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ADVANCING DECISION-CENTRIC WARFARE:

GAINING ADVANTAGE THROUGH FORCE DESIGN AND MISSION INTEGRATION

BRYAN CLARK, DAN PATT, AND TIMOTHY A. WALTON

HUDSON INSTITUTE, CENTER FOR DEFENSE CONCEPTS AND TECHNOLOGY

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Cover: An ADARO unmanned system interacts with the Navy's newest Independence-variant littoral combat ship USS Oakland (LCS 24) during US Pacific Fleet's Unmanned Integrated Battle Problem (UxS IBP) 21. UxS IBP 21 integrates manned and unmanned capabilities into challenging operational scenarios to generate warfighting advantages. (US Navy photo by Mass Communication Specialist 2nd Class Alex Perlman)

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ABSTRACT

Advancements in digital communication and virtualization are creating opportunities and challenges for integrating military capabilities similar to those associated with the emerging Internet of Things. Contemporary discussion in the Department of Defense (DoD) frames the military use case for integration as multi-domain operations, in which capabilities from different services and operating environments are combined to achieve a common objective. However, this paradigm merely perpetuates long-standing approaches to joint operations and misses the fundamental shift underway toward the centrality of information and decision-making in warfare. Attrition is receding as a mechanism to achieve national security objectives as computing and communication innovations enable military forces to gain a decision-making advantage through capability arrangement and orchestration that improves their own adaptability and creates uncertainty for opponents. To exploit this emerging opportunity, commanders in the field will need the ability to identify and implement new force combinations, communications paths, and courses of action.

This report describes a new model for joint force design and integration, where elements of military capability are able to be composed and tailored to the needs of specific operational challenges close to the time of use. Combined with appropriate command and control processes and systems, this model of mission integration has the potential to provide military advantage against capable adversaries through the surprise generated from force composition and recombination. Mission integration could also reduce the cost of operations and modernization by enabling aggregation of less-expensive weapons systems to realize capabilities provided today by large multimission platforms or formations.

However, institutional challenges will hinder implementation of mission integration. The plodding, supply-side processes of the Department of Defense are built on predictability and homogeneity of forces, in which weapon system performance and quantity are critical parameters. Supply-focused capability development and integration worked when the US military was broadly superior to its potential opponents following the Cold War. Today, US forces face peer competitors and must adopt more agile approaches to deliver and deploy capabilities. In addition to supply-side improvements in interoperability and decision-support tools to recompose forces, achieving mission-tailored adaptability will require demand-side customization of military capabilities such as radio waveforms, sensor packages, decision aids, warhead characteristics, or electromagnetic warfare algorithms to address evolving threats. Unfortunately, the Pentagon's centralized industrial base and forecast-centric requirements and budgeting processes do not afford the flexibility to deliver this kind of heterogeneity at scale.

This study uses an operational challenge vignette to describe a plausible pathway to implement mission integration that illustrates how clever and sustained force recomposition could fundamentally alter an adversary's strategic calculus without developing a new weapon system. The vignette and associated analysis highlight specific recommendations for the Department of Defense to fund and explore the concept of mission integration, and to take an evolutionary approach to modernizing its institutional processes to exploit the opportunities afforded by changing technology and the emerging character of warfare.

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CHAPTER 1. INTRODUCTION: MISSION INTEGRATION FOR DECISION ADVANTAGE

Advancements in communication technology, modularized electronics, and software-defined systems are propelling explosive growth and specialization across most sectors of the US economy. Driven by technology companies' business models, consumers are able to obtain increasingly tailored products and services, often delivered directly to their homes. Although accelerated by 2020's coronavirus pandemic and the exigencies of remote work, these developments reflect underlying trends that are inexorably leading toward a future of diverse products and services being delivered to rapidly expanding markets.[1]

Military forces are also evolving toward a combination of heterogeneity and scale. The US Department of Defense (DoD) is pursuing greater resilience through distributed force structures intended to grow the number of targets an enemy would need to engage and to expand the variety of ways US forces could conduct offensive operations.[2] In a fiscally constrained environment, further distributing the US military will necessarily increase its heterogeneity. If today's US joint force were distributed into a larger number of units having approximately

Photo caption: A field artillery automated tactical data systems specialist operates a computer during Key Resolve, March 11, 2015 at a tactical operations center at Camp Casey, South Korea. The exercise was conducted to ensure all units are trained and ready to deter Northern aggression in defense of South Korea. (US Army photo by Gun Woo Song)

the same capability and capacity, either the overall US military would be too small because each unit would be a costly multimission platform or formation, or DoD would lack needed high-end capabilities such as air defense or long-range fires that are too expensive to be carried by every unit. Therefore, compared to the current US military, DoD's future force will likely be more disaggregated and heterogeneous, combining fewer large, multimission platforms and troop formations with a larger number of smaller, more specialized units.

