platforms and troop formations be protected, further reducing the flexibility of U.S. force packages.

The number of dilemmas and speed at which U.S. forces can impose them is likewise constrained by the reliance of U.S. commanders on theater-wide C2 structures. The range of environments and situations at the theater level limits the ability of commanders to employ automated decision aids, slowing decision-making to the speed of a commander's planning staff. Moreover, communications at theater ranges are likely to be contested, reducing the ability of theater commanders to dynamically manage forces in an effort to implement maneuver warfare.

As in the Cold War, DoD could exploit the emerging generation of technologies to overcome the challenges that U.S. forces would face in implementing new operational concepts. During the late Cold War, stealth, guided weapons, and communications networks were the technologies that enabled the shift to penetrating precision strike operations. Today, the most prominent emerging technologies are artificial intelligence (AI) and autonomous systems, which are being used by DoD merely to speed up or automate operations already conducted by humans.[13] These technologies could instead be the foundation of a decision-centric approach

10 Anthony Cordesman, *Terrorism: U.S. Strategy and the Trends in Its "Wars" on Terrorism* (Washington, DC: Center for Strategic and International Studies, 2018).

11 Robert Leonhard, *The Art of Maneuver: Maneuver Warfare Theory and AirLand Battle* (New York: Ballantine Books, 1991), pp. 66–74.

12 Tiago Cavalcanti, Chryssi Giannitsarou, and Charles R. Johnson, "Network Cohesion," *Economic Theory* 64, no. 1, 2017.

13 "Gartner Identifies Top 10 Data and Analytics Technology Trends for 2019," press release, Gartner, February 18, 2019.

to warfare. For example, autonomous systems could enable a more disaggregated force design that makes U.S. military units and platforms more numerous and recomposable; AI could empower decision support tools that enable commanders to manage rapid and complex operations.

The Shift to Decision-Centric Warfare

Decision-centric warfare is intended to enable faster and more effective decisions by U.S. commanders while also degrading the quality and speed of adversary decision-making. The focus on both U.S. and adversary decision-making distinguishes decision-centric warfare from preceding concepts such as Network-Centric Warfare, which focused on improving U.S. military decision-making by centralizing it.[14]

Network-Centric Warfare relies on theater commanders with unfettered situational awareness over wide areas and the ability to communicate with all forces under their command. Centralized decision-making, however, will likely be neither possible nor desirable during future conflicts in highly contested environments. Improving adversary electronic warfare (EW) and other counter-C2 and intelligence, surveillance, and reconnaissance (C2ISR) capabilities will reduce the ability of U.S. commanders to understand or communicate across theaters. These actions will constrain the ability of U.S. commanders to gain awareness or exert control over large groups of U.S. forces.

Whereas Network-Centric Warfare assumes a high degree of clarity and control, decision-centric warfare embraces the fog and friction inherent in military conflict. Decision-centric warfare improves the adaptability and survivability of U.S. forces by leveraging distributed formations, dynamic composition and recomposition, reductions in electronic emissions, and counter-C2ISR actions to increase the complexity and uncertainty an adversary would perceive regarding U.S. military operations and degrade the decision-making of opposing commanders.[15]

14 Arthur K. Cebrowski and John H. Garstka, "Network-Centric Warfare: Its Origin and Future," *Proceedings,* January 1998, p. 1139, available at https://www.usni.org/magazines/proceedings/1998/january/network-centric-warfare-its-origin-and-future.

15 These approaches are described in operational concepts under development by U.S. military services, including Distributed Maritime Operations, Electromagnetic Maneuver Warfare, Multi-Domain Operations, and Expeditionary Advanced Base Operations. See Sydney J. Freedberg Jr., "Navy Forges New EW Strategy: Electromagnetic Maneuver Warfare," *Breaking Defense*, October 10, 2014; Navy Warfare Development Command, "CNO Visits Navy Warfare Development Command," *Navy News Service*, April 13, 2017, available at https://www.navy.mil/submit/display.asp?story_id=99893; and Christopher H. Popa et al., *Distributed Maritime Operations and Unmanned Systems Tactical Employment* (Monterey, CA: Naval Postgraduate School, 2018), available at https://apps.dtic.mil/docs/citations/AD1060065; U.S. Army Training and Doctrine Command (TRADOC), *The Army in Multi-Domain Operations 2028* (Ft. Eustis, VA: U.S. Army, 2018), pp. 32–44, available at https://www.tradoc.army.mil/Portals/14/Documents/MDO/TP525-3-1_30Nov2018.pdf; and "Expeditionary Advanced Base Operations," Marine Concepts and Programs, U.S. Marine Corps, available at https://www.candp.marines.mil/Concepts/Subordinate-Operating-Concepts/Expeditionary-Advanced-Base-Operations/.

The two most significant operational challenges that arise with decision-centric warfare are distributing and obscuring the disposition and intent of U.S. forces while sustaining the ability of U.S. commanders to make and enact prompt, effective decisions. Autonomous systems and AI could help address these challenges.

Autonomous systems to enable distribution and mission command

Autonomous systems such as unmanned vehicles and communications network management systems could help U.S. forces conduct more distributed operations. Unmanned vehicles could enable more distributed formations by disaggregating the capabilities of traditional multi-mission platforms and units into a larger number of less-multi-functional and less-expensive systems.

Decision-centric warfare assumes communications will be contested and often denied during military confrontations. Therefore, C2 relationships would follow communications availability, rather than attempting to build a communications architecture that supports a desired C2 structure, as in Network-Centric Warfare. Arguably, DoD's efforts to build communications networks have failed in part precisely because they sought to impose a desired C2 structure through a ubiquitous and resilient network that is possibly unachievable and unaffordable.

Under the C2 and communications (C3) approach used in decision-centric warfare, also called "Context-Centric C3," commanders would exert control over those forces with which they are in communication. Autonomous network controls would manage tradeoffs between bandwidth, reach, and latency to connect communications with the forces needed by a commander to accomplish his or her tasking and prevent the commander's span of control from becoming unmanageable. Forces that are too hard to reach or unnecessary for required tasks would be left out of the commander's forces.

AI-enabled decision support

The U.S. military describes the concept of subordinate leaders taking initiative during independent operations, including when communications are lost with senior leaders, as "Mission Command." As currently practiced, however, Mission Command would undermine the effort to gain a decision advantage over adversaries. Junior commanders will not have a planning staff to assist in managing or operating forces under their command. As a result, they could make poor decisions or fall back on habitual or doctrinal tactics that will be more predictable to an adversary.

Decision-centric warfare would address the limitations of Mission Command with a new C2 structure combining human command with AI-enabled machine control. AI-enabled decision support tools would allow junior commanders to control distributed forces, adapt to environmental or adversary actions, and impose complexity on enemy decision-making. In this way, commanders would be able to execute Context-Centric C3.

Human command and machine control would leverage the respective strengths of humans and machines; humans provide flexibility and apply their creative insights, and machines provide speed and scale to improve the ability of U.S. forces to impose multiple dilemmas on adversaries. This approach would also accommodate the likely difficulties in fielding AI-enabled decision support systems. Human commanders would initially scrutinize and assess recommendations from machine control systems before issuing orders, allowing them to adjust or revise operational plans. Over time, as decision support tools improve and establish a history of effective performance, commanders may become more willing to accept machine recommendations.

Mosaic Warfare

DARPA's Mosaic Warfare concept offers one approach to implementing decision-centric warfare.[16] The central idea of Mosaic Warfare is to create adaptability for U.S. forces and complexity or uncertainty for the enemy through the rapid composition and recomposition of a more disaggregated U.S. military force using human command and machine control. Implementing Mosaic Warfare or other forms of decision-centric warfare will require substantial changes to U.S. force design and C2 processes.

Force Design

Today, U.S. forces consist predominantly of manned multi-mission units such as aircraft, ships, and troop formations that are self-contained, or monolithic, and incorporate their own sensors, C2 capabilities, and weapons or electronic combat systems. The relatively inflexible configuration of monolithic multi-mission units, as well as constraints on communications interoperability between different units, results in a given force package only being capable of executing a small variety of effects chains. This reduces the adaptability of the force, makes its operations more predictable, and limits the ability of U.S. forces to confuse an enemy as part of operational concepts focused on gaining a decision-making advantage.

DoD could better pursue decision-centric warfare by decomposing some of today's monolithic multi-mission units into a larger number of smaller elements with fewer functions that would be more composable. For example, a frigate and several unmanned surface vessels could replace a surface action group of three destroyers. A section of strike-fighters could be replaced by a strike-fighter acting as a C2ISR platform for a group of standoff missiles and sensor- and EW-equipped unmanned aerial vehicles (UAV). In a ground force, rather than having to rely on large troop formations, smaller units and subunits could be augmented with small and medium-sized unmanned ground vehicles (UGV) and/or UAVs to improve their self-defense, ISR, and logistics capability.

16 "Strategic Technology Office Outlines Vision for Mosaic Warfare," DARPA, August 4, 2017, available at https://www.darpa.mil/news-events/2017-08-04.

Fielding more disaggregated units would not require a wholesale replacement of traditional U.S. forces. Only a small fraction of monolithic units would need to be retired or canceled to enable a large number of smaller, less-multi-functional forces to be procured and fielded. A disaggregated force able to quickly compose and recompose itself could provide the U.S. military several advantages:

Easier incorporation of new technologies and tactics. Mosaic force elements with fewer functions would not be as highly integrated as multi-mission units. As a result, fewer modifications would be needed in a platform or troop formation to allow a new capability to be incorporated.

Greater adaptability for U.S. commanders. Disaggregated forces would be able to combine in a larger variety of ways to deliver effects compared to traditional monolithic platforms and troop formations.

Higher complexity for the adversary. An enemy would have more difficulty assessing distributed and disaggregated forces to determine U.S. intentions and effects chains.

Improved efficiency. Commanders would be able to more finely calibrate force packages composed of disaggregated units to match the capability and capacity needed for an operation as well as their desired risk level.

Wider span of action. The ability of a disaggregated force to be more finely calibrated to an operation could reduce unnecessary overmatch and enable it to be spread over a larger number of tasks.

Improved implementation of operational strategy. The larger number of simultaneous tasks, the improved capability and capacity calibration, and the larger portion of unmanned systems in a disaggregated force would better enable the force to conduct feints, simultaneous offensive and defensive actions, or high-risk/high-payoff missions. As a result, commanders could be better able to pursue their strategy.

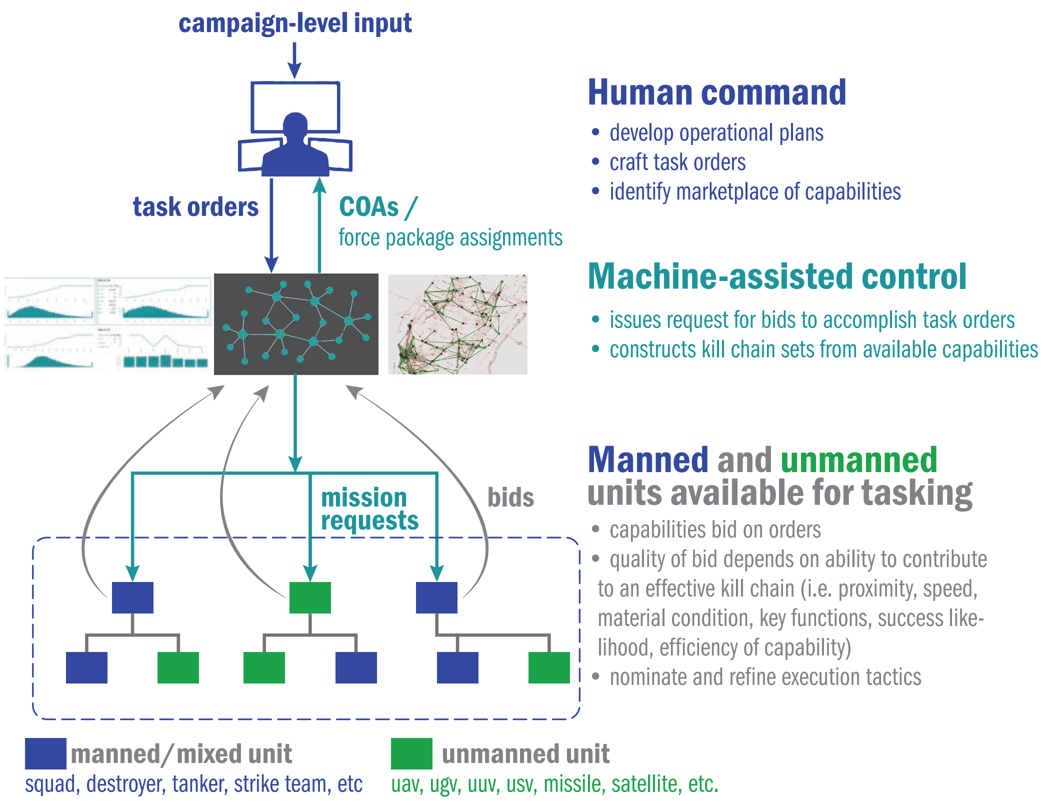
The force design needed for Mosaic Warfare will require new approaches to C2 that can compose and recompose large numbers of distributed units. C2 processes will also need to enable faster and more effective decisions while imposing complexity on enemy sensors and C2 processes.

C2 processes

Perhaps the most disruptive element of decision-centric warfare is how it would change U.S. military C2 processes. To fully exploit the value of a disaggregated and more composable force, Mosaic Warfare would rely on a combination of human command and machine control. If the force design were implemented without changing the associated C2 process, commanders and their staffs would have difficulty managing the larger number of elements in a disaggregated force compared to a traditional force. Without automated control systems, commanders would also be much less able to take advantage of the decision-centric force's composability in creating complexity for an adversary or recomposing in response to enemy defenses and countermeasures.

In the Mosaic Warfare C2 process, as shown in Figure 1, human commanders develop an overall approach to an operation that reflects their strategy and the intent provided by the commander's superiors. The commander directs the machine-enabled control system via a computer interface, assigning tasks to be completed and inputting estimates for the opposing force size and effectiveness. The machine-enabled control system implements Context-Centric C3 by identifying the forces in communication that could be tasked while maintaining the commander's span of control at a manageable size. The commander then chooses from the forces in communication the units to be made available for tasking.

FIGURE 1: EXEMPLARY CONTEXT-CENTRIC C3 APPROACH



Commanders direct tasks and identify forces available for tasking. The machine-enabled control system then develops a course of action (COA) to complete tasks within the commander's parameters and constraints.

Time will be an important consideration in the Context-Centric C3 approach. Units that commanders would need for their operations could move out of position, lose communications, or be destroyed while commanders decide which forces to make available for tasking and review recommended COAs. This delay, however, is likely to be much less than using a traditional planning process. This potential disadvantage could also be outweighed by the benefit to U.S. forces of imposing increased complexity on the opponent.

Insights from Wargames

To assess the validity of the theory behind decision-centric warfare and the practicality of Mosaic Warfare, CSBA conducted three wargames that compared the performance of U.S. Mosaic forces and C2 processes against traditional U.S. forces and C2 processes in plausible future great power and regional conflict scenarios.[17] The wargames were constructed to test five hypotheses regarding the feasibility and operational benefits of the Mosaic Warfare concept:

1. Commanders and planners can achieve trust in a machine-enabled control system;
2. Mosaic Warfare will increase the complexity of U.S. force packages and degrade adversary decision-making;
3. Mosaic Warfare will enable commanders to mount more simultaneous actions, creating additional complexity for adversaries and overwhelming their decision-making;
4. The Mosaic force design and C2 process will increase the speed of the U.S. force's decision-making, enabling commanders to better employ tempo; and
5. Mosaic Warfare will better enable U.S. commanders to implement their strategy than operations with a traditional force.

The workshops and wargames found evidence for many of the potential benefits hypothesized for Mosaic Warfare, with caveats. In addition to assumptions made about logistics, communications, and AI and autonomous systems, the game version of the machine-enabled control system lacked the modeling and simulation capabilities of a real control system. The characteristics of Mosaic force elements used by the control system were also extremely simplified. As a result, participants tended to accept the force packages and implied tactics in the control system's proposed COAs without significant question or analysis.

17 To increase the number of participants who gained experience with Mosaic force design and C2, the Mosaic force was divided between three Mosaic teams. The Traditional team was provided the whole traditional force.

Implementing Decision-Centric Warfare

Although the implementation of decision-centric warfare would not require replacing current U.S. military forces, DoD would need to change many of the processes it uses to develop military capabilities to field a disaggregated force. For example, requirements for elements in a highly composable force will not emerge in the form of gaps, because the machine-enabled control system will assemble bespoke force packages to conduct the commander's tasking as closely as possible for a particular situation. Instead of asking technologists to create solutions to fill specific and defined capability gaps, DoD will need to pursue new capabilities that enable improved performance in a wide range of potential situations and force configurations.

Despite the challenges of implementing decision-centric warfare, the U.S. military needs to adopt a new approach to deter aggression and succeed in future conflicts. The sources of advantage it drew upon in previous competitions are now readily available to America's competitors, and trends in warfare are reducing the value of the U.S. military's capability and experience in large-scale precision strike warfare. The next major arena of military competition could be information and decision-making, and the U.S. military could establish a prolonged advantage in it by harnessing emerging technologies for AI and autonomous systems.

New operational concepts will be essential for the U.S. military to fully exploit the potential of new technologies. If DoD continues to view AI and autonomous systems only as a means to improve its current operational approaches, the U.S. military could find itself the victim of disruption rather than imposing it on America's competitors.

CHAPTER 1

The Need for a New Approach to Warfare

The United States is increasingly engaged in a long-term competition with the People's Republic of China and the Russian Federation—a competition in which U.S. defense leaders and experts argue the U.S. military is falling behind technologically and operationally.[18] To regain its advantage, the DoD is pursuing new defense strategies and operational concepts designed to improve U.S. military capability by realigning defense posture and better integrating actions between air, land, sea, space, and cyberspace domains.[19] Implementation of these new approaches has led the U.S. government to increase DoD R&D spending to levels not seen since the Cold War, accounting for inflation.[20]

Despite these efforts, the U.S. military may be unable to gain and maintain superiority over its great power competitors by simply using improved versions of today's forces to conduct modest variations on existing tactics. The capabilities DoD developed to help win the Cold War—including stealth aircraft, precision weapons, and long-range communications networks—have proliferated to other militaries. Potential adversaries have likewise observed U.S. operations during post-Cold War conflicts in Kosovo, Iraq, and Afghanistan, and adapted their operational concepts accordingly.[21] As a result, U.S. military leaders acknowledge any future advantage U.S. forces gain under these circumstances may be narrow and fleeting.[22] Moreover, sustaining an advantage using only better versions of today's capabilities and tactics could become unaffordable.

18 Paul Sonne and Shane Harris, "U.S. Military Edge Has Eroded to 'A Dangerous Degree,' Study for Congress Finds," *The Washington Post*, November 14, 2018.

19 Freedberg, "Services Debate Multi-Domain."

20 David Vergun, "DOD Leaders Make Case to Congress for Budget Request," *DoD News Service*, March 12, 2019.

21 Ochmanek, "Restoring the Power Projection Capabilities of the U.S. Armed Forces."

22 John Richardson, *A Design for Maintaining Maritime Superiority*, version 2.0 (Washington, DC: U.S. Navy, 2018), p. 17, available at https://www.navy.mil/navydata/people/cno/Richardson/Resource/Design_2.0.pdf.

Instead of competing with other great powers using capabilities and operational concepts that have already proliferated to adversaries, the U.S. military should consider adopting new approaches to warfare that could lead to a prolonged advantage. During the Cold War, for example, the United States was able to combine prominent emerging technologies with new operational concepts to overcome the numerical superiority of Soviet forces, first with nuclear weapons and later with precision weapons and stealth.[23]

The most significant operational challenges facing U.S. forces today include the long-range sensor and precision weapons networks fielded by the Chinese and Russian militaries. The PLA employs these capabilities as part of a comprehensive SoS designed to attack perceived vulnerabilities in U.S. and allied forces. The PLA and Russian military also use their long-range weapons to help protect gray zone paramilitary operations in their near-abroad. Countering the Chinese or Russian operational approaches will require that U.S. and allied militaries improve their ability to survive and fight at different levels of escalation that are sustainable over the long term.

The U.S. military has responded to the growing precision weapons threat during the last three decades by deploying force packages that combine multi-mission units and platforms into relatively large formations such as Army BCTs, MEUs, or Navy CSGs. These formations aggregate forces to provide mutually supporting defenses, coordinate large volumes of offensive fires, and gain sustainment and management efficiencies. Despite their robust defenses, these units are increasingly vulnerable due precisely to their size and aggregation, which constrains their operational flexibility and increases their detectability. Moreover, their presence risks unduly escalating a confrontation and could make the U.S. deployed force posture fiscally unsustainable.[24]

The prioritization of fires and efficiency in current U.S. formations reflects an attrition-centric approach to warfare in which the objective is to destroy enough of the enemy that it can no longer fight. And although emerging DoD concepts such as Distributed Maritime Operations, Multidomain Operations, and Expeditionary Advanced Base Operations emphasize the use of distribution and deception, they still seek victory primarily through the destruction of the enemy.[25] Accordingly, DoD's most recent budgets still concentrate spending in relatively small

23 Martinage, *Toward a New Offset Strategy*, pp. 5–16.

24 The escalation and dynamics imposed by Chinese and Russian militaries' combination of long-range precision weapons with gray zone tactics are described in more detail in Clark, Gunzinger, and Sloman, *Winning in the Gray Zone*.

25 These approaches are described in operational concepts under development by U.S. military services, including Distributed Maritime Operations, Electromagnetic Maneuver Warfare, Multi-Domain Operations, and Expeditionary Advanced Base Operations. See Sydney J. Freedberg Jr., "Navy Forges New EW Strategy: Electromagnetic Maneuver Warfare," *Breaking Defense*, October 10, 2014; Navy Warfare Development Command, "CNO Visits Navy Warfare Development Command," *Navy News Service*, April 13, 2017; and Christopher H. Popa et al., *Distributed Maritime Operations and Unmanned Systems Tactical Employment* (Monterey, CA: Naval Postgraduate School, 2018), available at https://apps.dtic.mil/docs/citations/AD1060065; U.S. Army Training and Doctrine Command (TRADOC), *The Army in Multi-Domain Operations 2028* (Ft. Eustis, VA: U.S. Army, 2018), pp. 32–44, available at https://www.tradoc.army.mil/Portals/14/Documents/MDO/TP525-3-1_30Nov2018.pdf; and "Expeditionary Advanced Base Operations," Marine Concepts and Programs, U.S. Marine Corps, available at https://www.candp.marines.mil/Concepts/Subordinate-Operating-Concepts/Expeditionary-Advanced-Base-Operations/.

numbers of multi-mission platforms and troop formations that lack the numbers or decision support tools to enable distributed operations.[26] Furthermore, the U.S. military's operations during the last two decades have increasingly relied on killing or capturing terrorists and insurgents rather than denying enemies the benefits of their aggression.[27]

To better address the operational challenges presented by great power competitors, this study proposes that DoD embrace a new theory of victory and operational concepts that focus on making faster and better decisions than adversaries, rather than attrition. Instead of destroying an adversary's forces until it can no longer fight or succeed, a decision-centric approach to warfare would impose multiple dilemmas on an enemy to prevent it from achieving its objectives.[28]

Operational concepts focused on decision-making, like maneuver warfare, may also be more effective at deterrence than concepts that rely on attrition. An opponent can field more forces with better capabilities to counter an attrition-centric operational approach and subsequently gain the confidence to mount an offensive. The countermeasures needed to overcome the ability of U.S. military forces to impose dilemmas and create a complex operational picture are less straightforward. As a result, a potential aggressor facing a decision-centric military force may be more easily deterred than one facing an attrition-centric force.

The current U.S. military would be constrained in its ability to execute decision-centric and maneuver warfare. Because of their cost, multi-mission platforms are not numerous enough to achieve sufficient distribution or diversity of presentations to impose multiple operational dilemmas on a great power adversary. This cost and scarcity also require that multi-mission platforms and troop formations be protected, further reducing the flexibility possible when assembling groups of forces, or force packages.

The number of dilemmas and speed at which U.S. forces can impose them is likewise constrained by the reliance of U.S. commanders on theater-wide C2 structures. The range of environments and situations at the theater level limits the ability of commanders to employ automated decision aids, slowing decision-making to the speed of a commander's planning staff. Moreover, communications at theater ranges are likely to be contested, reducing the ability of theater commanders to dynamically manage forces in an effort to implement maneuver warfare.

26 For example, the FY 2020 DoD budget invests more than $100 billion in procurement of multi-mission manned ships and aircraft, about 20 times more what it spends on all development and procurement of smaller, unmanned systems. See Office of the Undersecretary of Defense (Comptroller)/Chief Financial Officer (OUSD[C]/CFO), *United States Department of Defense Fiscal Year 2020 Budget Request: Defense Budget Overview* (Washington, DC: DoD, March 2020), available at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2020/fy2020_Budget_Request_Overview_Book.pdf.

27 Cordesman, *Terrorism*.

28 By 'dilemma', we mean a circumstance which the adversary assesses all of their feasible choices as undesirable due to the potential for losses or because the option takes the adversary farther from it objective.

DoD will need to change its force design and C2 processes to fully exploit decision-centric warfare. Figure 2 graphically depicts how the report will describe this new warfighting approach and its implications. Chapter 1 highlights the challenges DoD will face if it attempts to continue competing with other great powers using its current warfighting concepts, force structure, and tactics. Chapter 2 argues there is an emerging shift in the conduct of military operations toward maneuver warfare and exploiting technologies for automation and AI to provide a decision-making advantage, enabling forces to more quickly impose a larger number of dilemmas on an opponent to deny success and degrade the ability to effectively counter-attack. This variation on maneuver warfare is characterized as decision-centric because its emphasis is on improving the speed and quality of decisions relative to the adversary, which would enable maneuver warfare to be conducted more effectively.

Chapter 3 describes the force design and C2 principles of an approach to decision-centric warfare. The central idea is to create adaptability for U.S. forces and complexity or uncertainty for the enemy through the rapid composition and recomposition of a more disaggregated and diverse U.S. military using human command and machine control. Decision-centric warfare would seek to create multiple simultaneous operational dilemmas for an opponent to address by making and enacting decisions faster than the adversary. Chapter 4 provides an evaluation of Mosaic Warfare that CSBA conducted through a series of wargames and highlights needed areas of future research. Chapter 5 ends the report by exploring the implications of Mosaic Warfare for DoD decision-making and planning processes.

This study explains the logic behind decision-centric approaches to warfare and provides some evidence for their potential effectiveness. The report and its supporting research are not intended to conclusively prove that Mosaic Warfare or other decision-centric concepts will enable the U.S. military to gain and maintain an enduring advantage. More research is needed to reach conclusions about its value in future military operations.

What is clear, however, is that DoD cannot remain on its current force development path and retain U.S. military superiority against other great powers within its anticipated fiscal constraints. A new approach to achieving military success will be needed. Emerging technologies for gathering, manipulating, and analyzing information may enable a decision-centric warfare approach that would improve deterrence and provide the U.S. military a superior position against its great power rivals.

FIGURE 2: RATIONALE BEHIND DECISION-CENTRIC WARFARE: OPERATIONAL AND INSTITUTIONAL IMPLICATIONS

Chapter 1. The need for a new approach to warfare

Motivation: A changing, multipolar world
Proliferation of technology, connectivity, information
Multipolar power competition with economic constraints

Chapter 2. A decision-centric approach to military operations

Attack adversary orientation
Shatter cohesion with dilemmas ***over*** Attriting targets
Deliberately instilled confusion ***over*** Stealth
Create optionality for blue = Create complexity for red

More decisions, faster
Scalability and speed ***over*** Optimality
Rapid, distributed action ***over*** Assured overmatch
AI and automation for speed, humans for context

New metrics for a new era
Anti-fragility ***over*** Invulnerability with effects webs
Virtual attrition ***over*** Actual attrition
Factorial feasible kill chains ***over*** Invincible systems

Design Principles

Chapter 3. Pursuing decision superiority through Mosaic Warfare

Force Design
Distributed ***over*** Co-located
Disagreggated ***over*** Monolithic and integrated
Heterogenous ***over*** Homogenous
More and smaller ***over*** Fewer and better
Single-function ***over*** Omni-function

Force Composition
Functional composition ***over*** Pre-architected system integration
Exposed functions (sense/decide/act) ***over*** Integrated capability
Just-in-time composition ***over*** Gap assessment and requirements

Command and Control
Context-centric ***over*** Network-centric
Local autonomy & initative ***over*** Central omniscience
Tempo and parallelism ***over*** Optimality

Information Exchange
Opportunistic ***over*** Assured
Ad-hoc interoperability ***over*** Mandated standards

Chapter 4. Assessing Mosaic Warfare

Hypotheses to test
Commanders will achieve trust in the Mosaic Warfare command & control scheme
Mosaic Warfare increases complexity in force packages and degrades enemy decision-making
Mosaic Warfare enables more simultaneous actions
Mosaic Warfare speeds U.S. decision-making
Mosaic Warfare enables better implementation of commander's strategy

Chapter 5. Institutional reform: changes needed to shift to a decision-centric approach to warfare and competition

Strategy
Decision-centric warfare ***over*** Attrition-centric warfare

Acquisition & Budget processes
Mission or concept-centric acquisition ***over*** Platform or system-centric structure

Requirements process
Concept-driven ***over*** Gap-driven
Stochastic ***over*** Deterministic

Doctrine and training
Mission command and autonomy ***over*** Centralization and uniformity

R&D process
Idea-centric ***over*** PM-driven requirements-centric

Today's Unsustainable Path

U.S. defense budgets have risen since DoD spending was cut in 2013 by the Budget Control Act (BCA) of 2011.[29] However, the United States will be hard-pressed to spend its way back to military superiority for several reasons: the geostrategic advantages possessed by its adversaries; future constraints on funding available for U.S. military R&D or procurement; a leveling of the technological playing field; and the need to engage in a long-term competition that is unlikely to be resolved in a short, decisive confrontation. These trends will likely make current U.S. plans unsustainable.

The following sections describe these challenges for the U.S. military and highlight how a decision-centric approach to warfare could help address them. Mitigating the major strategic, fiscal, and technical challenges facing DoD will be essential to enabling the U.S. military to compete more effectively over the long term with those of other great powers.

A geostrategic disadvantage

A fundamental strategic challenge facing the United States is the "home field" advantage that America's great power adversaries enjoy due to their proximity to potential military objectives such as Taiwan for China or the Baltic States for Russia. The Chinese and Russian governments have exploited this proximity to pursue a strategy focused on increasing territory and influence in their regions. They concentrate military deployments locally and establish sensor and precision weapons networks on their own soil that are able to threaten U.S. or allied forces up to hundreds of miles away. By establishing regional military superiority and seeking to delay intervention by U.S. and allied forces, these great power adversaries can threaten a rapid invasion or seizure and present the international community with a *fait accompli*. The Chinese and Russian governments may exploit this latent threat for additional leverage in their relationships with neighboring countries, some of which are U.S. allies.[30]

The geostrategic advantage enjoyed by China and Russia requires the U.S. military to adopt a new strategy for deterrence and warfighting. Since the end of the Cold War, the United States has, in effect, deterred regional powers like Iraq, Iran, and North Korea by threatening to reverse the results of aggression and potentially overthrow the aggressor's government. This approach was employed in Operations Desert Storm and Iraqi Freedom against Iraq and in Operation Enduring Freedom against Afghanistan; It has also been discussed as an approach to defeat North Korean aggression.[31]

29 Jeff Stein and Aaron Gregg, "U.S. Military Spending Set to Increase for Fifth Consecutive Year, Nearing Levels during Height of Iraq War," *The Washington Post,* April 18, 2019.

30 Defense Intelligence Agency (DIA), Russia Military Power: Building a Military to Support Great Power Aspirations (Washington, DC: DIA, 2017), p. 23..

31 Michael J. Mazarr et al., *The Korean Peninsula: Three Dangerous Scenarios* (Santa Monica, CA: RAND Corporation, 2018), p. 7.

Today, the threat of a U.S. military response only after limited objectives are achieved is unlikely to deter Chinese or Russian aggression. If a rapid Russian or Chinese invasion or seizure is successful, attempting to reverse the results would require U.S. forces to deploy under the threat of adversary precision weapons, rather than safely mobilize in adjacent countries as U.S. and allied forces did to prepare for Operation Desert Storm. U.S. forces would need to execute an extensive campaign to suppress enemy sensors, networks, and weapons launchers, followed by a counter-offensive of sufficient size to both defend U.S. forces in theater and attrite enemy forces. The resulting great power conflict would be economically disruptive, incur significant casualties, and could escalate to a nuclear confrontation. These factors would likely reduce diplomatic or military support for the operation among U.S. allies and partners.[32]

An unexecutable defense strategy

In response to these geostrategic disadvantages, the U.S. military shifted its operational approach from responding to aggression after the fact to denying, delaying, or degrading aggression when it occurs. The emphasis on denying aggression has significant implications for force posture, capabilities, and metrics. For example, U.S. forces operating closest to allies and adversaries would conduct day-to-day engagement and promptly counter enemy offensives. Forces deployed to the region but not in the immediate conflict area would augment first responders; surge forces based in the continental United States (CONUS) or other rear areas could be used as reinforcements.[33]

Unfortunately, current and planned U.S. forces will likely lack the capacity to support deterrence by denial. Slowing or stopping aggression instead of responding after the fact will require more forces operating forward using a rotational deployment model in which multiple units are needed to sustain one in a ready status where it can promptly reach the potential confrontation. For forces based in CONUS, the rotation would allow for rest, repair, and training in between deployments overseas. For forward-based units, the rotation may simply be between periods of rest and alert. DoD leaders argue the U.S. military needs to grow by up to 15 percent during the next decade to meet the capacity requirements of the new posture model.[34]

32 Elbridge Colby, "Hearing on Implementation of the National Defense Strategy," testimony before the Senate Armed Services Committee, January 29, 2019, available at https://www.armed-services.senate.gov/imo/media/doc/Colby_01-29-19.pdf; and Eric Edelman and Gary Roughead, *Providing for the Common Defense: The Assessment and Recommendations of the National Defense Strategy Commission* (Washington, DC: U.S. Institute of Peace, 2018), available at https://www.usip.org/sites/default/files/2018-11/providing-for-the-common-defense.pdf.

33 This is the approach described in the 2018 U.S. National Defense Strategy. In the strategy, forward forces are categorized as a "Contact Layer" and regional forces are called a "Blunt Layer." see Mattis, *Summary of the 2018 National Defense Strategy of the United States of America*, p. 7.

34 See Heather Wilson, "The Air Force We Need," *U.S. Air Force Public Affairs,* September 17, 2018, available at https://www.af.mil/News/Article-Display/Article/1635070/the-air-force-we-need-386-operational-squadrons/; Richard Spencer, "Secretary of the Navy Announces Need for 355-ship Navy," *Navy.mil*, December 16, 2016, available at https://www.navy.mil/submit/display.asp?story_id=98160; and Jen Judson, "Army Seeks $182 Billion in FY20 to Pave Way for Modernized Force," *Defense News*, March 12, 2019.

The planned U.S. force will likely also fall short in terms of capability. The design of current or planned U.S. platforms makes them difficult to reconfigure, the roles of different U.S. force elements are readily identifiable, and the communications links between them are detectable or can be inferred. As a result, adversary forces have fielded capabilities to rapidly disintegrate relatively static U.S. SoS architectures or defeat self-contained U.S. platforms. The PLA, for instance, designed its operational concept of System Destruction Warfare and its own SoS to attack the essential components and communications of known and anticipated U.S. capabilities. System Destruction Warfare is an important element of the PLA's overall approach to seek a *fait accompli* in future conflicts with neighboring countries.[35]

Under these conditions, U.S. forces deployed forward would require ships, aircraft, and troop formations that can fight while defending themselves against intense electronic or cyber warfare and large volumes of enemy precision weapons. Planned U.S. naval forces, ground troops, and forward land bases will probably lack sufficient defensive capacity to counter the precision weapons that opposing militaries could bring to bear in their near abroad. And if U.S. forces survive, they are unlikely to have sufficient offensive capacity remaining to attrite enough enemy forces to deny an act of aggression.[36]

An opportunity in maneuver warfare

Deterrence by denial depends on creating uncertainty in the mind of the adversary regarding its likelihood of success. The U.S. military could more effectively create this uncertainty and deter aggression by employing decision-centric approaches such as maneuver warfare. Two fundamental applications of maneuver warfare are *dislocation*, or preventing the enemy from reaching their objective at their intended time, and *disruption*, or attacking the enemy's center of gravity.[37] This can be viewed as attacking the cohesion of an adversary battle network.[38]

More disaggregated and composable forces would be better able than today's U.S. military to cause dislocation. They would have fewer readily identifiable nodes and would be more capable of reorganizing themselves to confuse enemy sensing or compensating for enemy actions such as the loss of a force element. The uncertainty of a more complex and recomposable posture could also degrade the ability of the enemy to identify and attack the key components or communications links of U.S. forces operating inside enemy weapons range. The adversary would either need to attack most or all of the U.S. force or take more time to understand the U.S. force disposition and tactics. Either approach would put the adversary at a disadvantage and enable U.S. forces to deny or delay aggression with smaller levels of force than needed with traditional forces and attrition-centric operational concepts.

35 Robert O. Work and Greg Grant, *Beating the Americans at their Own Game: An Offset Strategy with Chinese Characteristics* (Washington, DC: Center for a New American Security, 2019), p. 7.

36 David Ochmanek et al., *U.S. Military Capabilities and Forces for a Dangerous World* (Santa Monica, CA: RAND Corporation, 2017), pp. 8–19.

37 "Center of gravity" here refers to the critical vulnerability that is essential to the enemy's conduct of the particular campaign or operation in question. See Robert Leonhard, *The Art of Maneuver: Maneuver Warfare Theory and AirLand Battle* (New York: Ballantine Books, 1991), pp. 66–74.

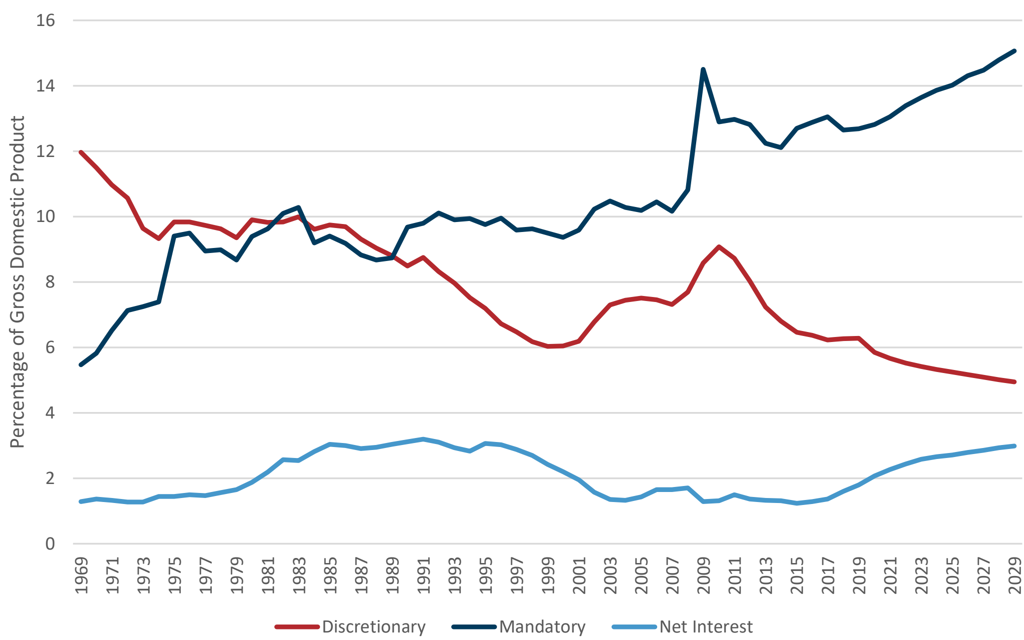
38 Cavalcanti, Giannitsarou, and Johnson, "Network Cohesion."

Composable forces may also improve the U.S military's ability to disrupt enemy operations using maneuver warfare. As will be discussed further in Chapters 4 and 5 of this study, the ability to calibrate the capability and capacity of more composable forces could enable the U.S. military to take more calculated risks, employ its forces with greater efficiency to execute more independent tasks, and employ tempo more effectively compared to today's U.S. forces.

Constrained funding

The U.S. government will likely have difficulty funding improved defense capacity and capability unless it changes U.S. force design. Although U.S. defense budgets are technically capped until 2021 by the BCA, a combination of temporary waivers and supplemental Overseas Contingency Operations (OCO) funding have allowed DoD spending, in inflation-adjusted terms, to reach its highest levels ever, despite the U.S. military not being involved in a major combat operation.[39] Some Congressional leaders oppose further defense budget growth, in part out of concern for rising costs to service U.S. federal debt and fund non-discretionary Medicare and Social Security benefits, as shown in Figure 3.[40]

FIGURE 3: FEDERAL DISCRETIONARY AND MANDATORY FUNDING AND DEFICIT INTEREST AS A PERCENTAGE OF GDP



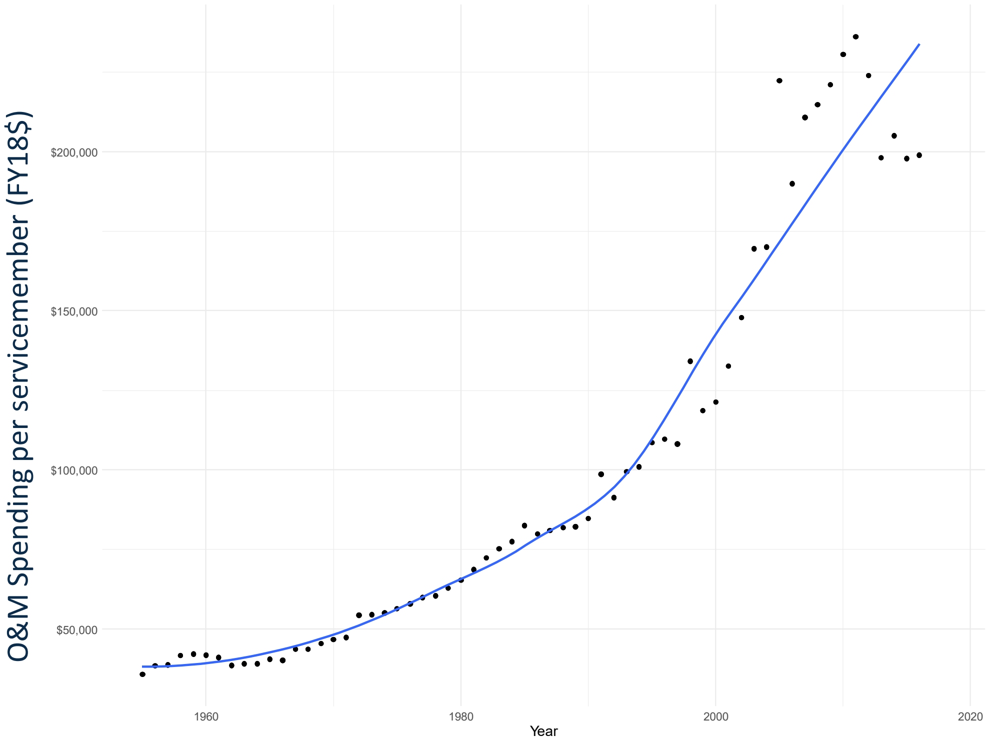
Costs to service the federal debt and support mandatory spending on social programs is predicted by the Congressional Budget Office (CBO) to crowd out discretionary spending, including that on Defense, during the next decade. See Congressional Budget Office (CBO), *The Budget and Economic Outlook: 2019 to 2029* (Washington, DC: CBO, 2019), p. 5, available at https://www.cbo.gov/publication/54918.

39 John Donnelly, "After Bitter Fight, Defense Budget Will Stay High," *Roll Call,* March 13, 2019.

40 Joe Gould, "Lawmakers Push and Pull over $750B Defense Policy Bill NDAA Top Line at HASC Markup," *Defense News,* June 13, 2019.

Within the defense budget, operations and maintenance (O&M) costs have risen sharply since the 1990s, as depicted in Figure 4. These increases were driven in part by the introduction of increasingly sophisticated combat systems and their incorporation into more highly integrated multi-mission platforms.[41] Replacement parts for new combat systems and platforms are more expensive than their predecessors, and repairs require more extensive interference removal, rewiring, and reprogramming compared to legacy capabilities.[42]

FIGURE 4: U.S. MILITARY O&M COSTS PER SERVICE MEMBER



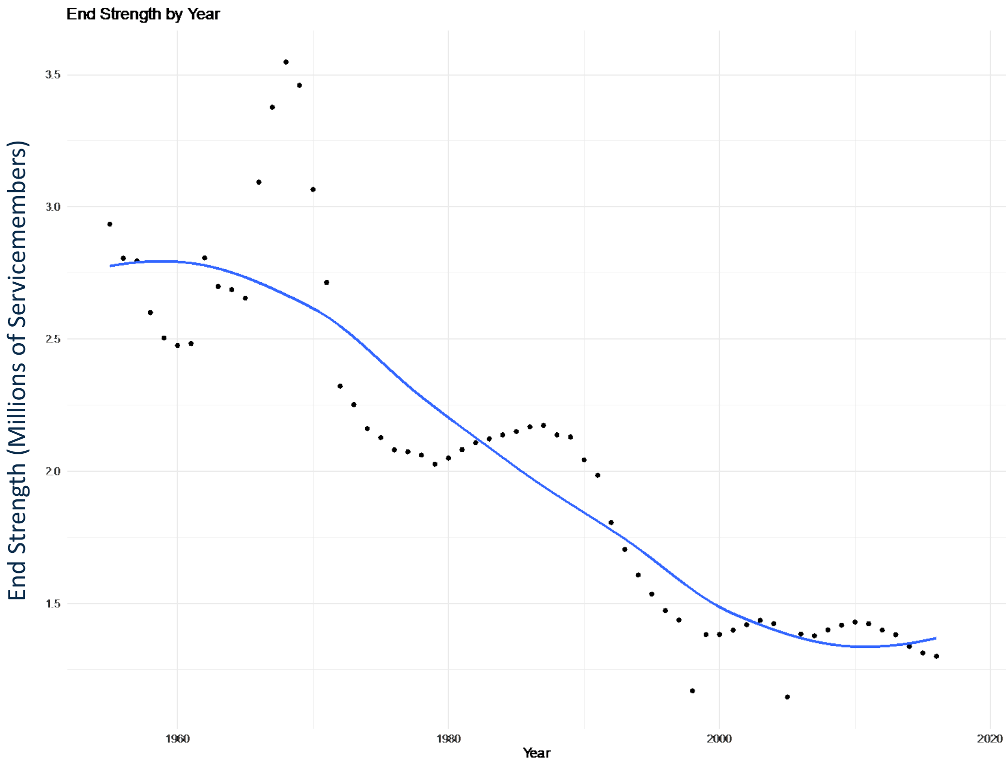
U.S. military operations and maintenance (O&M) costs are increasing for each platform or piece of equipment, as measured by O&M costs per service member. OUSD(C), *National Defense Budget Estimates for FY 2019*, Green Book (Washington, DC: DoD, April 2018), available at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2019/FY19_Green_Book.pdf; and "DoD Personnel, Workforce Reports & Publications," database, Defense Manpower Data Center (DMDC), accessed June 10, 2019, available at https://www.dmdc.osd.mil/appj/dwp/dwp_reports.jsp.