In addition to the improved resilience arising from distribution, a more heterogeneous US force will likely be more effective in confrontations where success results increasingly from information and decision superiority rather than attrition. For example, the Defense Advanced Research Projects Agency's (DARPA) Mosaic Warfare concept contends that a military able to exploit heterogeneity at scale could gain a decision-making advantage over opponents by affording commanders greater adaptability and creating more complex presentations for the enemy to assess, understand, and defend.[3]

A contemporary example of mosaic-like force design is US Special Operations Forces, which consist predominantly of small, specialized units supported by a few multimission platforms or troop formations. However, the special operations forces model for training, equipping, and planning would be too expensive and time-consuming to apply across the entire US military. Enabling greater adaptability and composability by DoD's general-purpose forces within likely fiscal and organizational constraints will require new approaches to force management and preparation that balance scalability with the goal of providing more options to commanders.

Although not yet widely adopted by the US military, decision-centric warfighting constructs are being implemented by US competitors in concepts such as the People's Republic of China's (PRC) System Destruction Warfare or Russia's New Generation Warfare, which treat the information environment and cognition as central battlegrounds for future conflict.[4] Under the PRC or Russian concepts, commanders are directed to electronically and physically attack sensors, communication networks, and command and control (C2) systems to undermine an opponent's coordination while introducing false data through electromagnetic warfare and cyber operations that erode the defender's ability to orient.[5]

In concert with attacks on adversary sensing and communications, PRC and Russian military and paramilitary forces would create operational dilemmas that further degrade the defender's decision-making.[6] For example, China's People's Liberation Army (PLA) and Russia's armed forces deploy extensive sensor and weapon networks on their territory that would threaten US forces intervening on behalf of American allies.[7] Under the protection of these networks, PRC or Russian paramilitary or proxy forces conduct gray-zone operations against US allies, occupying territory, harassing opponents, and constraining access to disputed areas without escalating confrontations in ways that could justify US military retaliation. Given DoD's preponderance of large, multimission units, US commanders are left with two response options: Deploy individual platforms or units at significant risk that are proportional to the gray-zone confrontation or aggregate forces into survivable formations that could be seen by allies or adversaries as unduly provocative.[8]

Decision-centric operations like those pursued by the PRC and Russian governments will likely be a significant form of future conflict, especially as more confrontations occur outside the context of large-scale existential combat. When a government's survival is at stake, its leaders would be more likely to fall back to attrition-based approaches if needed to avoid defeat. Although decision-making and information would remain important when a conflict becomes attritionary, the lethality and survivability of individual units could be equally decisive.

Decision-centric warfare implies two levels of competition. Operationally, militaries will need the ability to exploit the

adaptability possible with more distributed and heterogeneous forces by recomposing and integrating forces in the field. Institutionally, militaries will need to compete by evolving capabilities over time through the adoption of new technologies and concepts that exploit emerging opportunities or address new threats and challenges. This report will describe how DoD could pursue decision-centric operational and institutional competition through force design and mission integration.

The Integration Imperative

Heterogeneity at scale would improve the US military's composability, but decision superiority will depend as much or more on command, control, and communications (C3) capabilities that integrate units and coordinate their operations. In addition to the difficulty of organizing more numerous and diverse military units, today's planning and management processes are likely to be overwhelmed by the complexity created by the greater variety of possible force compositions and effects chains inherent in a more disaggregated force. New C3 organizations, processes, and systems will therefore be needed to implement decision-centric warfare regardless of the level of heterogeneity eventually achieved by the US military.

DoD's C3 efforts today are organized under its Joint All-Domain Command and Control (JADC2) strategy,[9] which includes the US Air Force's Advanced Battle Management Command System (ABMS),[10] the Army's Project Convergence,[11] and the Navy's Project Overmatch.[12] System development under JADC2 has largely focused on communications to connect a greater variety of disparate units via ABMS, but gaining a decision-making advantage will require that commanders go beyond merely connecting forces to also develop courses of action and compose force packages faster or more effectively than their opponents.[13] Although JADC2 should help commanders communicate with a more diverse and dynamic set of forces, the current staff-driven US military planning approach will be unable to review the growing range of possible courses of action at an operationally relevant tempo. To speed up planning, staffs are likely to fall back on doctrine or habit that an enemy would more easily predict, reducing the decision advantage of US forces.

Framed another way, merely establishing machine-to-machine communications across the existing force is unlikely to deliver an asymmetric advantage against adversaries. And while networking everything all the time is a noble long-term goal, it is impractical for the foreseeable future. A more fertile competitive field will be managing the timing and orchestration of force combinations with the units that commanders can communicate with to pursue immediate, focused military objectives. Decision-support tools could help commanders understand their communications availability and harness the complexity of a more heterogeneous force that embodies a greater variety of potential force packages and courses of action. The US military is already expanding its use of computer-based C2 aids, some of which employ artificial intelligence, to speed the development and improve the effectiveness of courses of action using modeling and simulation and the results of previous operations.[14]

A previous report of this project, *Implementing Decision-Centric Warfare: Elevating Command and Control to Gain an Optionality Advantage* (Hudson Institute, 2021), detailed the capabilities and characteristics needed in C3 architectures for US forces to gain a decision-making advantage.[15] This study will address organizational and process changes needed to continuously compose, integrate, and employ a more heterogeneous and adaptable US military force. The construct DoD normally uses to assess needs associated with new operational approaches considers doctrine, organization, training, material, leadership, personnel, and facilities (DOTMLPF). Because doctrine for Mosaic Warfare, JADC2, and the joint warfighting concept are already under development, this study will focus on the remaining DOTMLPF elements, organized into three main categories: mission integration, operational infrastructure, and institutional processes, as described below and detailed in the following chapters of this report.

Mission Integration

Today force composition is largely performed by the military services, which organize, train, and equip units that are then deployed to combatant commanders (CCDRs) and their domain-specific service component commanders.[16] DoD's reliance on services to create force packages, however, can constrain the variety of compositions to those using a single service's capabilities. Moreover, services are incentivized to limit the variety of force packages they create to contain costs associated with preparing and certifying units before deployment.

To exploit the potential of a more heterogeneous and recomposable military, CCDRs will need mechanisms in theater to recompose and integrate forces from multiple services and domains. However, identifying when recomposition is warranted will require ongoing assessment of current force packages' effectiveness and adaptability across a range of potential situations the CCDR could need to address. Integrating new force packages in theater will also incur costs in terms of operational infrastructure such as logistics, protection, transportation, and C3 capabilities. To contain the scope and cost of their recomposition efforts, CCDRs could focus on a small set of operational challenges that must be tackled to enable their plans for deterrence and warfighting preparation. A mission integration cell on the CCDR staff could continuously evaluate the ability of available forces to address the CCDR's operational challenges and direct the recomposition of forces in theater when the improvement in effectiveness and adaptability outweighs the costs associated with operational infrastructure.

The process of mission integration will also yield insights that should be applied to future capability development. Through their assessments, mission integration cells may discover potential new capabilities that would yield a substantial improvement in effectiveness or adaptability compared with current approaches to an operational challenge. To act on these opportunities, DoD will need to leverage a federated model of capability development encompassing service program offices, rapid capability organizations, and "mission factories," such as Navy and Air Force warfare centers.[17]

Operational Infrastructure

Realizing the greater potential optionality of a more heterogeneous future force will depend on changes to the nature and provisioning of military transportation, protection, logistics, energy, C2, and communications infrastructure. Smaller specialized units such as patrol vessels, crewless (or unmanned) aircraft, or troop formations at the battalion level and below will often need to be carried into theater and afforded more inorganic support and protection than larger self-contained multimission platforms and formations. In some cases, multimission units could operate in concert with smaller, more specialized forces to provide protection and support. When operating independently, less multifunctional troop formations and crewed or crewless platforms may need more disaggregated support infrastructure and logistics forces compared to today's efficient, but centralized, supply and fuel depots, aircraft, and ships.