41 David A. Arthur, "The Increasing Costs of the Department of Defense," presentation, Congressional Budget Office, November 9, 2018, pp. 3–5, available at https://www.cbo.gov/system/files/2018-11/54688-presentation.pdf.

42 Robert Warren Button et al., *Assessment of Surface Ship Maintenance Requirements* (Santa Monica, CA: RAND Corporation, 2015), pp. 6–13; Bloomberg, "The Air Force Could Lose 590 F-35 Fighters Because It Can't Afford to Maintain Them," *Fortune*, March 28, 2018.

Compensation costs for each U.S. servicemember also increased dramatically after 2000 with the introduction of larger annual pay increases and new benefits such as Tricare For Life and the Post 9/11 GI Bill.[43] Due in part to increases in costs to buy, operate, maintain, and crew each platform and unit, the U.S. military shrank during the last two decades, as shown in Figure 5, despite large and steadily increasing defense budgets.[44]

FIGURE 5: TRENDS IN U.S. MILITARY END STRENGTH



The size of the U.S. military has been shrinking steadily since the Second World War. Recent increases only temporarily arrest this trend, but reductions are likely to continue as compensation and O&M costs continue to rise. "DoD Personnel, Workforce Reports & Publications," database, DMDC, accessed June 10, 2019; Kosiak, *Is the U.S. Military Getting Smaller and Older?* p. 2.

As challenges from great power adversaries intensify during the coming decade, the need for more robust defenses and improved offensive capabilities will likely require platforms and systems of even greater capability than today, which could further accelerate rising operations and support costs. Intensifying great power competition will also demand more highly skilled operators. Recruiting those workers could require further growth in compensation, especially

43 Mark Cancian, "The Impact of Rising Compensation Costs on Force Structure," *Joint Force Quarterly*, October 1, 2015; and Harrison Schramm, "Three Postcards From the Changing Face of Military Manpower," *USNI Proceedings*, January 2020.

44 Steve Kosiak, *Is the U.S. Military Getting Smaller and Older?* (Washington, DC: Center for a New American Security, 2017), p. 1.

in an increasingly competitive employment environment where a decreasing number of young people are eligible for military service.[45]

Growing costs to maintain and crew ships, aircraft, vehicles, and troop formations will constrain the resources needed to develop and procure the next generation of military capabilities. Increases in the overall defense budget, which compensated for increasing sustainment and personnel costs during the past decade, are unlikely to be as large or common in the coming decade as mandatory spending for social programs and debt servicing take a greater share of federal outlays.

A new approach to military operations could help DoD break the connection between increasing cost and improving U.S. force effectiveness. A concept that relies less on attrition and more on achieving superior decision-making could deter conflict by creating a more complex and adaptable force that is difficult for an enemy to suppress, as well as defeat enemy forces more effectively by attacking their operational centers of gravity. The composable military needed for a decision-centric operational concept would require individual force elements that are less multi-functional than those in today's U.S. forces, leading to more affordable units that would likely be less expensive to sustain over time.

A more level playing field

The U.S. military has enjoyed technological superiority over its rivals since the Cold War. Increasingly capable ships, aircraft, satellites, unmanned systems, and combat systems contributed to long-term success against the Soviet Union and the defeat of several regional or transnational powers during the last several decades. This edge is now eroding. The Chinese and Russian militaries have both fielded stealth aircraft, information networks, satellite sensing and communications constellations, and comprehensive air defense systems. These capabilities may be on par or better in some cases than their U.S. counterparts.[46] Going forward, commercial investment in the global technological base will likely continue to outstrip U.S. government spending, making the next generation of technologies more widely available.

Although its great power competitors have largely caught up in terms of technology, DoD could stay ahead by more quickly incorporating new technologies or systems into existing and planned platforms. Unfortunately, the U.S. military's multi-mission aircraft, combat vehicles, and ships use highly integrated designs to maximize sensor and payload capacity within a constrained space while providing operators the ability to centrally control and monitor

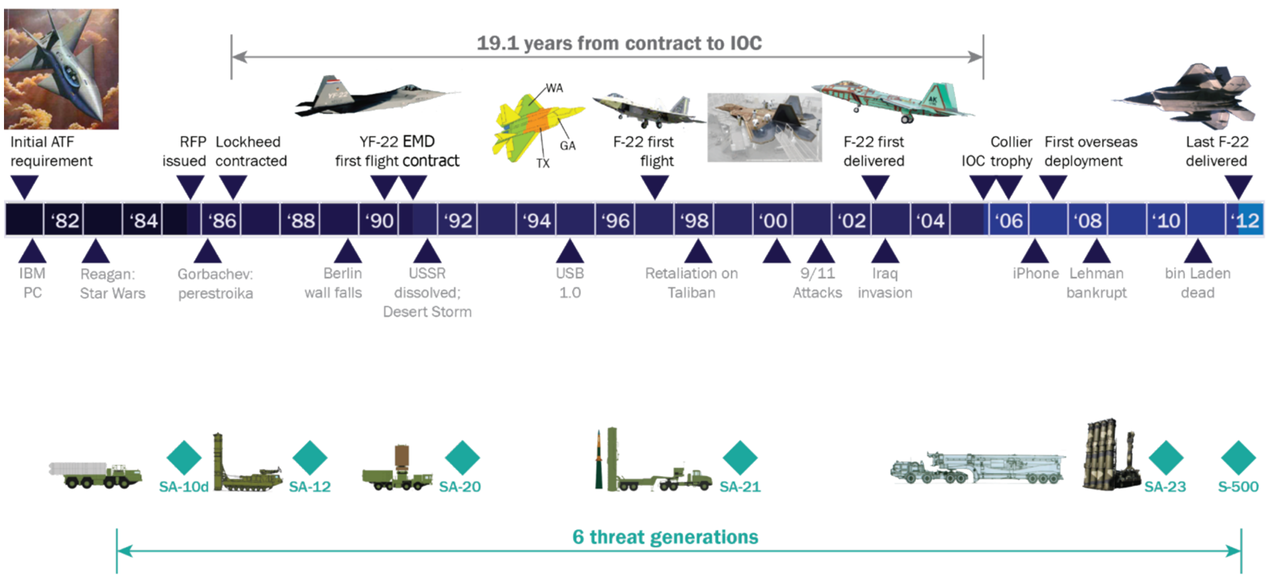
45 Meghann Myers, "The Army is Supposed to be Growing, but This Year, It Didn't At All," *Army Times*, September 21, 2018; and Kim Strong, "71% of Young People are Ineligible for the Military—and Most Careers, Too," *USA Today,* May 14, 2019.

46 Defense Intelligence Agency (DIA), *Russia Military Power: Building a Military to Support Great Power Aspirations* (Washington, DC: DIA, 2017), available at https://info.publicintelligence.net/DIA-RussiaMilitaryPower2017.pdf; and OSD, *Military and Security Developments Involving the People's Republic of China 2019*, Annual Report to Congress (Washington, DC: DoD, 2019), available at https://media.defense.gov/2019/May/02/2002127082/-1/-1/1/2019_CHINA_MILITARY_POWER_REPORT.pdf.

combat systems and weapons. Integration increases the planning needed for modifications and the amount of tailoring new systems require before they can be incorporated. As a result, integrated platforms are less able to adopt new off-the-shelf systems. Further complicating the adaptation process, contractors may own the specifications to platforms or combat systems. This can reduce initial procurement costs to the government but creates additional costs when combat systems are updated.[47]

The difficulty of quickly changing hardware or software components of integrated multi-mission ships or aircraft reduces the pace of U.S. military innovation. For example, Figure 6 shows the development cycle of the F-22 fighter compared with the Soviet and the Russian air defense systems against which the F-22 was intended to operate. During the period in which DoD developed and procured the F-22, the Soviet and then Russian military fielded six generations of air defense systems.[48]

FIGURE 6: F-22 DEVELOPMENT VERSUS SIX GENERATIONS OF RUSSIAN DEFENSES



During the 30-year development of the F-22 fighter, the Russian military developed six iterations of air defenses against which the F-22 had to operate. Tim Grayson, "Mosaic Warfare," DARPA STO, July 27, 2018, available at https://www.darpa.mil/attachments/STO-Mosaic-Distro-A.pdf.

47 Oriana Pawlyk, "$10,000 Toilet Seats and Data Rights: The Air Force Faces New Challenges in Keeping Its Oldest Aircraft in Flight," *Business Insider,* June 21, 2018; John Schank et al., *Designing Adaptable Ships* (Santa Monica, CA: RAND Corporation: 2016), pp. 101–133.

48 Dan Patt, "Observations in Aircraft Fielding Time," DARPA STO, DARPA DISTAR, Case 20064, approved October 9, 2012. Based on Center for Strategic and International Studies, "Missile Threat: CSIS Missile Defense Project," available at https://missilethreat.csis.org/system/russian-air-defense/.

This is not necessarily a surprising result. A multi-mission fighter will likely be more costly and time-consuming to build than a modular air defense system that can perform only one or two functions. Systems with fewer functions likely require less integration and would be able to more easily incorporate new components into each successive generation. The Russian and Chinese militaries rely on modular, limited function systems to a greater degree than the U.S. military, which may give them an advantage in terms of incorporating new technologies.[49] To improve its ability to introduce new technologies and tactics, DoD could also adopt an operational approach that relies on combining limited-function systems and platforms to create effects.

The wrong approach for long-term competition

The 2017 U.S. National Security Strategy and 2018 National Defense Strategy posit that the emerging great power competition between the United States, Russia, and China will persist over the long term.[50] The goal in such a competition would be to achieve political objectives through a combination of military, economic, information, and diplomatic actions, but competitors would not necessarily expect prompt capitulation by their opponents or a rapid overturning of the status quo.[51]

Forces optimized for high-intensity combat during attrition-centric warfare are potentially too costly to sustain and disproportionate for long-term competition. Attrition warfare implicitly assumes that a conflict will progressively intensify to war and combatants will continue fighting until the level of attrition prevents sustained operations. As evidenced by the increased use of gray zone tactics by U.S. rivals, America's great power adversaries appear satisfied with achieving incremental results over the long term using a combination of small-scale traditional warfighting and information operations; if an act of aggression is delayed or degraded, they may seek an off-ramp or simply pause operations to avoid the reputational risk of losing.[52] The use of gray zone tactics may partly be in response to the conventional superiority of U.S. and allied forces in attrition warfare, but sustaining a force designed for attrition is costly over the long term, and the success of Chinese and Russian gray zone actions suggests the investment in attrition-centric forces is not preventing U.S. competitors from achieving their objectives.

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49 Kevin McCauley, *PLA System of Systems Operations Enabling Joint Operations* (Washington, DC: Jamestown Foundation, 2017); and Jeff Engstrom, *Systems Confrontation and System Destruction Warfare* (Santa Monica, CA: RAND Corporation, 2018), p. 27; DIA, *Russia Military Power*, p. 82

50 Mattis, *Summary of the 2018 National Defense Strategy of the United States of America*, p. 2.

51 Hal Brands, "The Lost Art of Long-Term Competition," *The Washington Quarterly* 41, no. 4.

52 Joseph L. Votel, Charles T. Cleveland, Charles T. Connett, and Will Irwin, "Unconventional Warfare in the Gray Zone," *Joint Force Quarterly,* January 1, 2016, available at https://ndupress.ndu.edu/JFQ/Joint-Force-Quarterly-80/Article/643108/unconventional-warfare-in-the-gray-zone/; and Frank Hoffman, "Examining Complex Forms of Conflict: Gray Zone and Hybrid Challenges," *PRISM*, November 8, 2018, available at https://cco.ndu.edu/News/Article/1680696/examining-complex-forms-of-conflict-gray-zone-and-hybrid-challenges/.

Arguably, attrition-centric capabilities could be kept in reserve or at a lower level of readiness to save money, then mobilized when the threat of major power war arises. That approach, however, has led to poor maintenance of inactive platforms and systems and reduced operator and troop proficiency. It also takes longer to mobilize than may be feasible in the lead up to a confrontation with China, Russia, Iran, or North Korea due to the opponent's proximity to the likely conflict area.[53] Maneuver warfare concepts, on the other hand, would rely on smaller, less expensive units and employ them in ways that overwhelm adversaries' decision-making with multiple dilemmas and complexity rather than speed or firepower.

A Way Forward

The geographic, fiscal, and force design challenges faced by the current and planned U.S. military will likely prevent it from gaining a persistent advantage in long-term competitions with great and regional powers. American military leaders, however, have overcome similar challenges in previous generations. During the Second World War and Cold War, the U.S. military combined emerging technologies with new operational concepts to create disruptive strategies that sustained U.S. military superiority against adversaries with geographic or numerical advantages.[54] A similar approach may be needed to deter aggression in the future fiscal and operational environment.

New technologies could help enable warfare concepts centered on gaining a decision-making advantage over an opponent. AI-enabled decision aids, autonomous unmanned systems, improved passive sensors, smaller weapons, and electronic and cyber warfare capabilities could impose complexity and confusion on an opponent and execute focused attacks on essential targets.[55] The emergence of a new warfighting paradigm centered on decision-making and maneuver is addressed in the next chapter. Chapter 3 describes Mosaic Warfare as a specific form of decision-centric military operations, and Chapter 4 highlights findings from CSBA's assessment of Mosaic Warfare through wargaming and quantitative analysis.

53 Joshua Klimas and Gian Gentile, *Planning an Army for the 21st Century* (Santa Monica, CA: RAND Corporation, 2018); and Walter L. Perry et al., eds., *Operation Iraqi Freedom: Decisive War, Elusive Peace* (Santa Monica, CA: RAND Corporation, 2015).

54 James R. FitzSimonds and Jan vanTol, "Revolutions in Military Affairs," *Joint Force Quarterly*, Spring 1994, p. 24, available at https://ndupress.ndu.edu/portals/68/Documents/jfq/jfq-4.pdf.

55 In this document, AI is defined as computing systems that mimic the human brain and are used to perform tasks that, until recently, were considered the sole domain of humans.

CHAPTER 2

A Decision-Centric Approach to Military Operations

The U.S. military is losing the technological superiority it built up during the guided weapons revolution that helped end the Cold War. Stealth capabilities, precision navigation, and networked sensors and weapons have proliferated to America's great power competitors and regional rivals, limiting the ability of U.S. forces to sustain their lead by modestly adjusting current operational concepts. At the same time, rising procurement and sustainment costs will likely prevent DoD from simply buying more and better versions of its current systems and platforms. Rising costs will have less impact on U.S. adversaries because the geographic advantages of China and Russia enable their militaries to focus their most capable forces on likely areas of conflict.

Regaining an advantage will likely require DoD to change both its force design and the way it fights. Maneuver warfare points to a potential approach, relying on decision superiority and the imposition of uncertainty on adversaries, rather than trying to achieve objectives primarily through attrition. A decision-centric operational concept could leverage emerging technologies such as AI and autonomous systems to create a new warfighting paradigm in the same way stealth and guided weapons technologies were combined with long-range precision strike concepts during the late Cold War.

Combining Concepts with Technology

Defense leaders recognize the U.S. military must change to retain its predominant position. The Obama administration's "Third Offset Strategy" was one effort to move DoD in a new direction and focused mostly on emerging technologies such as learning machines and network-enabled autonomous weapons.[56] This emphasis was logical, given the tight historical

56 Katie Lange, "3rd Offset Strategy 101: What It Is, What the Tech Focuses Are," *DoD Live*, March 30, 2016, available at http://www.dodlive.mil/2016/03/30/3rd-offset-strategy-101-what-it-is-what-the-tech-focuses-are/.

coupling between technology and military superiority. But, as CSBA's study of battle network competitions suggested, technology alone is unlikely to establish an enduring military advantage.[57] Using a new technology with current operational concepts constrains the technology to the imagination of yesterday's military thinkers, and proliferation soon enables adversaries to pursue similar advancements. This kind of move-countermove cycle played out several times during the Second World War and Cold War in competitions between radar and electronic warfare, submarines and anti-submarine warfare, and nuclear capabilities.[58]

Instead of only improving current ways of fighting, new technologies could be more fully exploited by combining them with new operational concepts. For example, the U.S. Navy eventually gained an advantage in anti-submarine warfare (ASW) relative to the Soviet fleet by shifting from a defensive approach using active sonar and radar—the primary Second World War sub-hunting sensors—to an offensive approach using passive sonar during the early Cold War. Compared to defensive ASW, offensive concepts better leveraged the longer-range detections possible with passive sonar against nuclear submarines, which became the most significant undersea threat during the Cold War.[59]

Studies of commercial innovation also found a new technology's use case often makes the difference between a modest improvement and a revolutionary new product that redefines the market. For example, the small hard drives used in early minicomputers performed poorly using the metrics of error rate and speed that were applied to mainframe computers. These small drives, however, performed adequately in metrics such as size and durability to enable the development of portable music players such as the iPod.[60]

A way of envisioning the relationship between technologies and operational concepts is depicted in Figure 7. In this model, sustaining technologies provide incremental improvements to current systems and use similar mechanisms to achieve warfighting effects. Disruptive technologies use new mechanisms to provide military value, which would be measured using different metrics than preceding technologies. For example, a new radar jammer can be assessed, like its predecessors, by how well it obscures or deceives the target radar. The performance of a stealth platform, on the other hand, is assessed by how well it avoids being detected or targeted by radar. New sustaining or disruptive technologies can be combined with evolutionary operational concepts that introduce small changes to today's tactics—such as using radar instead of sight to locate navigational aids—or revolutionary operational concepts that pursue military objectives in entirely new ways—like using satellite signals to navigate.

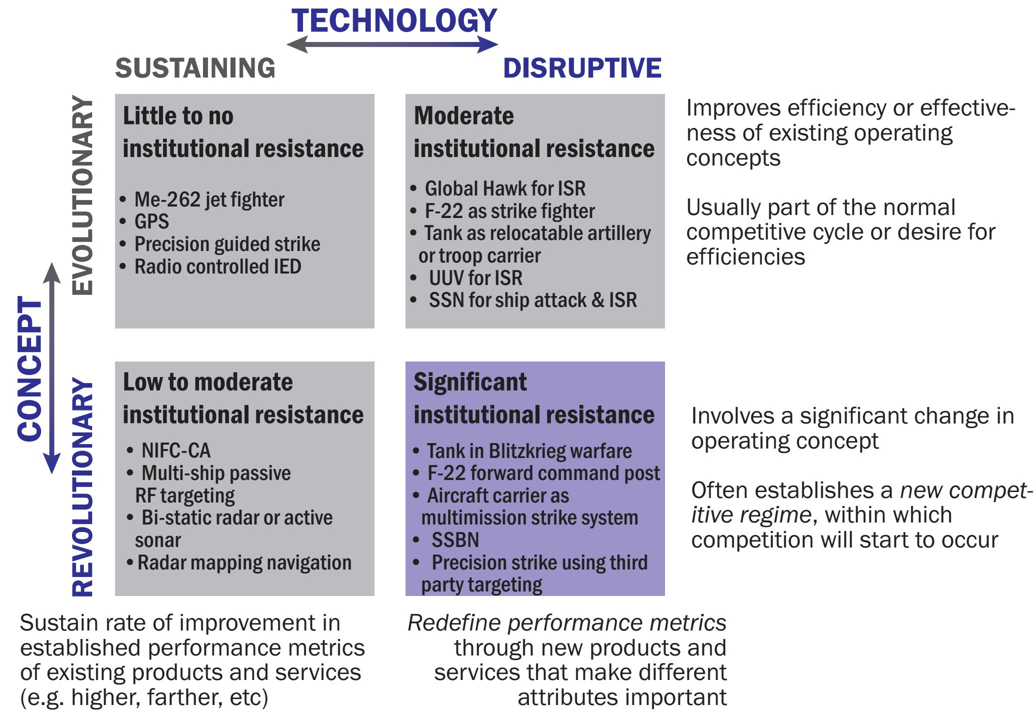
57 John Stillion and Bryan Clark, *What it Takes to Win: Succeeding in 21st Century Battle Network Competitions* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015), p. 12.

58 Stillion and Clark, *What it Takes to Win*, pp. 34–46.

59 Owen Cote, *The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines* (Newport, RI: U.S. Naval War College, 2000); and John Benedict, "The Unraveling and Revitalization of U.S. Navy Antisubmarine Warfare," *U.S. Naval War College Review* 58, no. 2, Spring 2005.

60 Clayton Christensen, *The Innovator's Dilemma* (Cambridge, MA: Harvard Business Review Press, 1997), pp. 3–29.

FIGURE 7: MILITARY INNOVATIONS EMERGE FROM COMBINING SUSTAINING OR DISRUPTIVE TECHNOLOGIES WITH A NEW EVOLUTIONARY OR REVOLUTIONARY OPERATIONAL CONCEPT



Military innovations combine a sustaining or disruptive technology with an evolutionary or revolutionary operational concept. The combination of a revolutionary concept with a disruptive technology has the potential for initiating new competitive regime but is also the most challenging innovation to implement. This figure is based on the discussion in Richard H. Van Atta et al., *Transition and Transformation: DARPA's Role in Fostering an Emerging Revolution in Military Affairs*, vol. 1, *Overall Assessment*, Paper P-3698 (Alexandria, VA: Institute for Defense Analyses, November 2003), available at https://fas.org/irp/agency/dod/idarma.pdf.

Some combinations of disruptive technology and revolutionary operational concept created significant innovations that established new metrics for success and resulted in new competitive regimes; an example would be the combination of stealth and precision strike technologies with operational concepts for third-party targeting in DoD's Assault Breaker program. Because the emergence of new metrics is only recognizable after the fact, some of these innovations have been retrospectively characterized as revolutions in military affairs.[61]

As Figure 7 shows, a combination of disruptive technology and revolutionary concept can be implemented all at once, as in the Assault Breaker concept.[62] A new technology can also be initially deployed in support of an existing concept, such as using stealth aircraft as strike-fighters similar to their predecessors; later, the new technology could enable a dramatically different way of operating, such as employing stealth fighters as C2ISR platforms.

61 FitzSimonds and van Tol, "Revolutions in Military Affairs," p. 31.

62 Lange, "3rd Offset Strategy 101."

Previous Competitive Regimes

During the Second World War and Cold War, U.S. leaders used combinations of new technologies, operational concepts, and strategies to gain the advantage by establishing new competitive regimes. For example, the U.S. victory in the Second World War can in part be attributed to harnessing the emergence of technologies and processes for industrialization and mass production. This was exemplified by the mile-long assembly line at the Willow Run bomber plant run by the Ford Motor Company, which could produce a B-24 bomber every 63 minutes. The expansion of American industrial capacity reached its limits late in the war, however, as weapon systems became more sophisticated and expensive. Furthermore, budget deficits and the need for domestic investment prevented the U.S. military from continuing to simply out-produce its competitors.[63]

The need to reduce U.S. defense spending shrank the U.S. military following the Second World War. Because it had the only complete nuclear weapon delivery systems at the outset of the Cold War, the U.S. military was able to use its nuclear superiority to offset the Soviet forces' growing numerical superiority in troops and conventional weapons. However, the U.S. nuclear advantage diminished in the following decades as the Soviet Union achieved parity and both superpowers fielded survivable second-strike nuclear capabilities in their ballistic missile submarines.[64] U.S. leaders then pursued a new approach that would use technologies for precise surveillance and targeting, stealth aircraft, and guided weapons to empower concepts for finding and attacking Soviet and Warsaw Pact forces in Central Europe; the Assault Breaker program was an example of this approach. The efficiency of precision attacks would, in theory, enable U.S. and NATO forces to stop larger enemy formations. This precision strike competition is now reaching maturity as the underlying technologies proliferate and the operational concepts become more widely understood by U.S. adversaries.[65]

The maturation of successful commercial innovations, or combinations of a new product and a use case, are often depicted using "S-Curves" that show how the innovation's performance improves in relevant metrics over time.[66] The S-curve model can also be used to represent the competitive regimes described above, as shown in Figure 8. Generally, a military innovation within the new regime slowly improves at first, during what could be called an *embryonic* phase, accelerates as its technologies and operational concepts develop during an *immature* phase, and eventually reaches a point of diminishing improvements during a *mature* phase when the technology has been fully exploited in service of that particular use case or operational concept.[67]

63 Kat Eshner, "How Detroit Went from Motor City to the Arsenal of Democracy," *Smithsonian Magazine,* March 28, 2017.

64 The discussion of previous revolutions is derived from Martinage, *Toward a New Offset Strategy*, pp. 5–16.

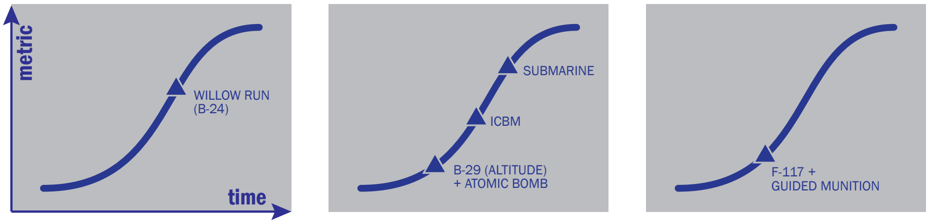
65 Andrew Krepinevich, *Maritime Competition in a Mature Precision-Strike Regime* (Washington, DC: Center for Strategic and Budgetary Assessments, 2016), p. 82.

66 Frank Bass, "A Dynamic Model of Market Share and Sales Behavior," Proceedings, Winter Conference American Marketing Association, Chicago, IL, 1963, p. 269.

67 Thomas G. Mahnken, "Weapons: The Growth & Spread of the Precision-Strike Regime," *Daedalus* 140, no. 3, 2011..

FIGURE 8: INNOVATIONS IN MODERN MILITARY HISTORY

INNOVATIONS (S-CURVES) IN MODERN MILITARY HISTORY



ERA	INDUSTRIAL CAPACITY	NUCLEAR WEAPONS	INVISIBILITY & PRECISION
exemplary metrics	• quantity produced	• yield • number of launch options • prosecutable targets	• signature / detectability • collateral effect size • navigation precision
key technologies	• mass production	• fission • delivery mechanisms	• radio frequency stealth • electronic warfare • computer control
DoD institutional innovation	• effective relations with private industry	• strategic decision making	• performance-driven product development
counters	• centralized state control of industry	• equivalent capability creates stasis	• multi-mode detection • basing denial

Previous competitive regimes introduced new performance metrics. As with new commercial technologies, military performance in these metrics follows an "S-curve" in which military forces quickly improve as they adopt new technologies and concepts. Performance levels off as the innovation culminates and the relevant technologies and concepts proliferate to competitors. Dan Patt, "Decision Maneuver," DARPA STO, DARPA DISTAR, Case 28907, publicly released January 2, 2018.

The Emerging Era of Decision-Centric Warfare

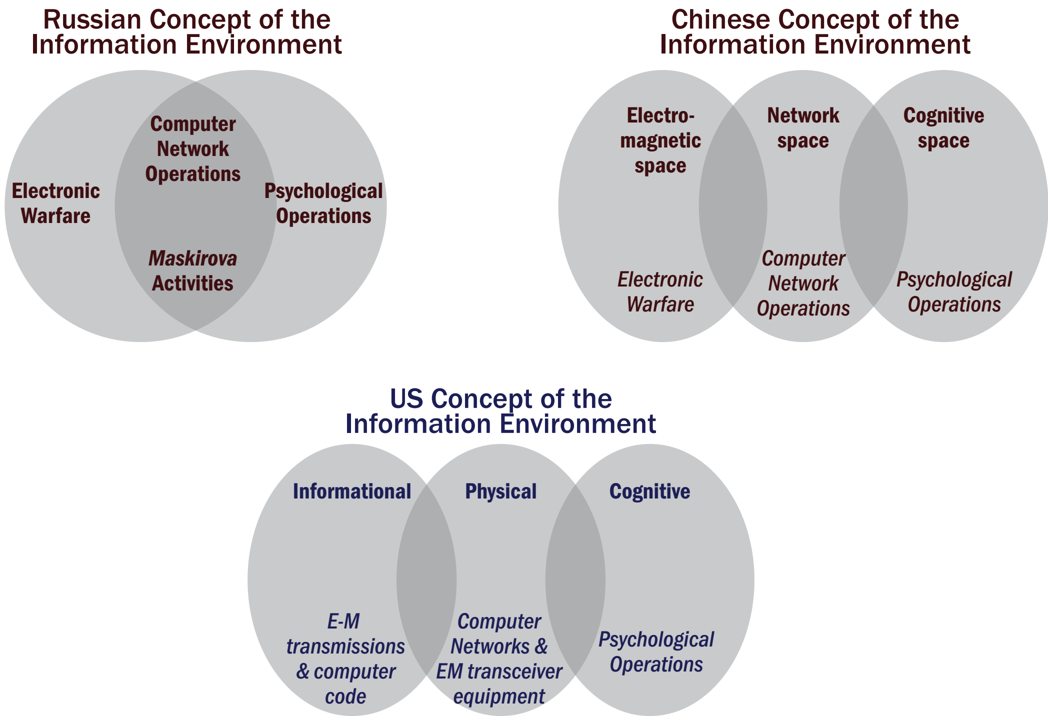
The current competitive regime centered on stealth, guided weapons, and precision strike concepts is culminating. To improve its position relative to the PLA or Russian military, DoD will need to establish a new source of advantage that reflects and exploits new trends in technology and military operations.

Today's foremost emerging technologies are AI and autonomous systems, which are being employed in a growing number of military and commercial applications to aid in decision-making and expand the reach and endurance of human operators.[68] The most prominent trend in international security today is the increasing importance of information in competition and conflict. The military strategies and doctrine of China, Russia, and the United States all describe the information environment, shown in Figure 9, as central to future confrontations.[69] These trends suggest the next major revolution in military affairs could center on the ability to manage one's own information and decision-making while degrading those of the enemy.

68 "Gartner Identifies Top 10 Data and Analytics Technology Trends for 2019."

69 Dmitry Adamsky, "ההתערבות הרוסית בסוריה: משמעויות אסטרטגיות ולקחים מערכתיים [Russian Intervention in Syria: Strategic Implications and Systemic Lessons]," עשתונות [Esh'tonot/Thoughts], November 2016, p. 61.; Ye Zheng, ed., *Lectures on the Science of Information Operations* (Chinese) (Beijing: Military Science Press, 2013), p. 31; and James Mattis, *National Defense Strategy of the United States* (Washington, DC: DoD, 2017), available at https://www.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

FIGURE 9: DIFFERING CONCEPTS OF THE INFORMATION ENVIRONMENT



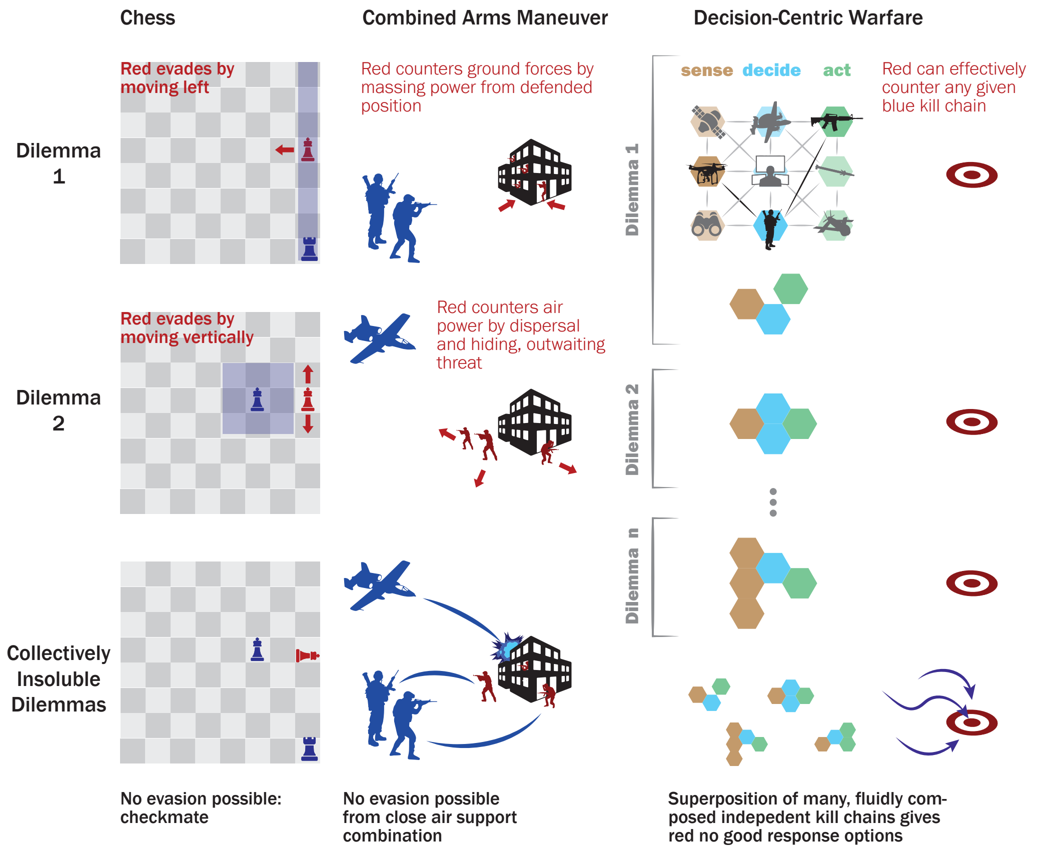
Each great power competitor considers the information environment as central to future warfare. It consists of the electromagnetic spectrum (EMS), computer networks, and human cognition. Automation, autonomy, and artificial intelligence are three related but distinct concepts that are often conflated. For the purposes of this study, automation is a technology element that operates without continuous human input, usually according to a set of understandable and programmable rules; autonomy is the delegation of a defined portion of decision-making to a human, machine, or combination thereof; and artificial intelligence is a computer capable of imitating human behavior for reaction, prediction, and classification. This class of technologies tends to be data-driven (instead of built around human-developed models) and have a basic learning capability for improved adaptability. It should be noted that autonomy is a relational construct—describing how authority or responsibility is divvied up between units or agents—and not a property of a machine. Artificial intelligence is an advanced form of automation that is data-driven and adaptable. Realistically, in military applications, this study's focus is not on automating warfare, but on harmonizing complex combinations of artificial intelligence, traditional automation, and humans for superior effect.

DoD's recent efforts to field AI and autonomous systems have focused on improving current ways of operating, rather than developing new warfighting concepts. For example, Project Maven, an early DoD AI-enabled program, uses AI to improve the speed and accuracy of image interpretation compared to human analysts. Many of those images are gathered by autonomous satellite or UAV-based sensors that perform the same functions as manned aircraft, but they can do so longer or over wider areas. This approach does not fundamentally change how DoD gathers or uses information. Referring to the S-curve of Figure 9, Project Maven and autonomous sensors move DoD farther along the flat portion of the curve for the current competitive regime combining precision weapons and networked sensors; Project Maven does not start a new curve in which DoD gathers and manages information differently to gain a substantial decision-making advantage.[70]

70 Cheryl Pellerin, "Project Maven Industry Day Pursues Artificial Intelligence for DoD Challenges," *DoD Newsroom,* October 27, 2017, available at https://www.defense.gov/Newsroom/News/Article/Article/1356172/project-maven-industry-day-pursues-artificial-intelligence-for-dod-challenges/.

A decision-centric approach to warfare would combine AI and autonomous systems with new operational concepts to enable faster and more effective decision-making by U.S. forces compared to adversaries. The core metrics of this approach, as with maneuver warfare, would be the number of distinct dilemmas presented to the adversary and the speed with which they are imposed. Ideally, U.S. forces would impose multiple dilemmas such that the enemy must become more vulnerable to one to counteract another. To compound the challenge, U.S. forces would seek to fight at a rate that does not permit the adversary to regroup or concentrate. As a result, the adversary would be unable to adapt and implement an effective course of action.

FIGURE 10: IMPOSING DILEMMAS USING A DECISION-CENTRIC APPROACH TO WARFARE

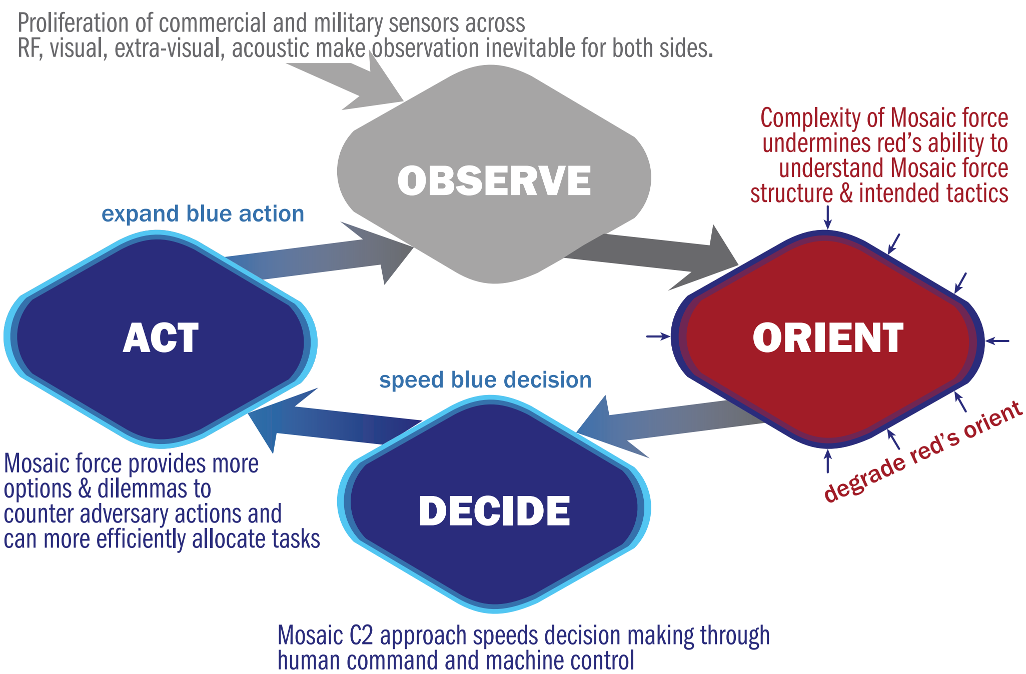


A decision-centric approach to warfare would enable the imposition of more simultaneous dilemmas on an adversary by enabling the composition of forces to form a wider variety of attacks or kill chains than is possible in games like chess or military combined-arms operations. In decision-centric warfare, the adversary is unable to deploy an effective response to all the possible U.S. approaches.

Military theorist John Boyd advocated a decision-centric approach to military operations in his writings and presentations. Boyd broke down the military decision-making process into the observation of adversary and friendly forces; orientation to assess what the enemy is doing and why; the decision to develop and choose a course of action (COA); and implementation of the COA. He called this the observe-orient-decide-act (OODA) loop. Boyd proposed that military operations should focus on defeating the enemy's orientation to slow and eventually collapse its decision cycle.[71]

Following Boyd's proposal, decision-centric warfare is focused on disrupting the orient phase. The focus of decision-centric warfare on orientation circumvents the impact of proliferating and improving military and commercial airborne, satellite, and third-party sensors, which will make observation almost impossible to prevent. Instead, decision-centric warfare enables a U.S. force to confuse the enemy regarding the most advantageous targets to attack, the intended objectives of the U.S. force, and the approach it will take to achieve them.

FIGURE 11: IMPACT OF MOSAIC WARFARE ON THE O-O-D-A LOOP



Mosaic Warfare degrades the enemy's ability to orient while improving the ability of friendly forces to decide and act.

71 Frans Osinga, Science, Strategy, and War: The Strategic Theory of John Boyd, (New York, NY: 2007, Routledge).

Fully embracing an operational concept centered on information and decision-making would likely require changes to the U.S. military's structure and C2 processes. Today's multi-mission units such as aircraft, ships, and troop formations tend to execute either self-contained effects chains or participate in static architectures that combine certain sensors, weapons, and C2 elements in a specific order.

To better enable a decision-centric warfare concept, U.S. military platforms and troop formations could be disaggregated into elements with only one or two functions that form an "effects web" in which many different combinations of sensors, weapons, and C2 elements could accomplish the same tasking. The performance of an effects web could be further enhanced by dynamically composing and recomposing its elements, including the unexpected or nontraditional combinations of capabilities. Managing the composition and operation of a large collection of disaggregated forces would likely need to rely on a combination of human command and machine control.[72]

The U.S. military is beginning to make the shift toward decision-centric warfare with new concepts that emphasize distribution and its establishment of the Strategy for Operations in the Information Environment. DoD, however, has not yet implemented an operational concept designed to gain or exploit decision superiority.[73] DARPA's Mosaic Warfare concept offers one approach for doing so, which will be described in the following chapters.[74]

72 Megan Eckstein, "Interview: Rear Adm. Mike Manazir on Weaving the Navy's New Kill Webs," *USNI News*, October 3, 2016, available at https://news.usni.org/2016/10/03/interview-with-rear-adm-mike-manazir-weaving-the-navys-kill-web.

73 OSD, *Strategy for Operations in the Information Environment* (Washington, DC: DoD, 2016) available at https://dod.defense.gov/Portals/1/Documents/pubs/DoD-Strategy-for-Operations-in-the-IE-Signed-20160613.pdf.

74 "Strategic Technology Office Outlines Vision for 'Mosaic Warfare'," DARPA, August 4, 2017, available at https://www.darpa.mil/news-events/2017-08-04.

CHAPTER 3

Pursuing Decision Superiority through Mosaic Warfare

The central idea of the Mosaic Warfare concept is to create adaptability and flexibility for U.S. forces and complexity or uncertainty for an enemy through the rapid composition and recomposition of more disaggregated U.S. forces using human command and machine control. This approach could enable a deployed force to better achieve deterrence by denial in support of U.S. defense strategy.

The significant changes needed to U.S. force design and C2 processes described below will be difficult to implement quickly. Therefore, the U.S. military may only initially establish an experimental force that executes decision-centric operational concepts to evaluate their practicality and effectiveness. This method was employed during previous changes in military competitive regimes: for example, the development of AirLand Battle by the U.S. Army and the fielding of stealth and precision strike capabilities by the U.S. Air Force.[75]

A More Composable Force Design

Today, U.S. forces consist predominantly of manned multi-mission units such as aircraft, ships, and troop formations that are self-contained, or monolithic, incorporating their own sensors, C2 capabilities, and weapons or electronic combat systems. U.S. force elements that are not self-contained multi-mission units are required to be part of pre-architected SoS in accordance with DoD requirements and acquisition policies.[76] The relatively inflexible config-

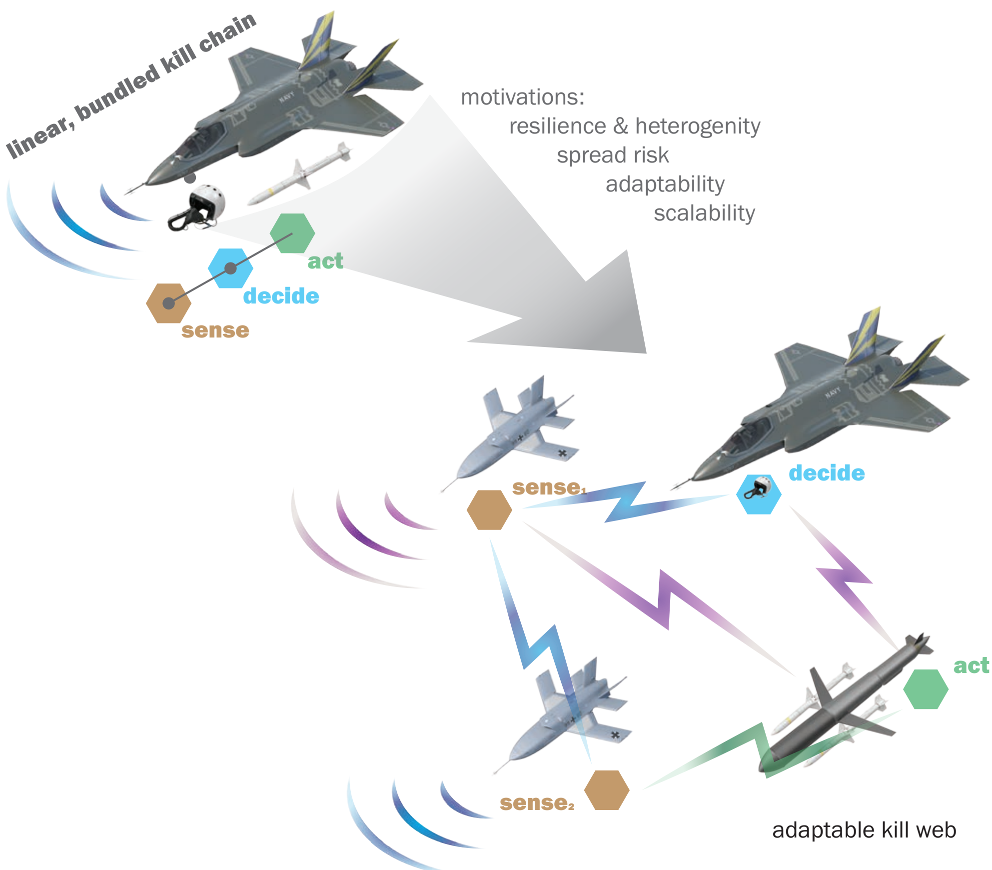
75 Charles W. Sasser, "The F-117 Nighthawk's Near-Perfect Combat Record," *Military Times*, January 8, 2018; and David Johnson, "An Army Caught in the Middle Between Luddites, Luminaries, and the Occasional Looney," *War on the Rocks*, December 19, 2018.

76 U.S. Joint Staff, "Charter of The Joint Requirements Oversight Council (JROC) and Implementation of The Joint Capabilities Integration and Development System (JCIDS)," CJCSI 5123.01H, 2018, pp. D-1–D-3, available at http://acqnotes.com/wp-content/uploads/2018/11/CJCSI-5123.01H-Charter-of-the-Joint-Requirements-Oversight-Council-JROC-and-Implementation-of-the-JCIDS-31-Aug-2018.pdf; and DoD, "The Defense Acquisition System," DoDD 5000.01, 2018.

uration of monolithic multi-mission units and SoS limits the variety of ways a given force package could be composed. This reduces the adaptability of the force, makes its operations more predictable, and lowers the ability of U.S. forces to confuse an enemy as part of operational concepts focused on gaining a decision-making advantage.

DoD could better pursue decision and information superiority by decomposing some of today's monolithic multi-mission units into a larger number of smaller elements with fewer functions that would be more composable. For example, a frigate and several unmanned surface vessels could replace a surface action group of three destroyers, or a section of strike-fighters could be replaced by a strike-fighter acting as a C4ISR platform for a group of standoff missiles and sensor- and EW-equipped UAVs. In a ground force, rather than relying on large formations, smaller units and subunits could be augmented with small and medium-sized UGVs and/or UAVs to improve their self-defense, ISR, and logistics capability.

FIGURE 12: MONOLITHIC UNITS VERSUS COMPOSABLE FORCE PACKAGES

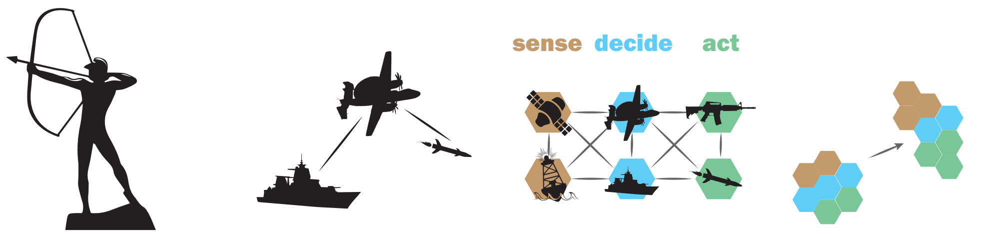


Disaggregating multi-mission units could increase the flexibility and adaptability of the force and create a more complex situation for the adversary to assess. In this graphic, traditional 'monolithic' strike-fighter (left) is replaced with a more composable force package (right) in which the strike-fighter acts as a C2 node for one or more groups of UAVs.