Military capabilities that are less geographically constrained, like space-based sensing and communications systems or information and cyber tools, will also need to be integrated by CCDRs into recomposed force packages. Like smaller, more specialized platforms and formations, these capabilities may also depend on operational infrastructure; cyber tools may need transportation for physical access to targets or a commercial satellite sensor may depend on interoperability software to connect with an uncrewed military surface vessel.

As noted above, mission integration cells will need to consider operational infrastructure in their analysis of new force compositions. The smaller, less multifunctional units in a more heterogeneous military force will not be able to meet all their own support requirements, necessitating operational infrastructure to be integrated into the new force packages that CCDRs create in theater.

DoD Institutional Processes

The forecast-based and supply-focused analysis, resource allocation, and capability-development processes used today by DoD are ill-suited to realize the force design and C3 architectures needed to implement decision-centric warfare. Most significantly, a more recomposable force will not result in predictable system configurations that can be used to identify capability gaps and define requirements for engineers to pursue through research and development. DoD will need new approaches to assess and satisfy its capability needs that reflect the greater optionality of a decision-centric force.

Today, the Joint Capabilities Integration and Development System is designed to identify system requirements by forecasting the performance of planned capabilities in predicted future scenarios.[18] This approach depends on assumptions regarding the configuration of US forces, but as the US military becomes more recomposable, the specific combination of units and their tactics will be less certain. To assess the future US force's effectiveness, DoD could instead evaluate all the reasonable combinations of units that could be pursued in a realistic range of situations. The force's effectiveness across configurations and scenarios can be represented as a statistical distribution, rather than the point solution directed through the current requirements process.

DoD is making some progress toward identifying requirements for composability through mission thread analysis and mission engineering.[19] The Office of the Secretary of Defense, US Joint Staff, and military services are beginning to use this methodology. As applied today, mission thread analysis examines the information and data flows necessary to complete a specific kill chain against a target, which can expose gaps in data transfer and sharing that are not reflected in simplistic operational architecture illustrations. However, by assuming a static arrangement of force elements, DoD's current mission engineering efforts risk creating brittle systems of systems that only work in a single configuration. An asymmetric US advantage should flow from the ability to rapidly decompose and recompose forces and create new systems-of-systems combinations.

During the last decade, the US Congress and DoD established new acquisition processes that could improve the US military's ability to develop capabilities based on emerging technical opportunities and operational challenges rather than predictions of future needs.[20] However, DoD's ability to start, stop, or change course on capability development is fundamentally constrained by supply-based government budgetary structures and processes that are built around programs, rather than missions or demands, and require years for funding allocation changes. New budgeting mechanisms with more flexibility, such as mission-based budgeting or DoD's new software appropriation, will be needed to address CCDR operational challenges by promptly modifying or introducing new capabilities that assessments suggest could improve the force's effectiveness or adaptability.[21]

The next chapter will describe the military and commercial evolutions that led to today's era in which military forces are adopting heterogeneity at scale to gain a decision-making advantage over opponents. Chapter 3 will propose a mechanism for CCDRs to compete with adversaries operationally by integrating heterogeneous forces in theater to tackle operational challenges. And Chapter 4 will describe how DoD could better compete institutionally with rivals through new analytic methods, resource allocation, and evolution of the defense industrial base.

CHAPTER 2. THE EMERGENCE OF HETEROGENEITY AT SCALE

The evolution of military forces toward heterogeneity at scale parallels developments in technology and the broader economy. During the preindustrial era, military advancements often led commercial R&D as only governments had the resources to advance new technologies, and warfare was government's most important mission. Since the Industrial Revolution, however, military and commercial innovation have been more closely aligned, with military advancements sometimes yielding commercial products as well as the reverse.[22] And even in cases where the military is developing its own weapons and systems, defense companies and research organizations draw upon workers and expertise from civilian and commercial organizations that bring with them training and best practices from the society at large.