Instead of a pre-defined kill chain, these more disaggregated forces could be thought of as kill webs or effects webs, in which several different configurations of independent sensors, countermeasures, weapons, and decision elements could be combined before the start of an operation to create a given effect. Going one step further, the force elements in an effects web could be dynamically composed and recomposed before and during an operation, including changing the roles of some elements of the force. In the example of Figure 12, even the limited function UAVs depicted in the disaggregated force package would be capable of being sensors, decoys, or communications nodes, and they could change their roles during an operation.

As shown in Figure 13, Mosaic Warfare can be thought of as the next step in progressively more disaggregated and complex approaches to warfare adopted by the U.S and other militaries. Notably, China's PLA has embraced SoS design to field a comprehensive set of capabilities intended to attack the perceived vulnerabilities of U.S. forces.[77] The adaptability and complexity possible with Mosaic Warfare could improve the ability of a military to defeat relatively inflexible SoS-based forces like those of the PLA.

FIGURE 13: EVOLUTION OF KILL CHAINS



self-contained
·kill chain wrapped around local decision making

key advantage:
·no external dependencies
·limits communication vulnerability

system-of-systems (static)
·predefined information exchanges enable a third party kill chain

key advantage:
·greater effect (e.g. range) possible by removal of co-location requirement

kill web
·more flexible information paths connect more systems

key advantage:
·allows pre-mission adaptation
·more lethal, imposes complexity on adversary

Mosaic
·resources can recompose during mission execution

key advantage:
·highly adaptable to dynamic threat and environment
·very scalable

The first kill chains were entirely self-contained, with units such as ships or aircraft carrying everything needed to complete a task. The SoS concept fostered the third-party kill chain, where information is shared to enable accurate engagement. Effects webs extend this concept to a larger number of more interoperable systems, and Mosaic Warfare envisions the dynamic in-task adaptation of resources for task execution.

An evolutionary process

The path to fielding disaggregated forces will be evolutionary, with the disaggregated portion of the military growing over time, but never completely replacing multi-mission ships, aircraft, vehicles, and ground formations. In part, this is because the technologies needed

77 Jeff Engstrom, *Systems Confrontation and System Destruction Warfare.*

to support decision-centric warfare will need time to mature. Also, however, self-contained, multi-mission units will continue to be required because of their efficiency in permissive environments, endurance, capacity, and familiarity to U.S. allies and adversaries.

Due to their smaller size and more limited functionality, disaggregated force elements would not necessarily have the communications, sensing, and habitability features to carry commanders and staffs, the endurance to travel long distances, or the ability to remain on station for extended periods. In less-contested regions, traditional multi-mission units and platforms may be needed as command nodes or to provide transportation and logistics support to disaggregated units; in contested areas or during widely distributed operations, disaggregated platforms and units such as unmanned vehicles could be a more effective solution.

Situations requiring predictability and the frequent use of human operators, such as security or counter-insurgency operations, may be better suited to traditional manned multi-mission units as opposed to disaggregated force elements. For instance, if a regional power threatens neighboring territory or access to important sea lanes, U.S. leaders could deploy larger manned multi-mission destroyers and armed patrol aircraft to the area. These platforms have relatively long endurance, and their crews can maintain them on deployment for an extended period to address a range of situations short of war that could arise. The predictable nature and TTPs of these traditional multi-mission units may also, in some situations, be better able to reassure allies or deter adversaries than more complex disaggregated forces.[78] Disaggregated Mosaic forces may be more appropriate than a traditional force in security operations that require uncertainty, wide coverage, and lower risk to operators, such as securing a base against terrorist attack.

A wholesale replacement of traditional forces is not needed to free up funds for disaggregated forces. Only a small fraction of traditional monolithic units would need to be retired or canceled to enable many smaller, less-multi-functional forces to be procured and fielded. For example, to create the forces used during the Mosaic Warfare wargame series described in Chapter 4, CSBA shifted 10 percent of future DoD procurement funding toward more disaggregated units. The resulting investment of more than $100 billion was able to create an operationally significant inventory of Mosaic forces.[79]

Some of a disaggregated force's elements may be located far from the operation. For example, cyber units, commercial imagery, and social media analysis could be composed into a disaggregated force package alongside platforms, weapons, and combat systems. Disaggregated

78 Samuel Huntington, "Conventional Deterrence and Conventional Retaliation in Europe," *International Security* 8, no. 3, Winter, 1983–1984.

79 To develop this estimate, data from the PB19 Budget was projected out to 2035 (when the wargames took place), which gives a total procurement budget of about $2.3 trillion for the 2019–2035 timeframe. Taking 10 percent of that yields ~$200 billion in FY19 dollars. To account for procurement of support equipment and supplies, and constraints on how much existing programs could be truncated to pay for Mosaic capabilities, the Mosaic force for the wargames only uses ~$100 billion of that funding.

units will need a level of assured information sharing but would not require continuous communications or connectivity to all other U.S. forces. Machine-enabled control systems would automatically align forces to the commanders with whom the forces can communicate to receive tasking or reporting results. These forces would operate autonomously once tasked and use AI-enabled models to predict the actions being conducted by other force elements during temporary communications outages. This approach is used today in ride-sharing applications.[80]

Although communications could be episodic and localized in the disaggregated force, interoperability will be a significant challenge. The ability to compose and recompose forces will be constrained by the diversity of communications standards in DoD and a lack of systems to translate between them. DoD is advancing several programs that could act as gateways between communications standards—including the Battlefield Airborne Communications Network (BACN) node—or translate between them—such as DARPA's System of Systems Technology Integration Tool Chain for Heterogeneous Electronic Systems (STITCHES) technology for ad-hoc interoperability.[81]

Endurance will be another significant consideration. Disaggregated force elements will often be smaller than traditional units, which could reduce their ability to carry substantial amounts of fuel. Force elements with longer endurance, such as large and extra-large unmanned vehicles, may not have substantial redundancy and may not be accompanied by human maintainers to conduct repairs during an extended mission. Force elements will therefore need to compensate for endurance shortfalls with larger numbers and be expendable, recoverable, or capable of being autonomously resupplied.

The conduct of logistics operations for disaggregated forces could be challenged by the more distributed operations being pursued by the U.S. military and the adaptation and recomposition conducted by Mosaic forces. Like the forces they support, logistics capabilities would likely need to be more disaggregated than today's conventional trunk and branch resupply system. They would need to incorporate prepositioned stores, predictive and just-in-time resupply, foraging, and additive manufacturing. More research is required in this area.

DoD would also need to change many of the processes it uses to develop military capabilities to field a disaggregated force. For example, as described in Chapter 5, requirements for a

80 David Ferguson, Dmitri Dolgov, and Google, Inc., "Modifying Behavior of Autonomous Vehicle Based on Predicted Behavior of Other Vehicles," U.S. Patent US 8,457,827 B1, 2013, available at http://scholar.google.com/scholar_url?url=https://patentimages.storage.googleapis.com/pdfs/US8457827.pdf&hl=en&sa=X&scisig=AAGBfm0WTXIQLnGMApv0cNEHPumJcsfsxg&nossl=1&oi=scholarr.

81 "Battlefield Airborne Communications Node (BACN)," Northrop Grumman, available at https://www.northropgrumman.com/Capabilities/BACN/Pages/default.aspx; Evan Fortunato, "System of Systems Technology Integration Tool Chain for Heterogeneous Electronic Systems," NDIA, September, 9, 2016, available at https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2016/systems/18869_Fortunato_SoSITE_STITCHES_Overview_Long_9Sep2016_.pdf; and Jimmy Jones, "Global Interoperability Without Global Consensus, A DARPA Solution via the STITCHES Toolchain (Conference Presentation)," Proc. SPIE 11015, Open Architecture/Open Business Model Net-Centric Systems and Defense Transformation 2018, 110150F, May 14, 2019, available at https://doi.org/10.1117/12.2519443.

highly composable force will be difficult to establish well in advance of a system's deployment, because the exact composition of systems for an operation will vary depending on the capabilities available at the time, the specific threat, and the commander's tasking. Therefore, instead of defining requirements for composable forces in terms of anticipated capability gaps, DoD will need to assess potential new systems through simulation or experimentation in terms of how they improve the overall effectiveness of the disaggregated force in relevant missions during a variety of potential situations. The implications of Mosaic Warfare for DoD strategy and processes are detailed in Chapter 5 and should be the subject of significant additional study.

Institutional benefits of composable force design

The design of a force employing composable forces could yield several long-term benefits to the military that adopts them. Like the advancement of Russian air defense systems described in Chapter 2, the decomposition of sophisticated multi-mission platforms and troop formations into smaller, less-multi-functional units could allow them to more easily adopt new technologies or systems. Force elements with fewer functions could be less highly integrated than multi-mission units. As a result, fewer modifications would be needed in a platform or troop formation to allow a new capability to be incorporated.

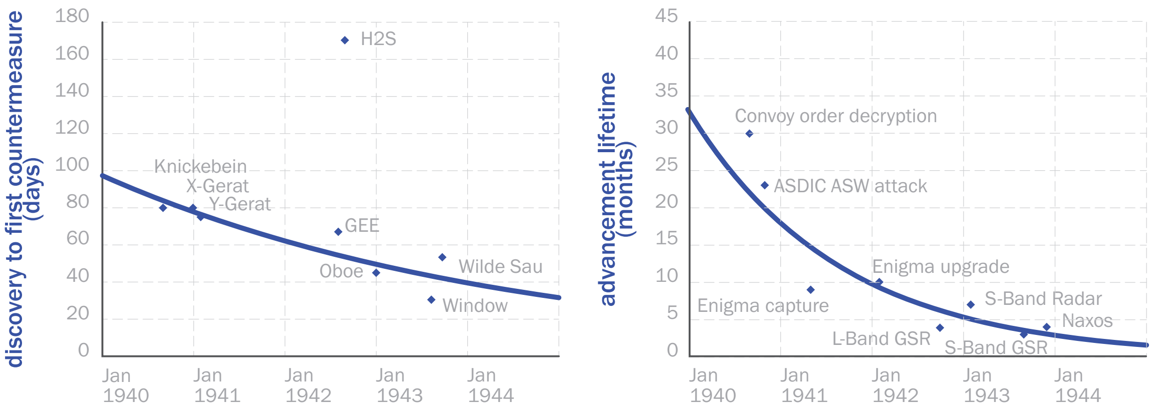
A more recomposable force may also be better able to experiment with and implement new TTPs compared to a traditional force of multi-mission units. In today's U.S. military, there are not enough multi-mission units to be expendable or to be used for a single function, compelling commanders to employ them for several functions simultaneously and protect them with self-defense systems or other platforms and formations. This constrains the degree of flexibility available to concept developers. In contrast, force elements that perform only one or two functions would be less expensive and more numerous and would not require protection. As a result, units could be incorporated into a wider variety of TTPs.

The ability of a force to incorporate new technologies and TTPs was essential to success in previous wartime competitions between the U.S. military and major adversaries. For example, during the Second World War, the competitions between Allied bombers and German air defenses and between Axis submarines and Allied ASW forces hinged on which side could better control the electromagnetic spectrum (EMS).[82] Within these competitions, the side that was able to adapt its EMS capabilities more quickly was able to gain a temporary advantage. As shown in Figure 14, the lifetime of each innovation was shorter than its predecessor, and although each competitor had the ability to introduce new technologies and tactics, the German military was less able to field them broadly throughout the force compared to the Allies.

82 Allied bombers dropping unguided bombs depended on radio navigation to reach their targets, which German defenders attempted to jam and deceive using EW. Allied ASW forces relied on radar and radio direction-finding to detect and track German U-boats, against which submarines used radar warning receivers and burst transmissions.

The eventual Allied success in the bombing and ASW competitions also resulted from a decision-centric approach to warfare. The Allies adopted strategies that imposed “virtual attrition” on German forces by preventing German fighters and submarines from finding or reaching their targets in time through a combination of deception, confusion, and suppression. Actual German attrition in these battles was not significant enough to prevent continued operations, but the strategic impact of successful Allied bombing attacks or convoy transits helped turn the war to the Allies’ favor.[83]

FIGURE 14: LIFETIME OF USEFUL ADVANCEMENTS IN SECOND WORLD WAR COMPETITIONS



The lifetime of each new innovation in the air defense (left) and submarine (right) competitions was shorter than its predecessor, suggesting the side with the more adaptable force was more likely to succeed. This analysis and the charts in Figure 16 come from Stillion and Clark, *What it Takes to Win*. In the diagram, Knickebein, X-Gerat, and Y-Gerat were German radio navigation aids used to direct bombers to targets in the UK. GEE and Oboe were radio navigation aids for British bombers attacking Germany, Wilde Sau was a German air defense fighter tactic, and Window was a British radar-obscuring chaff. For ASW, Enigma was a German code machine, and GSR stands for German Signal Receiver.

The ability of each side to adapt during wartime competitions was enhanced by the ability to quickly assess the efficacy of each succeeding innovation in combat. During the emerging long-term competitions with China and Russia, feedback will depend on fewer live interactions and more modeling and simulation than in wartime, but the ability to adapt over time would still help the U.S. military establish and sustain an advantage. U.S. adversaries have robust technical research and tactics development organizations and can focus their efforts on creating ways of defeating U.S. forces in likely scenarios they may choose to initiate. If U.S. forces can incorporate new technologies and concepts more easily, they may be able to do more than simply respond to adversary innovations and instead take the initiative to introduce new American warfare approaches that compel competitors to react.

83 Stillion and Clark, *What it Takes to Win,* p. 90.

Operational benefits of disaggregated force design

Disaggregation of today's U.S. military forces would help transform their pre-configured effects chains into adaptable effects webs, consistent with the emerging concepts that DoD is pursuing for distributed operations.[84] With distribution and the ability to rapidly compose and recompose, U.S. forces could gain several operational advantages compared to today's U.S. military:

Greater adaptability for U.S. commanders. Disaggregated forces capable of assembling and recomposing in a wider range of combinations would provide U.S. commanders more ways to avoid attacks, overcome defenses, or circumvent enemy countermeasures that likely focus on the small variety of monolithic platforms in today's U.S. military. For example, if an enemy plans to use anti-ship ballistic missiles (ASBM) to attack aircraft carriers and prevent carrier-based aircraft from launching strikes, a more disaggregated U.S. force could circumvent the enemy's plans by instead conducting strikes using a combination of UAVs and standoff missiles launched from unmanned surface vessels and submarines.

Higher complexity for the adversary. In theory, monolithic multi-mission units could create complexity for an adversary because all the units would be interchangeable. In practice, the complexity possible with traditional forces is constrained by the cost of monolithic multi-mission units, which limits their number. Furthermore, the co-location of all the kill chain elements in a single platform or formation constrains the number of independent paths and nodes possible in a force package. The high value of multi-mission units also requires they be protected, which limits the flexibility possible in the configuration of associated forces.

The disaggregation of traditional units into composable force elements would create a more complex picture for an adversary to assess by increasing the variety of ways the units in a force package could combine to conduct a particular task or recompose to conduct a new task. To defeat such a force, an adversary would need to develop and field a wider variety of countermeasures. Alternatively, an adversary would have to accept the risk that the disaggregated force could compose effects chains able to circumvent the defenses it is willing and able to establish.

Improved efficiency. The disaggregated force's larger number of smaller, less costly elements could enable commanders to more finely calibrate the capability and capacity of a force package to the task and the commander's risk tolerance. The ability to use the force more efficiently could, in turn, allow commanders to take more calculated risks and allocate forces across more simultaneous tasks.

Wider span of action. The ability of composable forces to be allocated across a greater number of missions could enable them to pursue more objectives simultaneously compared to

84 Todd South, "The Army's Updated Warfighting Concept Will Drive Its Formations, Planning and Experimentation," *Army Times,* December 6, 2018.

today's force, increase the complexity imposed on the adversary, and potentially overwhelm the adversary's decision-making process.

Faster operational tempo. The greater composability of the disaggregated force could provide commanders more flexibility regarding the configuration of force packages for a given task and result in faster decision-making. The C2 process, by integrating human command with machine control, would further speed the development of COAs and decision-making by commanders. Faster decisions and the ability to mount more simultaneous actions would enable commanders to better control operational tempo compared to traditional forces.

Improved implementation of operational strategy. The ability to more finely calibrate forces to tasks, spread the force over more tasks, better control tempo, and take more calculated risks could enable a commander to pursue an operational strategy centered on maneuver rather than attrition.

Human Command and Machine Control

Perhaps the most dramatic changes associated with decision-centric warfare would be in U.S. military C2 processes. To fully exploit the value of a disaggregated and more composable force, C2 would rely on a combination of human command and machine control. Without automated control systems, commanders would not be able to take full advantage of the force's composability in imposing dilemmas on an adversary or recomposing in response to enemy defenses and countermeasures. The use of machine-enabled control would also help commanders focus more attention on applying operational art and less on the mechanics of force employment.

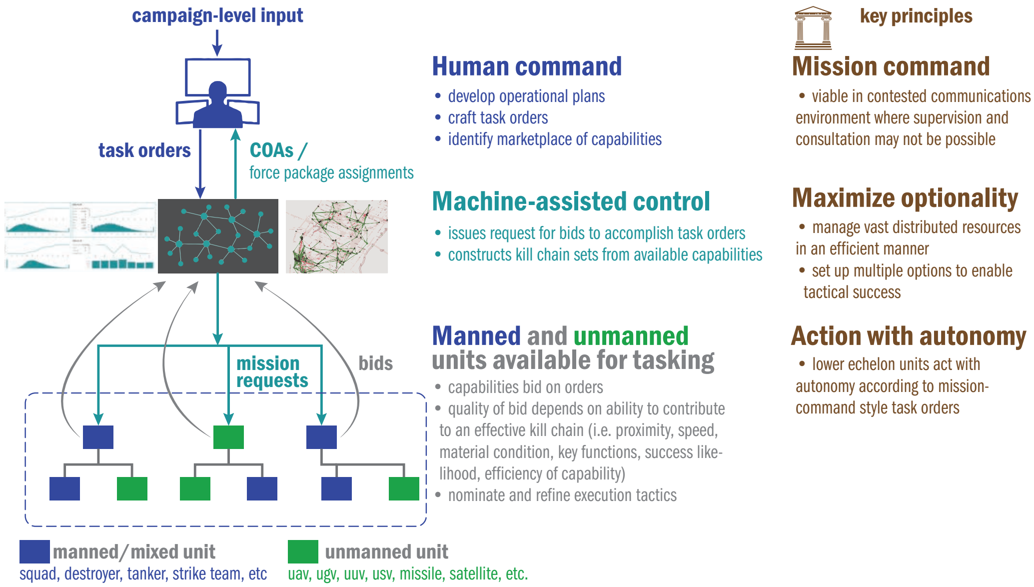
During the C2 process shown in Figure 15, human commanders develop an overall approach to an operation that reflects their strategy, applies operational art, and follows the intent provided by the commander's superiors. The commander identifies the tasks to be completed for the machine-enabled control system via a computer interface and selects an estimate for the opposing force size and effectiveness. The machine-enabled control system would implement Context-Centric C3 by identifying the forces in communication that could be tasked, from which the commander chooses the units to be made available for tasking.

The machine-enabled control system would query each participating unit or force element regarding its ability to support the commander's tasking. Units would respond with data such as their proximity to the operation, relevant capabilities to the task, and physical characteristics. Using modeling and simulation of potential CONOPs, the machine-enabled control system would then propose one or more COAs to the commander. This approach is not dissimilar from that employed by today's ride-sharing applications such as Uber.[85] A COA would include for each simultaneous task to be executed: the force package to be used, tactics

85 Ryan Waliany et al., "How Trip Inferences and Machine Learning Optimize Delivery Times on Uber Eats," Uber Engineering, June 15, 2018, available at https://eng.uber.com/uber-eats-trip-optimization/.

to be used in conducting the task, and associated movement and maneuver. The commander and his or her staff would review proposed COAs for consistency with strategy and higher guidance, which places a natural upper limit on the number of tasks and span of control a commander can manage.

FIGURE 15: NOTIONAL C2 APPROACH



Commanders direct tasks and identify forces available for tasking. The machine-enabled control system then develops a course of action (COA) to complete tasks within the commander's parameters and constraints.

Unlike a human staff, the machine-enabled control system could exhaustively assess combinations of force elements and tactics able to support the commander's orders. The resulting COAs could include novel approaches that would not normally be considered by a human staff. Although some of these non-doctrinal COAs may have a lower probability of success than traditional tactics, they could be more effective in practice because the enemy would not expect them.

The potentially unfamiliar nature of some proposed COAs suggests a key challenge for implementing Context-Centric C3 will be establishing commanders' trust in the ability of the machine-enabled control system to create successful COAs that have considered a wide variety of factors including logistics, C3ISR and counter-C3ISR capabilities, and enemy responses. Trust could be facilitated by the machine-enabled control system providing explanations of COAs. The control system could also be implemented first in a decision support role and later to manage task execution as users become more confident in the results it provides.

If the control system's proposed COAs are not consistent with the commander's intent or do not reflect the commander's operational approach, the commander can change the task orders and re-run the system to generate different COAs. This could occur, for example, if the commander initially wants to pursue a plan that is infeasible given the opposing force and the capabilities the commander made available for tasking. This iterative process of COA development would help commanders focus on applying operational art, rather than spending most of their time crafting tactics to attack specific targets—as is often the case in current military operations. The disadvantage of an iterative approach to COA development is that some of the OPTEMPO advantage possible with Mosaic Warfare could be lost.

Once the commander selects a COA, orders would be given to participating force elements either by human staffs or, later, by the machine-enabled control system itself. When communications are contested, units could use a combination of organic sensing and predictive analytics to project the location and actions of the other units to deconflict and integrate their actions. Units would report to the rest of the force and the commander when they complete their part of the tasking and the results, which may include battle damage assessment. Force elements could also report back to the commander when criteria established in the task orders are met, when conditions preclude task accomplishment, or when new conditions emerge as prescribed by the commander—such as the appearance of an unexpected enemy force or capability.

The role of AI

AI and other algorithmic approaches to advanced automation will be essential to achieving the vision described above. The C2 process envisions using narrow AI to inform modeling and COA development by the machine-enabled control system. Individual unmanned units may incorporate narrow AI techniques such as machine learning (ML) algorithms to improve their ability to, for example, recognize targets or avoid threats. But AI would not be required for them to receive orders, broadcast episodic updates, and prosecute their tasks.

The machine-enabled control system could incorporate ML in its modeling toolset to more quickly predict the likelihood of a given COA successfully executing a commander's orders in a scenario. Although traditional physics or statistical models could assess the feasibility and effectiveness of a COA, model builders must balance speed or runtime and fidelity; a high-fidelity model that runs in minutes is not helpful to a decision made in seconds. ML-enabled models could help speed COA analysis by rapidly comparing potential COAs to past actions by the same force or other friendly forces against a specific opposing force.[86]

In contrast to the specific characteristics of friendly and opposing capabilities needed to build traditional physics or statistical models, ML algorithms could use readily available data from friendly military systems operating in representative environments to train models that could predict the results of operations by different, but categorically similar, U.S. and adversary capabilities in new situations. This application of AI is considered narrow because it would be designed to support a particular function: in this case, predicting the outcome of operations

86 Thomas W. Lucas, "The Stochastic Versus Deterministic Argument for Combat Simulations: Tales of When the Average Won't Do," *Military Operations Research* 5, no. 3, 2000, available at http://www.jstor.org/stable/43940834.

defined by the commander's task orders and within the bounds of the operational environment. An example of general AI, in contrast, would be a machine-enabled control system that determines what tasks should be done, generates its own task orders, and then approves the COA to implement the tasks.[87]

The type of ML technique used to build a model can be varied based on the amount and relevance of training data available. Deep Neural Network (DNN) learning algorithms can create high-fidelity models but require large sets of data very similar to what it will receive in practice. ML techniques that use Bayesian inference, regularization, support vector machines, or model averaging can enable model development with smaller sets of data that are generally similar to the data provided to the machine-enabled control system during an operation.[88] For example, a DNN algorithm could be used to develop models for facial recognition that are trained using the large amount of labeled image data in various photo databases. An inference algorithm may be needed to build models for EW operations against air defense radars because only a relatively small amount of training data will be available, and that data may be from EW operations against emulated or simulated radars.

The use of AI-enabled models could increase the difficulty of establishing trust in a machine-enabled control system. Unlike traditional techniques, models developed using ML algorithms produce predictions that are not easily traced back to the input data. An essential feature of machine-enabled control system model outputs will therefore be an explanation of why the model produced its results, such as a graphical depiction of the proposed COA's scheme of maneuver, kill chain elements, and communications requirements.[89]

Context-Centric C3

Command relationships in today's U.S. military are generally established to support the commander's desired span of control without consideration for the availability of communications or the forces needed to support the commander's missions. This approach could create unachievable requirements for communications network connectivity or bandwidth. In contrast, the composability of the Mosaic force and the use of machine-enabled control systems would enable the employment of Context-Centric C3, as shown in Figure 16. In Context-Centric C3, command relationships are established based on communications availability rather than attempting to build a network for a desired C2 structure.

For communications, composable forces would likely rely on decentralized wireless networks, in which each force element or the commander would only need to communicate with one

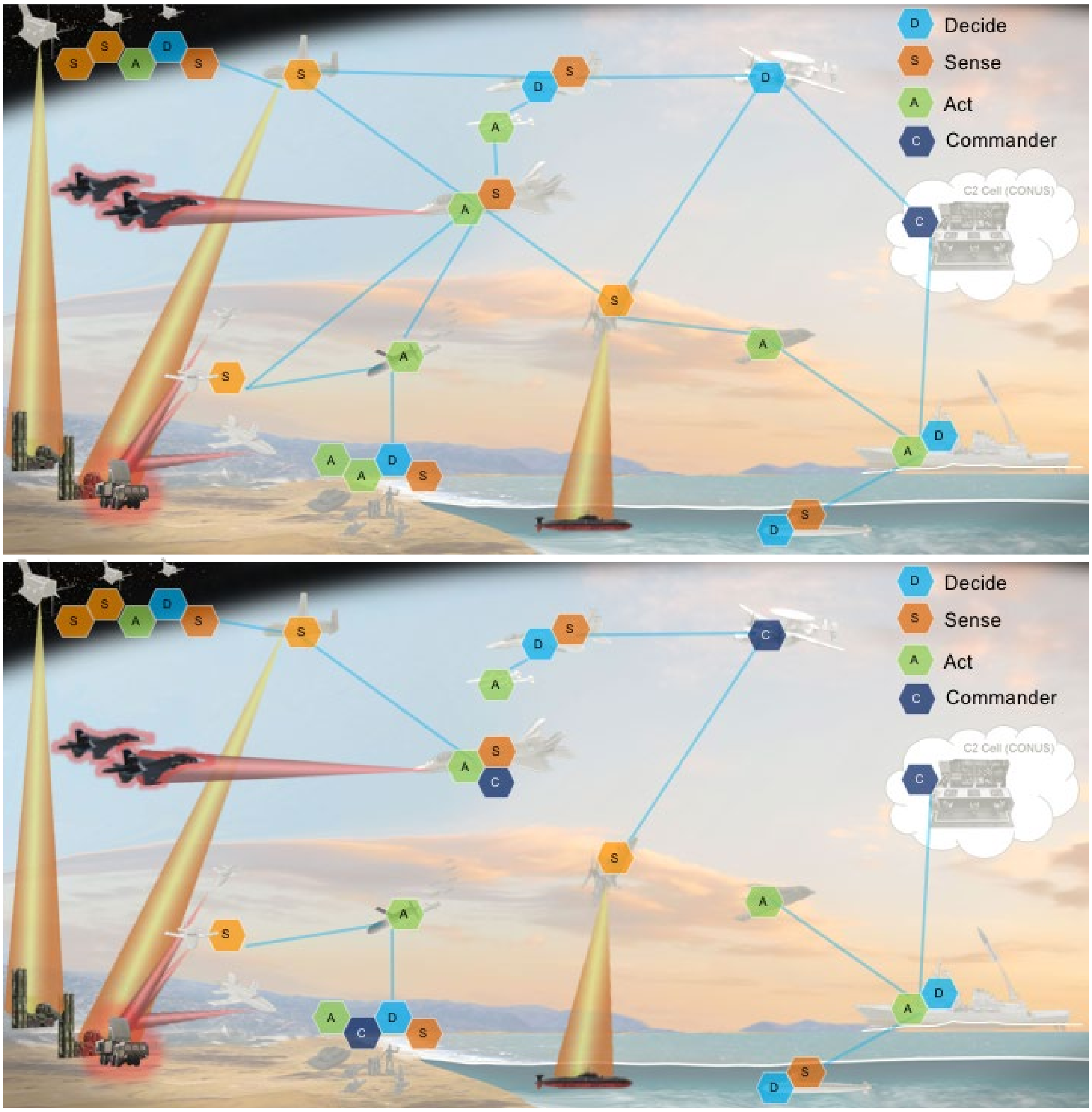
87 Tannya D. Jayal, "Distinguishing between Narrow AI, General AI and Super AI," *Medium,* May 21, 2018.

88 Ahmed El Deeb, "What to Do with "Small" Data?" *Medium,* October 6, 2015; and Parth Bhavsar et al., "Machine Learning in Transportation Data Analytics," in Mashrur Chowdhury, Amy Apon, and Kakan Dey, eds., *Data Analytics for Intelligent Transportation Systems*, (Amsterdam: Elsevier, 2017), pp. 283–307.

89 C. Rudin and B. Ustun, "Optimized Scoring Systems: Towards Trust in Machine Learning for Healthcare and Criminal Justice," *INFORMS Journal on Applied Analytics*, 2018.

other force element; messages would then be transmitted through the network and routed to the appropriate participant. These future wireless ad hoc networks (WANET) would be unlike existing mobile ad hoc networks (MANET) in that they would likely be heterogenous—using different communications and network protocols between various battle network nodes.

FIGURE 16: THE COMPOSABILITY OF A DISAGGREGATED FORCE ENABLES A CONTEXT-CENTRIC C3 ARCHITECTURE



Instead of building communications to meet a desired C2 architecture, the composability of a disaggregated force enables adapting a C3 architecture to align forces to commanders based on the available communications, maintaining a manageable span of control, and aligning forces needed for an interrelated set of operations under a single commander. In the first figure, a centralized commander is able to manage and communicate with a large, widely dispersed force. In the bottom figure, communications are degraded, and subordinate leaders must take mission command and pursue tasks aligned with the forces they can communicate with and have their planning facilitated by the machine-enabled control system.

Even with a resilient decentralized communications architecture and the machine-enabled control system distributed to each element of a composable force, a human commander may only be able to reliably communicate with forces over a portion of the operational area due to a lack of interoperability, enemy jamming, or environmental interference. Furthermore, a set of interrelated tasks should not be split across commanders because communications between commanders may be unreliable, and separate commanders may establish competing or inconsistent priorities and approaches for the interrelated tasks. To address these challenges, the machine-enabled control system would break down a large force into separate cells, each under its own commander and able to sustain communications across the forces in the cell. The machine-enabled control systems of the various cells would share data whenever able to deconflict operations between them and use a combination of organic sensors and AI-enabled modeling to predict the actions of other friendly forces in between updates.

Task organization using Context-Centric C3 is important because communications and cognitive limitations will likely preclude a large hierarchical organization under a single commander in future decision-centric conflicts. The machine-enabled control system would empower very junior leaders with minimal staff to manage the force under their command. In addition to enabling Context-Centric C3, the diffusion of command nodes throughout the force would also improve the force's adaptability and create a more complex operational picture for an enemy to assess.

Summary

Composable force design and Context-Centric C3 could enable a new approach to warfare centered on achieving faster and more effective decision-making than the adversary. By dynamically composing and recomposing forces in an effects web before and during an operation, a force could increase the U.S. military's adaptability while imposing greater complexity and uncertainty on an adversary.

As of yet, however, the potential benefits of this approach are largely theoretical. To begin assessing whether the principles of Mosaic Warfare might actually yield a prolonged advantage for the U.S. military, CSBA conducted a series of wargames to test and assess a set of hypotheses regarding Mosaic Warfare. The results of this effort are described in the next chapter. The implications for DoD of implementing Mosaic Warfare are addressed in Chapter 5.

CHAPTER 4

Assessing the Value of Mosaic Warfare

A shift toward decision-centric warfare is arguably underway, as evidenced by the recent military strategies of the United States, China, and Russia, as well as the increasing priority placed by competitors on concepts and capabilities designed to defeat U.S. communications and decision-making.[90] As described in Chapter 3, Mosaic Warfare could help enable DoD to gain a prolonged advantage in a new competitive regime centered on information and decision-making. CSBA explored the feasibility and benefits of Mosaic Warfare through a series of workshops and wargames that developed the concept's building blocks and assessed its potential utility compared to the U.S. military's current force design and operational approaches.

The wargames were constructed to test five hypotheses regarding the feasibility and operational benefits of the Mosaic Warfare concept:

- Commanders and planners can achieve trust in the COAs proposed by a machine-enabled control system;
- Mosaic Warfare will increase the complexity of U.S. force packages and degrade adversary decision-making;
- Mosaic Warfare will enable commanders to mount more simultaneous actions, creating additional complexity for adversaries and overwhelming their decision-making;
- The Mosaic force design and C2 process will increase the speed of the U.S. force's decision-making, enabling commanders to better employ tempo; and
- Mosaic Warfare will better enable U.S. commanders to implement their strategy than operations with a traditional force.

90 Adamsky, "Russian Intervention in Syria," p. 61.; Zheng, *Lectures on the Science of Information Operations*, p. 31; and Mattis, *National Defense Strategy of the United States* (2017).

Methodology

Figure 17 depicts the wargame methodology. The wargame scenarios were set in approximately 2035 and pitted U.S. forces against increasingly capable opponents (or Red) in situations that were designed to be relatively contained conflicts unlikely to escalate into large-scale war:

- Wargame 1: A Blue Joint Task Force is tasked with conducting a non-combatant evacuation and supporting the Democratic Republic of Congo government against Red maritime and ground forces attempting to overthrow the government, and which are supported by great power competitor troops and capabilities.

- Wargame 2: A Blue Joint Task Force is tasked with confronting a regional power that is attacking neighboring U.S. allies, including vignettes for hostage rescue, protection of oil and gas facilities, and locating and retrieving nuclear material.

- Wargame 3: A Blue Joint Task Force is tasked with degrading a Red sensor and weapons complex based in Tanzania and Kenya as part of a larger conflict against Red throughout the Indian Ocean. The sensor complex included long-range radars, overlapping active and passive air and missile defenses, advanced combat aircraft, and ballistic and cruise missiles, all of which were complemented by Red navy ships and submarines deployed in the Western Indian Ocean.

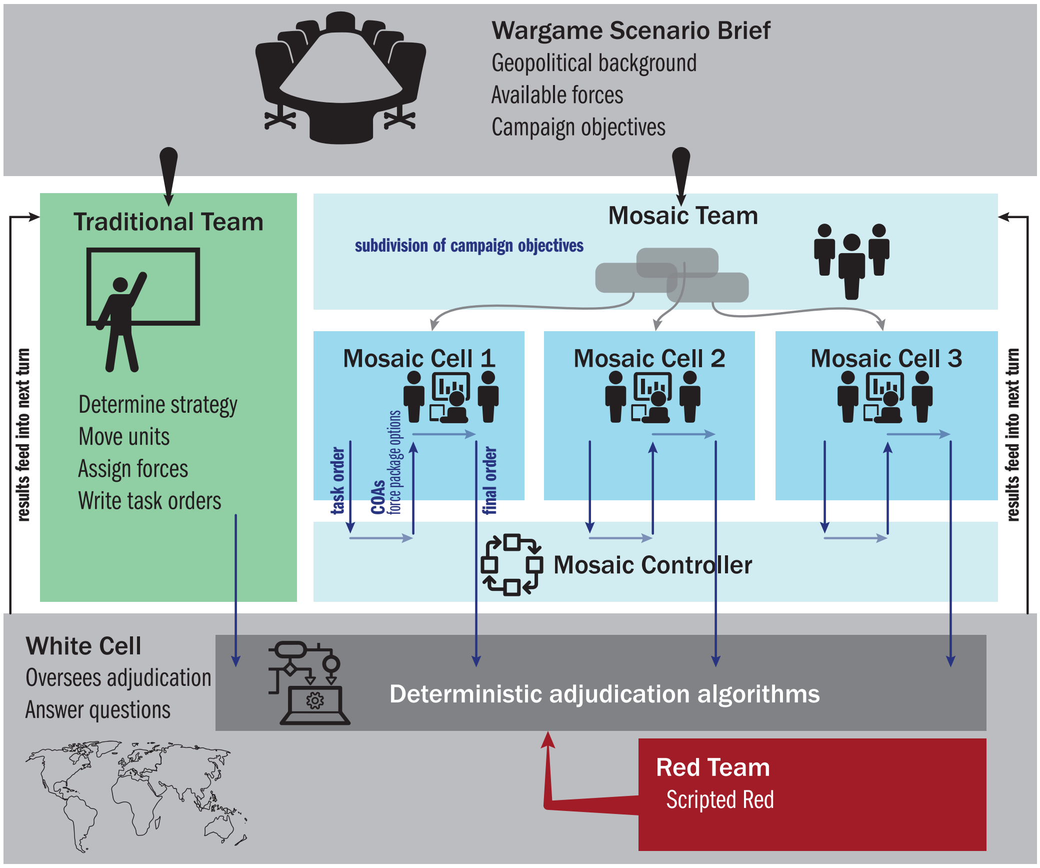
As shown in Figure 17, two Blue teams—one Mosaic, the other traditional—were used in the wargame to assess the impact of using Mosaic forces and C2 processes. The Mosaic and traditional forces were, in aggregate, of approximately equal capability and capacity.

The Traditional team used a force that projected DoD's current plans into the future and a C2 process similar to that of today's U.S. military in which commanders develop an overall strategy for the scenario and planners develop force packages and tactics to pursue that strategy. The Traditional team was allowed to organize itself as the participants saw fit.

The Mosaic team was divided into a command cell and three planning cells. The command cell was charged with developing an overall strategy, dividing up missions or geographies between the three planning cells, and managing the assignment to planning cells of traditional units such as multi-mission ships and aircraft. The planning cells were each provided one-third of the Mosaic units in the Blue force and used a computer-based simulation of a machine-enabled control system to develop task orders, review COAs, and assess results.

To enable the project to focus on developing and assessing the Mosaic Warfare concept, the wargames did not use a live adversary (or Red) team, and instead scripted the Red force's actions. The control (or White) cell running the wargame assessed whether the Red force's scripted actions should change in response to Blue team actions.

FIGURE 17: METHODOLOGY USED FOR THE THREE CSBA-LED MOSAIC WARGAMES



The construct allowed for the comparison of Mosaic forces and C2 processes against those of a future Traditional force and C2 process.

The wargames each consisted of three phases to allow the scenario to be updated between phases and provide teams an opportunity to periodically out brief their plans and results. Within each phase, the Traditional teams and the Mosaic planning cells executed multiple turns at their own pace. A turn comprised all the actions the team or planning cell wanted to execute simultaneously and was projected to last between two and six hours in game time, depending on the wargame scenario. Turns were assumed to be longer during wargames that included more ground operations.

After each team or planning cell formulated their actions for a turn, the White Cell adjudicated the results against the Red script using a deterministic modeling toolset and presented the results to the Blue teams, which would then conduct the next turn. A deterministic model was used to enable turns to be re-run after the wargame to assess paths not taken and the sensitivity of the results to Blue choices regarding force packaging.

Assumptions

Because the underlying systems and capabilities needed for Mosaic Warfare do not yet exist, the wargame series assumed future solutions had overcome the four main technical challenges to implementing Mosaic Warfare: logistics, communications, AI-enabled machine control, and autonomous systems. By assuming these challenges were addressed, the wargames could proceed to test hypotheses and evaluate the potential utility and feasibility of Mosaic Warfare. The ability of the future U.S. force to develop technologies in the four areas should be assessed in future Mosaic Warfare-related studies.

Logistics

Some advocates of disaggregated forces describe future warfare as being conducted almost exclusively by distributed swarms of small machines, but these proposals do not address the challenges of moving small, short-endurance vehicles or ground units into position for their assigned tasks—or supporting them with fuel, food, ammunition, or maintenance and repair.[91] Mosaic Warfare compounds these challenges by distributing systems throughout the operating area, which will require new supply chain models.[92]

To transport small platforms and troop formations into the operational area, Mosaic forces in the wargames used traditional units to transport small units forward—such as in the DARPA Gremlins program—or prepositioned small systems closer to the operating area.[93] Smaller Mosaic force elements were assumed to be expendable once deployed.

The wargames assumed sustainment requirements for traditional units could be met largely organically. This assumption was assessed as valid because the scenarios lasted less than one month and did not extend over more than 300 nm, allowing traditional platforms and formations to conduct operations without in-stride sustainment or in-flight refueling. For example, an MEU is designed to logistically support itself for 15 days, and the Army has a goal of 7 days of organic sustainment for Brigade Combat Teams (BCT).[94] Fuel and supplies beyond these limits were assumed to be transported by intra-theater lift to the operating area and delivered to individual units by logistics elements organic to the wargame forces.

Mosaic forces could address sustainment for longer or more contested operations by leveraging algorithmic and architectural approaches being pursued in the commercial sector that

91 Chris Brose, "The New Revolution in Military Affairs," *Foreign Affairs,* May/June 2019.

92 Timothy A. Walton, Ryan Boone, and Harrison Schramm, *Sustaining the Fight: Resilient Maritime Logistics for a New Era* (Washington, DC: Center for Strategic and Budgetary Assessments, 2019).

93 "Gremlins on Track for Demonstration Flights in 2019," *DARPA News and Events*, available at https://www.darpa.mil/news-events/2018-05-09.

94 15th Marine Expeditionary Unit, "What is a MEU," *Team BULLRUSH,* available at https://www.15thmeu.marines.mil/About/What-is-a-MEU/; and Todd South, "Forget the FOBs: Army Logistics Must Adapt for the Modern Battlefield," *Army Times*, November 6, 2018.

are reducing inventory and resupply time through predictive modeling, resilient multi-path distribution, and distributed inventory.[95] Mosaic forces could also use emerging technologies that would adapt local resources such as fuel, water, and food to requisite quality standards.[96]

Communications

The wargames assumed that at least one of the units in a Mosaic force would be able to periodically receive direction from the commander as well as provide the commander proposed COAs and the results of operations. Each Mosaic unit would not need to communicate directly with every other Mosaic unit; instead, it would only communicate with adjacent units that would then relay information throughout a mesh network. Heterogeneity in the network would allow communications to flow through an alternative path if one waveform is jammed.[97]

Although the Mosaic Warfare wargames incorporated the effects of enemy communications jamming, they assumed units participating in a Mosaic force would be interoperable with one another via translation systems like STITCHES or gateways such as BACN.

AI-enabled machine control and autonomous systems

The Mosaic Warfare wargames assumed that a machine-enabled control system would be possible and used a simplified proxy version of the system to facilitate gameplay. The proxy control system imitated emerging distributed marketplace resource management techniques, broadly similar to popular ride-sharing applications.[98] In the wargame C2 construct, a commander in a planning cell issued task orders via a text-based user interface to the machine-enabled control system. The commander's orders prescribed the nature, context, priority, timing, risk tolerance, and location of tasks for the force to conduct. Using the task orders, the machine-enabled control system established the Context-Centric C3 architecture by aligning forces to commanders based on communications availability, managing span of control, and aligning interrelated tasks to a single commander.

Acting in priority order, the control system used an auction-like process to assign units to tasks from the units made available for tasking by the commander. In the auction, individual units in the Mosaic force "bid" on tasks, with the quality of their bids based on their ability to successfully complete the task within the constraints described in the task order. Continuing the ride-sharing analogy, this would be similar to a driver being assigned a ride because the

95 Ajay Agrawal, Joshua Gans, and Avi Goldfarb, *Prediction Machines* (Boston, MA: Harvard Business Review Press, 2018), p. 105.

96 James T. Bartis and Lawrence Van Bibber, *Alternative Fuels for Military Applications* (Santa Monica, CA: Rand Corporation, 2010), p. 39–43.

97 Amy Butler, "5th-to-4th Gen Fighter Comms Competition Eyed In Fiscal 2015," *Aviation Week*, June 18, 2014; and "DARPA Uses Open Systems, 'Plug and Fly' to Boost Air Power," *U.S. Defense News Service,* March 30, 2015, available at https://dod.defense.gov/News/Article/Article/604383/darpa-uses-open-systems-plug-and-fly-to-boost-air-power/.

98 Waliany et al., "How Trip Inferences and Machine Learning Optimize Delivery Times on Uber Eats."

driver had an appropriate vehicle and was in a position to reach the rider faster than other drivers with less-appropriate vehicles. The resulting C3 architecture, units, and TTPs constituted a COA. The proxy control system provided teams three COAs, which were designed to conduct all the tasks directed by the commander for that turn, to choose from.

The sophistication needed in the machine-enabled control system could be reduced by increasing the autonomy possible in subordinate units or systems. For example, decision aids incorporating AI built into small manned units or unmanned systems could allow them to propose complex approaches to achieve the commander's tasks with relatively simple direction from the commander and the machine-enabled control system. This would be analogous to a ride-sharing company driver using local knowledge to improvise a route to avoid traffic without depending on the ride-sharing app to provide detailed directions.

Wargame Results

The workshops and wargames found evidence for many of the potential benefits hypothesized for Mosaic Warfare, as described below, with significant caveats. In addition to the assumptions made about logistics, communications, and AI and autonomous systems described above, the game version of the machine-enabled control system lacked the modeling and simulation capabilities of a real control system, and the characteristics of Mosaic force elements used by the control system were extremely simplified. As a result, participants tended to accept the force packages and implied tactics in the control system's proposed COAs without significant question or analysis.

The game construct also could have influenced the results. The three Mosaic planning cells included more personnel in total than the Traditional team. This was designed to allow more wargame participants to experience the Mosaic C2 process but could have enabled the larger Mosaic team to consider more tasks than the Traditional team. Alternatively, the Traditional planning cell could have been more efficient because it had fewer people to coordinate with and achieve consensus. The effects of these artificialities are addressed in the following discussion, organized around the hypotheses tested in the wargames.

1. Commanders and planners can achieve trust in the COAs proposed by a machine-enabled control system

Wargame participants quickly accepted the use of the machine-enabled control system, as well as most of the COAs it proposed. Perhaps most importantly, they were willing to consider, although not always approve, COAs that included novel force packages and implied unconventional tactics. When commanders did not approve a COA, they did not get to then assemble their own plan. They were required to adjust their task orders and rerun the control system to obtain new COAs. This helped prevent commanders from creating their own force package and tactics, which could lead them to fall back into predictable doctrinal or habitual planning.

Participants' trust was reinforced by their ability to interact with the machine-enabled control system. In addition to changing their task orders, the control system allowed teams to vary their estimate for adversary force size and effectiveness, the relative priorities of tasks, their preferences for manned vs. unmanned forces, and the amount of ISR capability and capacity to incorporate in force packages. By assessing how these changes impacted the proposed COAs, teams were able to establish an understanding of how the control system developed its results.

In some cases, participants asked for detailed descriptions of how the force packages proposed in a COA would operate, which was beyond the capability of the proxy control system used in the wargame. While the explanations need not be comprehensive, there are certain pieces of information teams believed would be particularly useful in explaining the control system's proposals:

- Communications expected between elements of the proposed force packages. As noted above, in Mosaic Warfare, the C2 architecture and commander's span of control will be driven by communications availability, rather than trying to establish a communications architecture to support a desired C2 construct. Therefore, for commanders to evaluate proposed COAs, they would need to understand the communications required for the COA and the control system's estimate for what communications would be available.

- Graphical depiction of the overall scheme of maneuver of the force package to include the intended effects chain, sensor usage, C2 architecture, and effectors. Participants in the wargame often questioned the utility of COAs that included novel force packages or implied unconventional tactics.

- The importance of each force element to the overall effectiveness of the kill chain. Novel force packages and tactics were more likely to lead wargame participants to question the need for particular units in the force package. Understanding the overall CONOPs for the COA and the relative importance of each unit to the COA's probability of success would reduce the inclination of commanders to attempt to break up force packages and reallocate forces.

A figure of merit (FoM) measurement was established to allow participants to quickly evaluate the relative utility of proposed COAs. This unitless number was derived from a combination of the Mosaic force's effectiveness against the adversary force and the degree to which the force package met the criteria established by the commander in task orders. Although the FoM was not a true measure of the force's capability, teams did focus on it as a way of evaluating which COA they should select of the three options provided by the control system.

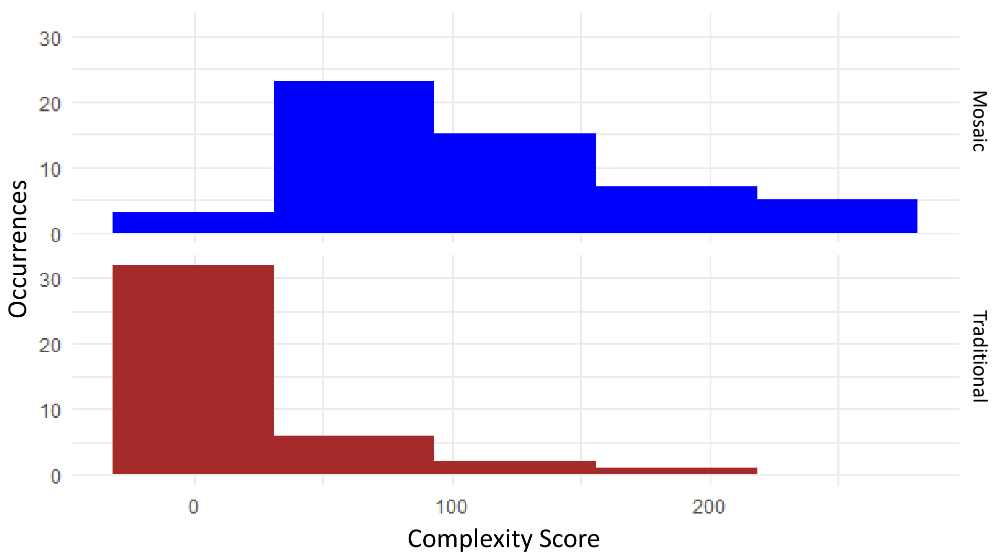
2. Mosaic Warfare will increase the complexity of U.S. force packages and degrade adversary decision-making

Mosaic Warfare is intended to increase the complexity of U.S. force packages in order to degrade the ability of an adversary to orient its forces, reducing the speed and effectiveness of enemy decision-making. In addition to being able to form multiple effects chains from an effects web, a Mosaic force and control system could allow recomposing effects chains in a force package once an operation is underway. As a result, an adversary may be uncertain regarding the tactics and functions the elements in a Mosaic force package will eventually use in an engagement.

The complexity imposed by a force package could be measured by the number of different ways units in the force package could be composed into a kill or effects chain. A more complex force package, or one with more potential compositions, should be better able to deceive an adversary regarding the force's true objective and intended tactics. This should increase the cost and effort needed by the adversary to develop and field countermeasures to all the possible Mosaic force's configurations and tactics. Otherwise, the adversary would need to accept the risk that the Mosaic force could implement a COA that would circumvent its defenses.

In the wargames, each force package proposed by the Mosaic machine-enabled control system or developed by the Traditional planning cell was assigned a complexity score based on the number of different combinations of sensors, C2 nodes, and effectors possible using the units in the force package. As shown in Figure 18, the complexity of Mosaic force packages was significantly higher than those of the traditional forces.

FIGURE 18: COMPLEXITY SCORE FOR WARGAME THREE BY TEAM



This figure depicts the complexity score, or the natural log of the number of possible kill chain combinations, for Wargame #3 by team. The lower quartile of complexity for Mosaic forces is above the upper quartile for traditional forces.

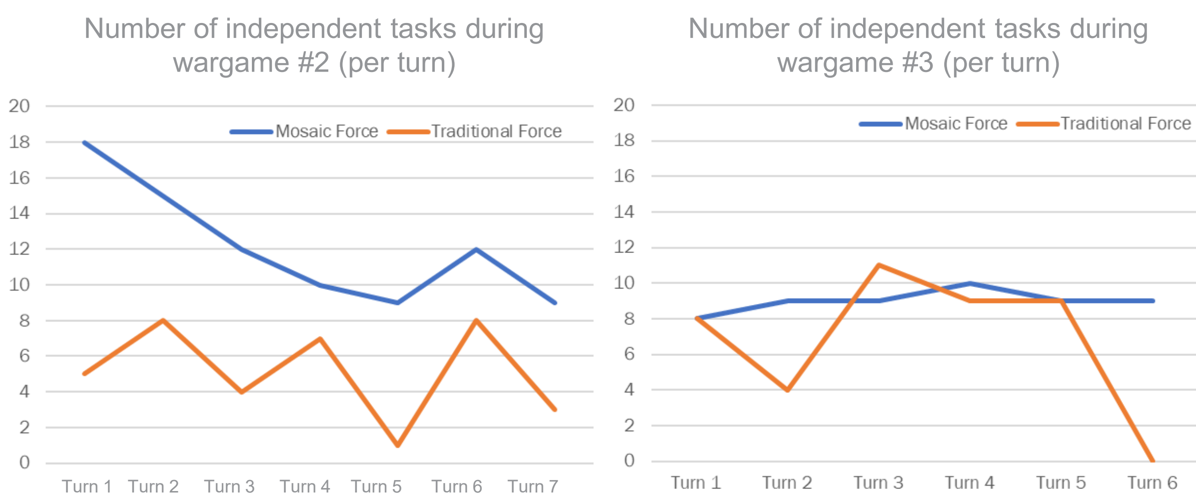
The wargame series did not, however, determine if the higher complexity possible with the Mosaic force degraded adversary decision-making. Although the White cell, representing the Red team, did adopt branch plans in response to some Mosaic team actions, these adjustments were not necessarily the result of the Mosaic force's complexity. A future wargame series should include a live Red team to enable this hypothesis to be more fully explored.

3. Mosaic Warfare will enable commanders to mount more simultaneous actions, creating additional complexity for adversaries and overwhelming their decision-making

The Mosaic force's smaller individual units and composability should allow the machine-enabled control system to calibrate the capability and capacity of force packages for specific tasks and environments. Force packages could be designed to achieve the desired level of overmatch against the adversary, as measured by the ratio of lethality and capacity in the Blue force to the Red force in an engagement or task. The ability to more finely calibrate force package capability and capacity could enable a Mosaic force to be allocated over more separate tasks or actions. A larger number of simultaneous tasks should be more complex for an adversary to assess and counter and could overwhelm an adversary's decision-making process.

The wargames suggested this hypothesis may be true, as shown in Figure 19. As noted above, however, a contributor to the Mosaic force's productivity could be that in aggregate, the Mosaic teams included more participants than the Traditional team, which potentially enabled them to plan more simultaneous tasks.

FIGURE 19: INDEPENDENT ACTIONS CONDUCTED BY MOSAIC AND TRADITIONAL TEAMS IN WARGAMES TWO AND THREE



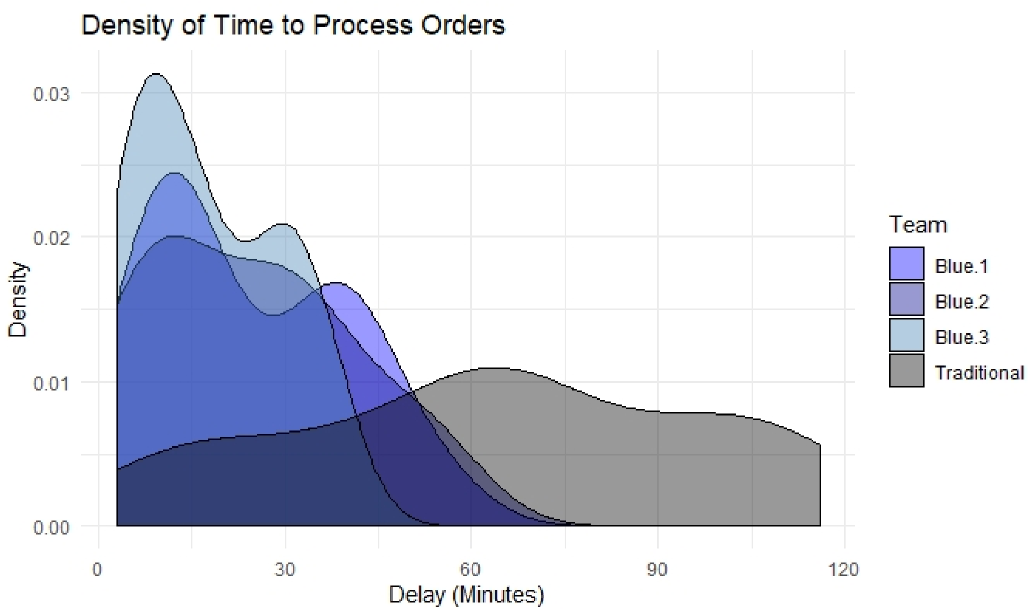
The number of independent actions conducted by Mosaic and Traditional teams during the second and third Mosaic Warfare wargames, broken down by turn. Each turn in the game was an approximately two-to-six-hour period during which a set of parallel actions could be initiated.

The difference in the number of actions conducted narrowed between Mosaic and Traditional teams in the third wargame. In large part, this was because returning participants on the Traditional team assumed more autonomous operations by subordinate manned units conducting Mission Command. This allowed the Traditional team to focus on the overall CONOPs its forces would pursue and spend less time planning tactics in detail. As the scenario became more intense, and the Traditional force suffered losses, tactics became more important to consider, slowing the Traditional team's planning. As a result, the fifth turn during wargame #3 took so long to plan that the Traditional team did not have time remaining to plan the sixth turn.

4. The Mosaic force design and C2 process will increase the speed of the U.S. force's decision-making, enabling commanders to better employ tempo

Mosaic Warfare is intended to improve the speed of decision-making and action by increasing the flexibility of the force and incorporating machine control into the C2 process. Commanders may also be more willing to quickly approve a COA because a Mosaic force would be more recomposable than a traditional force, allowing tasks or force package configuration to be more easily modified after an operation is underway.

FIGURE 20: TIME DELAY FOR PLANNING CELLS, TRADITIONAL VERSUS MOSAIC TEAMS



The time delay for wargame planning cells to issue orders was longer and more widely distributed for the Traditional team (gray) compared to the three Mosaic planning cells (blue).

During the wargames, Mosaic teams achieved shorter and more consistent planning times than the Traditional team, as shown in Figure 20. Although the Mosaic force's adaptability contributed to faster planning, the speed and consistency of Mosaic team decision-making was also a function of the machine-enabled control system developing COAs that participants considered to be "85 percent solutions." As a result, teams spent their effort fine-tuning nearly complete tactics and force packages, instead of having to assign forces to tasks and develop CONOPs like the Traditional team.

The importance of the machine-enabled control system to allow rapid decision-making suggests that perhaps the Traditional team could plan operations faster if it were provided a modeling and simulation-based tool that projected the performance of a potential force package. Even with improved planning tools, however, the Traditional team would still need to build force packages and develop their tactics manually, whereas the Mosaic teams could rely on the machine-enabled control system to automatically perform these functions.

5. Mosaic Warfare will better enable U.S. commanders to implement their strategy than operations with a Traditional force and C2 process

During the wargames, Mosaic teams were able to calibrate the size, effectiveness, and composition of force packages to match commanders' risk tolerances and achieve the desired level of overmatch. This enabled Mosaic teams to employ calculated risk and conduct probing, feints, or sensing operations that may result in high losses but achieve the intended objective. In combination with faster decision-making as described above, the ability to calibrate force packages enabled Mosaic teams to initiate more simultaneous actions than was possible with the Traditional force. Commanders were able to exploit these attributes to better implement their strategies through operational art.

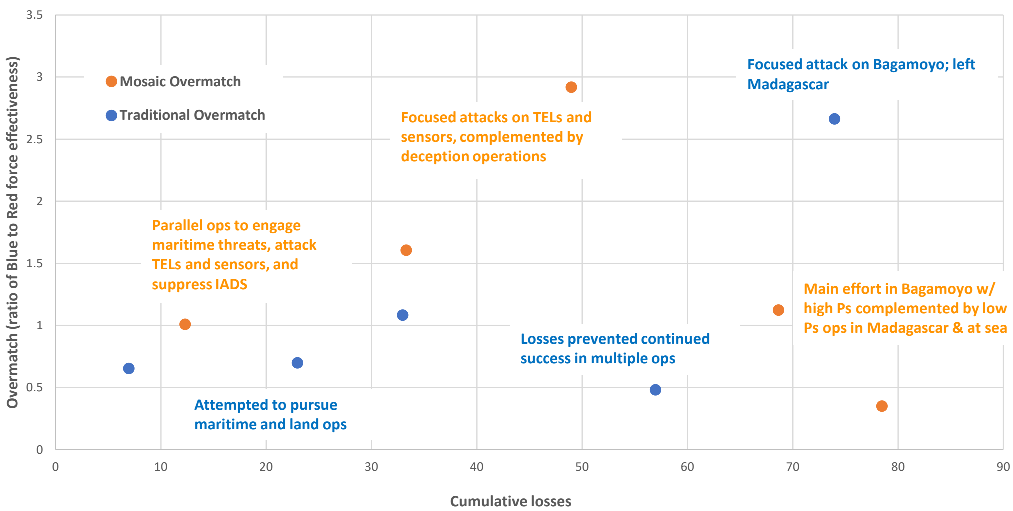
The wargame scenarios pitted U.S. forces against increasingly capable opponents. The discussion that follows focuses on the third wargame, which was the most difficult of the three and most reflective of the threats and challenges posed by great power competitors. During that final wargame, the Blue teams were tasked with degrading a Red sensor and weapons complex based in Tanzania and Kenya as part of a larger conflict against Red throughout the Indian Ocean. The sensor complex included long-range radars, overlapping active and passive air and missile defenses, advanced combat aircraft, and ballistic and cruise missiles and was complemented by Red navy ships and submarines deployed in the Western Indian Ocean.

To address the Red threat, Mosaic and Traditional teams both decided to pursue a series of rapid, parallel attacks against Red forces across the Western Indian Ocean to overwhelm Red decision-making, restore freedom of action for friendly forces, and pressure Red leaders to seek an off-ramp from the conflict. Only the Mosaic teams were able to successfully achieve this objective.

The Mosaic team exploited its ability to more precisely manage the capability and capacity of its force packages to shift between a large number of higher-risk tasks and a small number of lower-risk tasks, depending on what was needed to implement the strategy. As shown in Figure 21, the Mosaic team initially mounted several parallel tasks across the theater to dilute the enemy's efforts and immediately begin destroying long-range sensors and missiles. By spreading their forces across more tasks, the Mosaic force accepted less overmatch against Red, which resulted in higher losses; the losses, however, were mostly in small or unmanned units. The Mosaic team then concentrated attacks against the main Red missile sites and intentionally pursued greater overmatch to ensure a higher probability of success. Once the Red missile sites were degraded, the Mosaic team shifted back to a wider range of lower-probability-of-success operations across the theater to prevent Red reconstitution.

The Traditional team also initially attempted simultaneous attacks against Red forces across the theater and against Red long-range weapons and sensors in East Africa. The Traditional force suffered high losses that significantly impacted its size and effectiveness because the Traditional team's force consisted of fewer units that were individually more sophisticated and costly compared to those of the Mosaic force. The Traditional team then shifted to serial operations in which it could achieve a higher degree of overmatch and probability of success.

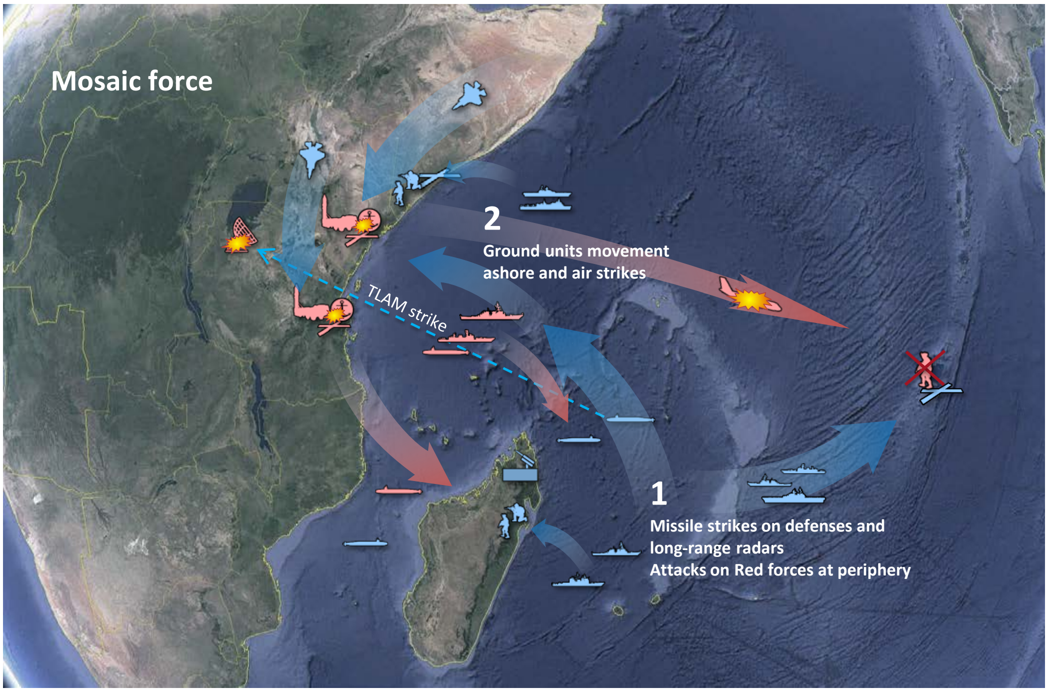
FIGURE 21: OVERMATCH ACHIEVED BY MOSAIC AND TRADITIONAL FORCES AGAINST RED

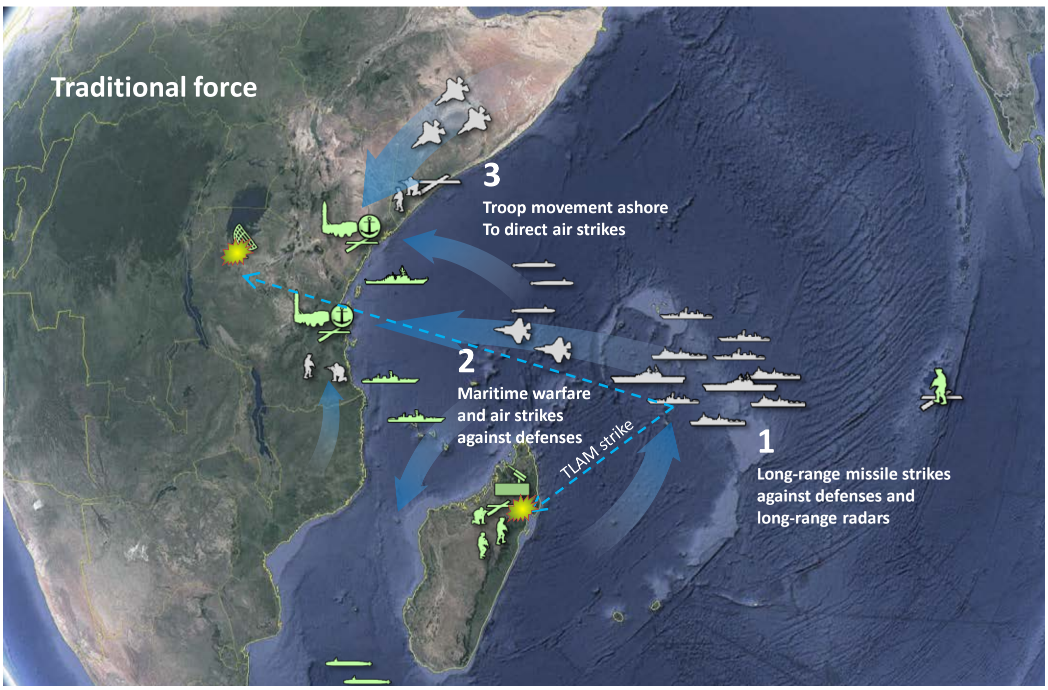


The overmatch achieved by Mosaic and traditional forces against Red forces in the third wargame shows the ability of the Mosaic teams to adjust the scope and intensity of effort to implement their strategy.

Using their ability to conduct more rapid, direct, and parallel action than the Traditional force, the Mosaic teams were able to reach their objectives after two phases of operations, as shown in Figure 22. They spent the final phase of the wargame using ground troops to search out and destroy remaining Red sensors and weapons launchers. In comparison, the Traditional team was unable to achieve its objectives because it conducted serial actions to degrade defenses, then attempted to eliminate long-range threats. By the third phase of the wargame, the Traditional team was still attempting to degrade long-range weapons launchers using a combination of ground force-enabled targeting and air attack.

FIGURE 22: TRADITIONAL VERSUS MOSAIC FORCE LAYDOWNS

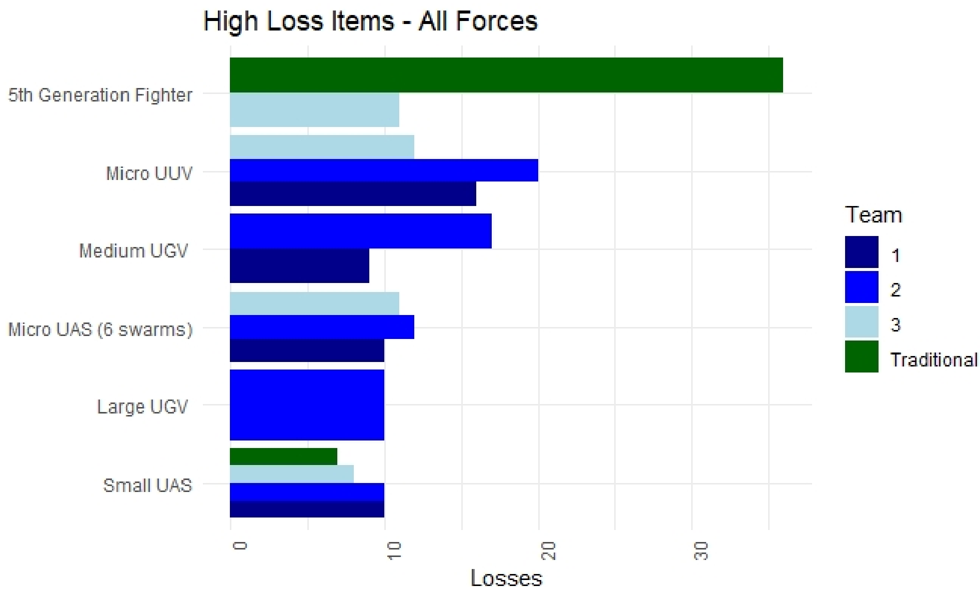




The Mosaic force design and C2 process enabled Mosaic teams to more directly pursue their objectives in the face of enemy threats and engage the enemy on multiple, simultaneous fronts. The Traditional force, in comparison, was forced to act in serial fashion, preventing them from achieving the tempo and geographic coverage their strategy required.

As shown in Figure 23, the Mosaic force was able to absorb higher losses without impacting its overall size and effectiveness because the losses were predominantly in smaller unmanned systems that were more numerous and less expensive than traditional platforms. For instance, the overall cost of the Mosaic force's lost platforms in the third wargame was less than one-third of the Traditional team's losses.

FIGURE 23: TRADITIONAL VERSUS MOSAIC FORCE ATTRITION



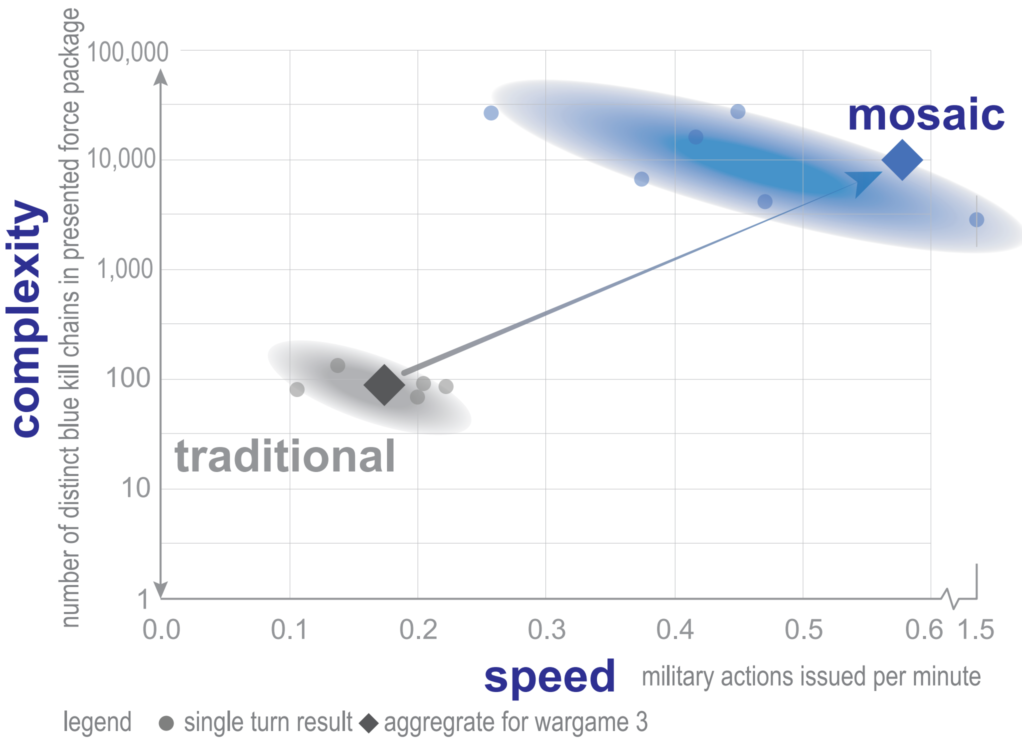
Although the Mosaic force suffered higher losses in the third wargame (in blue), the losses were weighted toward unmanned and smaller units. This reduced the impact of losses on the Mosaic force's overall size and effectiveness compared to the traditional force (in green).

Summary

The combination of greater complexity and the ability to take more actions, as shown in Figure 24, could enable Mosaic forces to overwhelm the decision cycle or OODA loop of opponents. This would likely generate major tactical and operational-level benefits. It could possibly also deter an adversary from committing an act of aggression or force it to seek an off-ramp after an operation begins.

This project was not able to address the impact of the Mosaic force's speed and complexity on adversary commanders and operations, because a live Red team was not employed. This enabled the project to focus on refining the Mosaic force design and C2 process. A future wargame series should examine the impact of Mosaic Warfare on adversary decision-making and actions, as well as the implications of adversaries fielding their own versions of Mosaic Warfare.

FIGURE 24: TRADITIONAL VERSUS MOSAIC FORCE COMPLEXITY AND SPEED



The complexity and speed possible with Mosaic forces far exceeded those of the traditional forces during each Mosaic Warfare wargame. The data from the third wargame, shown here, suggests the Mosaic force would have a higher likelihood of overwhelming the adversary's decision-making process compared to the traditional force.

CHAPTER 5

Implementing Decision-Centric Warfare

DoD will need to do more than simply replace some of its force structure and buy new decision support tools to implement a warfighting concept focused on decision-making. The U.S. military will need to also change the processes it uses to develop new capabilities and allocate resources to field more recomposable and disaggregated systems. Furthermore, to enable the C2 processes needed to operate a more disaggregated force and pursue decision superiority, DoD will need to revise its doctrine and training.

Although today's DoD investments and strategy are focused on the material and operational aspects of new approaches to warfare, institutional reforms are arguably more important to U.S. success in long-term competitions with China and Russia. The discussion that follows highlights some of the most significant implications of decision-centric warfare concepts for DoD institutional functions. Further study will be required to assess how DoD processes and structures should change to implement a decision-centric approach.

Adopting a New Strategy for Posture and Deterrence

The 2018 U.S. National Defense Strategy increased DoD's emphasis on decision-making by using Dynamic Force Employment to reduce the predictability of U.S. force deployments and create a more complex force presentation to adversaries. The strategy's more unpredictable deployments, however, are still in service of operational concepts such as DMO and MDO and an overall force posture designed to stop enemy aggression largely through attrition.

As described in previous chapters, decision-centric operational concepts like Mosaic Warfare could improve the ability of U.S. forces to counter adversary aggression. Decision-centric warfare enables greater adaptability for U.S. forces, imposes more complexity and uncertainty on adversaries, allows U.S. forces to mount more simultaneous operations, and could increase U.S. operational tempo compared to traditional forces and C2 processes. The force design of decision-centric units could also allow them to be less expensive and more sustainable over a long-term competition compared to the monolithic multi-mission platforms and troop formations that dominate today's U.S. military.

As noted in Chapter 3, however, disaggregated or composable forces may not be well suited to all situations. They may lack the endurance, mobility, and human operators to be useful in missions such as training, security, counterinsurgency, or disaster response. Moreover, the uncertainty and complexity created by decision-centric warfare may not always be useful in deterring adversaries or reassuring allies. U.S. allies and adversaries have become accustomed to U.S. forces deploying in large force packages of multi-mission units such as CSGs, BCTs, and MEUs. Adversary leaders may perceive a complex and uncertain U.S. force disposition as a prelude to attack or a sign of weakness, causing the adversary to preemptively and opportunistically attack. Allied leaders may likewise view U.S. force complexity as a lack of resolve and choose to act independently.

To provide the predictability and endurance needed for deterrence and reassurance, U.S. strategy should employ a combination of traditional and disaggregated units in the forward forces facing allies and adversaries day-to-day, which the National Defense Strategy calls the Contact layer. Disaggregated forces would provide scalable options for peacetime functions such as surveillance, counter-ISR, and gray zone interventions, and traditional platforms and formations could provide transportation and support. If a confrontation escalates into conflict, disaggregated units in the Contact layer could rapidly engage the enemy and enable traditional forces to withdraw.

Composable units would form a larger portion of forces in the defense strategy's Blunt layer, which is intended to augment forces in the Contact layer during conflict. Disaggregated units in the Blunt layer would be able to rapidly conduct multiple simultaneous and highly adaptive operations in support of Contact layer forces countering enemy aggression. Forces in the Contact and Blunt layers would employ human command and machine control to improve their adaptability and help integrate traditional with disaggregated units.

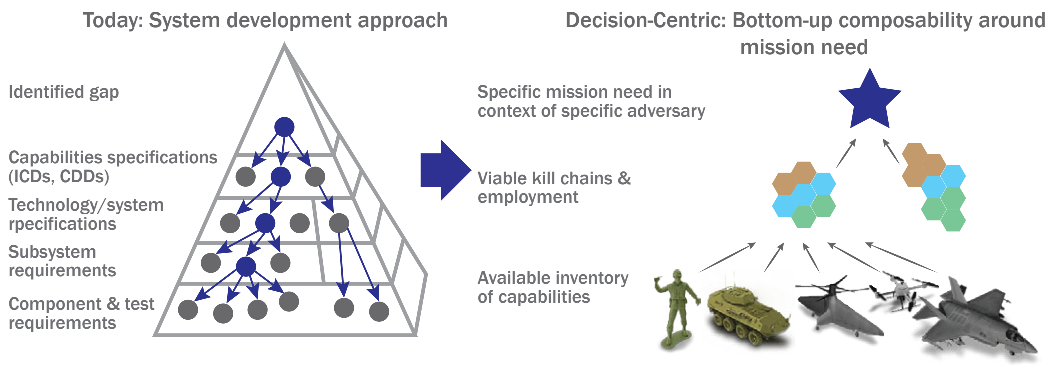
The balance of composable to traditional forces in the Contact and Blunt layers could vary over time and by region or competitor. Against great powers, for example, the Contact layer may frequently contain a larger portion of disaggregated forces than it would against regional powers. This would increase the complexity of U.S force presentation and enable more numerous risk-worthy options for commanders to use in responding to aggression. The addition of more disaggregated and composable units into a region's Contact layer may also be a way of deterring opportunistic aggression when U.S. Blunt layer and Surge forces are engaged in a conflict elsewhere. For example, during a military confrontation between China and Japan in the East China Sea, U.S. forces operating as part of the Contact layer in the Persian Gulf may begin to incorporate more composable force elements and adopt Context-Centric C3 processes to increase the uncertainty of Iranian leaders regarding the likelihood they could successfully pursue military objectives, even while the bulk of U.S. forces are focused elsewhere.

Developing Requirements to Enable Composability

Today's U.S. military consists of highly engineered systems and platforms architected into SoS that meet specific performance requirements. New systems in this architecture are intended to fill gaps in the ability of these SoS to address projected threats. This approach bases requirements on a set of assumptions regarding the future capabilities of adversaries, likely conflict scenarios, and the tactics and configurations of U.S. forces. If these assumptions are incorrect, the requirement may be more uncertain or less important than originally assessed.[99]

In contrast to the point solutions sought in today's top-down requirements development process, the needs for decision-centric warfare capabilities should address the range of compositions possible for a disaggregated or composable force. In the bottom-up requirements process for decision-centric forces, capability needs would be identified by evaluating the impact of potential new systems or platforms on the ability of an array of likely force packages to accomplish their missions in a variety of likely scenarios. New systems should be pursued that yield an improved overall capability in relevant missions and situations based on modeling and simulation or experimentation.

FIGURE 25: REQUIREMENTS DEVELOPMENT APPROACH FOR DECISION-CENTRIC FORCES



The requirements development approach for decision-centric forces will assess new capabilities in the context of a range of missions and scenarios.

Because composability would enable a particular system to be used in different ways each time it is employed, an individual system's requirements could be relaxed to reflect the contributions of other capabilities in potential force packages. As a result, individual elements or systems could be acquired using a less stringent approach that trades cost, schedule, and performance within the framework of the overarching mission. The Navy took this approach in their recent development of the MQ-25 Stingray UAV as an element in its concepts for the mission of long-range strike by carrier air wings, which Navy leaders argue enabled the Navy to better manage the new aircraft's cost and schedule.[100]

99 U.S. Joint Staff, CJCSI 5123.01H, pp. D-1–D-3.

100 Government Accountability Office (GAO), *Navy Unmanned Aerial Refueling System* (Washington, DC: GAO, 2017), p. 7.

Conducting Idea-based Innovation

Enabling complexity and adaptability in decision-centric forces will require systems that cause useful emergent behavior in force packages, rather than simply filling gaps in current or planned SoS and tactics. To identify ways to improve the force, innovation efforts should instead introduce new systems, first through modeling and simulation, and then assess how the change improves the force's performance in relevant metrics.

Developing new capabilities that do not service identified capability gaps will require a new process for defense R&D. One such approach is idea-based, or learning-based, innovation. In this R&D process, ideas for new capabilities and concepts would be solicited via open-ended requests for proposals, similar to today's Broad Area Announcements (BAA). However, rather than targeting an already-defined program need as in today's BAA, future requests for proposals would be to support overarching missions or concepts.[101]

In this model, ideas would continue to be proposed by innovators. However, instead of shepherding the development of a specific idea into a demonstration or deliverable, program managers would focus on evaluating new ideas through challenges that quickly weed out unfruitful ideas and retain those with promise. Before significant development work is started, the challenge process would determine, through experimentation or simulation, whether the new idea can create a useful emergent capability in the force. Overall, this approach would shift more of the expensive technical development until after an idea is assessed as being potentially useful.

Compared to a traditional requirements-driven R&D approach, an idea or learning-based R&D approach could improve DoD's ability to compete with great power adversaries. Great power adversaries study DoD budgets and likely have identified priorities for current DoD R&D efforts, assessed the potential results, and are pursuing countermeasures. Learning-based innovation would explore how new, potentially disruptive technologies and revolutionary concepts could change the way U.S. forces operate and establish new metrics for success. This may give the U.S. military a first-mover advantage in new capabilities compared to its adversaries.

Enabling Middle-Tier Acquisition

The DoD acquisition manual seeks flexibility, responsiveness, innovation, discipline, and effective management, but the Tailored Traditional Acquisition Process is tied to relatively rigid requirements and engineering processes.[102] The wide variety of force compositions and tactics possible with decision-centric warfare will not yield fixed, define requirements.

As the force becomes more disaggregated and emphasis shifts from perfecting individual systems to developing effective battle networks, individual force elements should become less complicated and easier to develop and acquire, alleviating the need for some of the

101 This approach is described in more detail in John D. Evans and Ray O. Johnson, "Tools for Managing Early-Stage Business Model Innovation," *Research-Technology Management*, September-October 2013, p. 52.

102 U.S. Department of Defense, "DoDD 5000.01: The Defense Acquisition System," (Washington, DC: DoD, 2018), p. 2.

management steps inherent in the traditional acquisition process. By breaking up capabilities into smaller elements, each unit of the force should have fewer dependencies, less risk of failure, and less development complexity compared to the current U.S. capabilities. In turn, this should enable a more rapid pace and broader front for technology developers and expand R&D to a larger number of smaller and commercial manufacturers beyond today's prime defense contractors.

DoD's new Middle-Tier Acquisition Process is well-suited to develop the less complicated and less-multi-functional capabilities needed for decision-centric warfare. This process enables, through rapid prototyping and rapid fielding, the development of new systems that are not based on an existing requirement but provide a new capability or meet an emergent need. DoD could expand the use of Middle-Tier Acquisition and provide more structured methods of evaluating the effectiveness of new capabilities through modeling and simulation or experimentation.[103]

Acquisition of small disaggregated systems such as unmanned vehicles may resemble those used today for software systems. Ongoing experiments with development operations (DevOps), software maintenance squadrons, and cyber units are forging schemes for software acquisition on faster timescales. One novel concept that emerges from these efforts is that some composable force elements may not need to be "acquired" at all, but development and implementation can happen directly at the maintenance and operational level.[104]

Implementing Mission-based Budgeting

Today's DoD programming and budgeting system, first developed during the 1960s, is a product-centered business process designed to develop and procure new weapons systems with high efficiency.[105] Implementing decision-centric warfare depends on the flexible combination of disparate weapon systems. With the current programming and budgeting system, spending cannot be organized such that portfolios of platforms, combat systems, sensors, and weapons are developed and fielded in a harmonized way.

To enable decision-centric warfare, a portion of the defense budget should be aligned around important missions, such as defeating air defenses, strike, or ASW.[106] Capabilities and experimentation related to these mission areas could be aligned by placing them together under the appropriate portfolio. This mission-centered budget could also fund the development of communications linkages and system interfaces to improve interoperability. Today, C3 architectures for a mission are sometimes difficult to resource because communications and other mission systems are funded under different program categories.

103 "Middle Tier of Acquisition," Defense Acquisition University, available at https://aaf.dau.edu/aaf/mta/.

104 "What is DevOps?" Amazon Web Services, available at https://aws.amazon.com/devops/what-is-devops/.

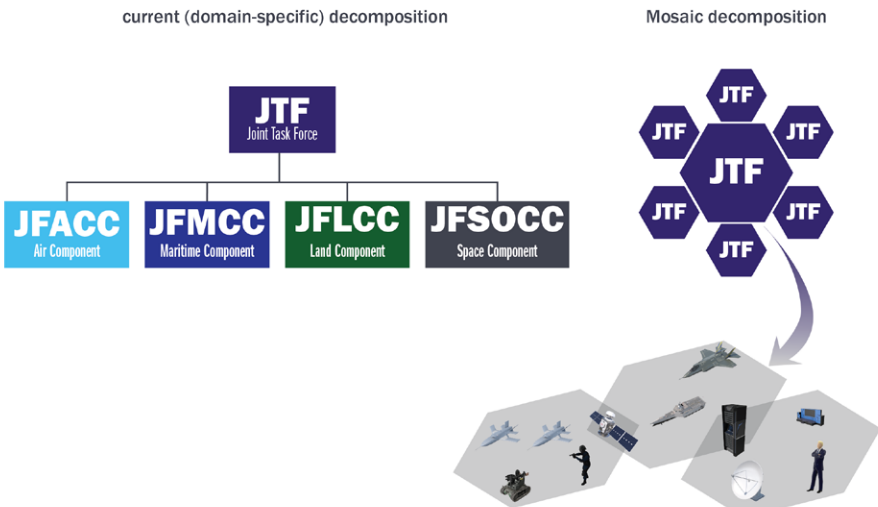
105 Brendan McGarry and Heidi Peters, *Defense Primer: Planning, Programming, Budgeting and Execution (PPBE) Process* (Washington, DC: Congressional Research Service, November 30, 2018), available at https://fas.org/sgp/crs/natsec/IF10429.pdf.

106 Authorization for this budgeting approach was included in the 2017 National Defense Authorization Act, Section 855 on Mission Integration Management.

Revising Doctrine and Training

Decision-centric warfare could drive significant changes to DoD doctrine, which should be explored in more detail. For example, Context-Centric C3 places commanders where needed throughout the force to accommodate communications limitations, promote unity of effort, and ensure a manageable span of control. Each force commander oversees an inherently multi-domain force whose size is based on the commander's assigned tasks and communications availability. By contrast, today's Joint Task Force (JTF) commander construct uses a hierarchical arrangement of domain-centric component commanders to manage operations.

FIGURE 26: FROM DOMAIN-BASED COMPONENT COMMANDERS TO INTERDEPENDENT JTF COMMANDERS



Decision-centric warfare will change JTF organization from today's domain-based component commanders to a construct of interdependent JTF commanders.

Changes to joint C2 procedures are just one area of likely doctrinal change. A new force design and the need for composability would likely also promote changes to TTPs and doctrine throughout the services. Additional and enhanced training will be needed for commanders and operators to be more comfortable with autonomous systems and better understand how machine-enabled control systems work. Training could also help operators and commanders more effectively complement the control system's operation with human creativity and operational art. Much of today's training regimen emphasizes uniformity and process in an attempt to ensure harmonized effort once conflict has begun. In the future, training for commanders might center on creativity in crafting task orders or improving commanders' adaptability under stress and in novel situations.

The underlying competence needed among new recruits to enable them to effectively implement decision-centric warfare will place an additional burden on military accessions. In a competitive labor market, with a shrinking portion of the population eligible for military service, the costs to incentivize troops to join and remain in the military will likely grow. Issues surrounding recruiting, training, developing, and retaining personnel will need further study, including an assessment of cost impacts.

CHAPTER 6

Conclusion

The U.S. military needs a new operational approach to succeed in future confrontations and conflicts. The sources of advantage it drew upon in previous competitions are now readily available to America's opponents, and fiscal constraints will prevent the U.S. military from regaining its dominant position by simply buying more and better systems to improve its current approach of large-scale precision strike warfare.

The next major arena of military competition is likely to be information and decision-making, and the U.S. military could establish a prolonged advantage in it by harnessing disruptive technologies for AI and autonomous systems. New operational concepts will be essential for the U.S. military to fully exploit the potential of these technologies. If DoD continues to view AI and autonomous systems only as a means to improve its current operational approaches, the U.S. military could find itself the victim of disruption. Conversely, it could be imposing it on America's competitors.

Decision-centric operational concepts such as Mosaic Warfare could harness the benefits of AI and autonomous systems while reducing the impact of their potential disadvantages. For example, by disaggregating today's manned monolithic platforms and troop formations into smaller, less-multi-functional units, decision-centric force design would reduce the pressure on an individual autonomous system to replace an entire multi-mission platform. At the same time, disaggregation would take advantage of the reach and persistence that autonomous systems can provide. By combining human command with machine control, the C2 processes of decision-centric concepts leverage human creativity in crafting tasks, allocating forces, and orchestrating missions as part of an operation.

mplementing decision-centric operational concepts will likely be evolutionary. Elements of the U.S. military could adopt decision-centric force design and C2 process over the next decade as legacy systems are replaced and new training and doctrine are adopted. Moreover, decision-centric concepts like Mosaic Warfare may not be appropriate for the entire U.S. military. Some operations, such as security, training, deterrence, and reassurance will be best conducted by traditional multi-mission platforms or troop formations—although these units may use human command machine control to improve their efficiency and creativity.

DoD could implement concepts like Mosaic Warfare using today's requirements, R&D, acquisition, and budgeting processes. Doing so, however, will be time consuming and inefficient. Today's capability development processes are fundamentally designed to conduct the system engineering of future SoS architectures based on innumerable assumptions regarding the most likely scenarios, threats, tactics, and SoS configurations to be in effect when the new capability is eventually fielded. This top-down approach yields point solutions that are unlikely to reflect the actual conditions they will face and does not exploit the composability and flexibility of decision-centric operations. To realize the benefits of concepts like Mosaic Warfare, DoD will need to evolve the ways in which it develops the next generation of defense capabilities.

The U.S. military is at a crossroads. It can continue to field an increasingly unsustainable force of large multi-mission platforms and troop formations that will eventually constrain U.S. national interests and alliance relationships. Alternatively, DoD could adopt new warfare approaches that are more complex and challenging to develop and use but might provide a prolonged advantage against potential adversaries. Although implementing decision-centric warfare depends on new technologies and tactics, it represents the best opportunity DoD has to sustainably counter its great power competitors.

LIST OF ACRONYMS

AI	artificial intelligence
ASBM	anti-ship ballistic missile
ASW	anti-submarine warfare
BAA	Broad Area Announcement
BACN	Battlefield Airborne Communications Network
BCT	Brigade Combat Team
C2	command and control
C2ISR	command, control, intelligence, surveillance, and reconnaissance
C3	command, control, and communications
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CBO	Congressional Budget Office
COA	course of action
CONOPs	concept of operations
CONUS	continental United States
CSG	Carrier Strike Group
DARPA	Defense Advanced Research Projects Agency
DMO	Distributed Maritime Operations
DNN	Deep Neural Network
DoD	Department of Defense
EABO	Expeditionary Advanced Base Operations
EMS	electromagnetic spectrum
EW	electronic warfare
FoM	figure of merit
ISR	intelligence, surveillance, and reconnaissance
JTF	Joint Task Force
MANET	mobile ad-hoc network
MDO	Multi-domain Operations
MEU	Marine Expeditionary Unit
ML	machine learning
O&M	operations and maintenance
OCO	Overseas Contingency Operations
OODA	oberve-orient-decide-act
OPTEMPO	operational tempo
PLA	People's Liberation Army
PRC	People's Republic of China
R&D	research and development
SoS	system of systems
STITCHES	Systems of Systems Technology Integration Tool Chain for Heterogenous Electronic Systems

TTPs	tactics, techniques, and procedures
U.S.	United States
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle

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