Military innovation can be viewed as having three major eras corresponding to the dominant models of commercial product and service delivery of the time. Each era is exemplified by a distinct approach to developing and introducing technologies and operational concepts or commercial use cases. Each era also corresponds with industrial revolutions that swept through technology and business during the past two centuries.[23]

Photo caption: A line of cannons sit on Henry Hill at the battlefields of Manassas, the site of two major Civil War battles between the armies of the North and South in 1861 and 1862, in Manassas, VA. (Joe Raedle/Getty Images)

Figure 1. The three major eras of US military innovation

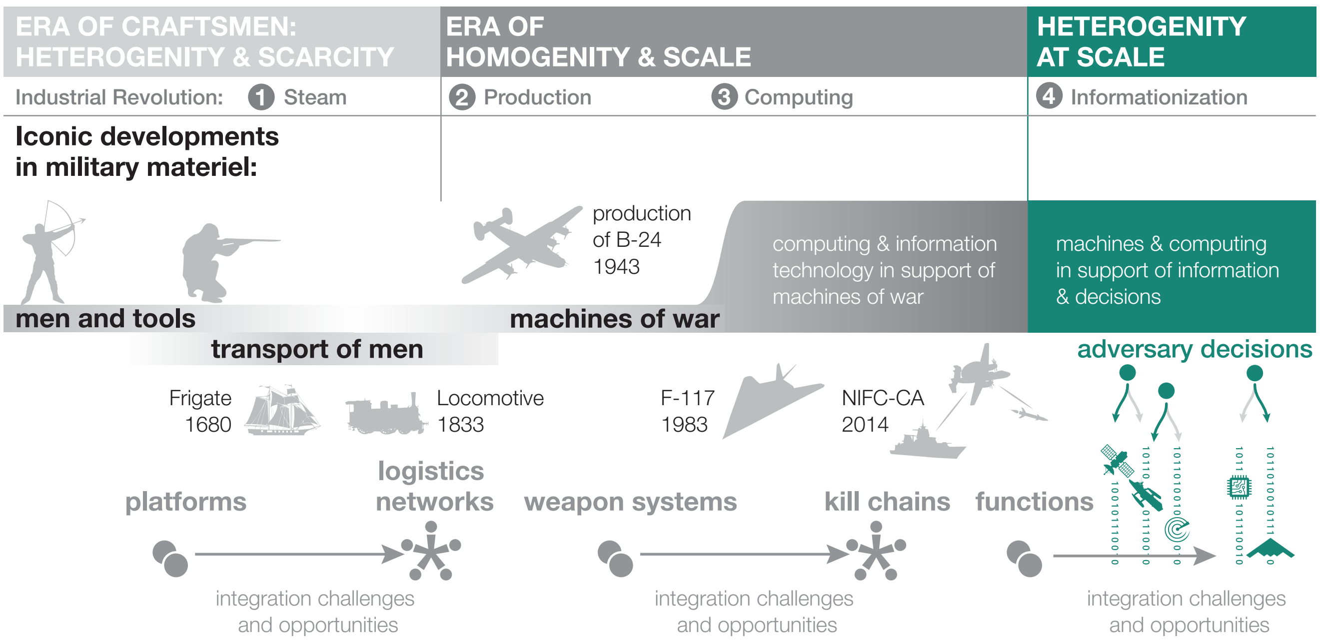


Figure Source: Report authors.

The force design eras depicted in Figure 1 are also defined by a dominant military operational approach that harnesses fundamental technologies introduced by the prevailing industrial revolution. For example, the era of homogeneity and scale exploited mass production of craftsman-era weapons to support attrition warfare in existential confrontations where a force's endurance and firepower were it most important characteristics—such as the US Civil War and both World Wars. Today, heterogeneity at scale enables military operations that are increasingly focused on decision-making, with US forces seeking to deter aggression and US adversaries using gray-zone tactics to achieve their objectives while avoiding an existential confrontation.

Heterogeneity and Scarcity

Before the First Industrial Revolution, finished goods such as tools, textiles, dining ware, or vehicles were created by craftspeople working alone or in small teams. Every product was custom-built and unique. And because each material good required an artisan, industrial capacity was constrained by the number of experts trained in a particular discipline. Although market forces would incentivize apprentices to go into fields with unmet demand, they would take years to accumulate the training and experience needed to reliably produce goods.[24]

The preindustrial era's commercial markets could be characterized as having a combination of heterogeneity and scarcity. Handmade or simple machine-made goods were available in relatively small numbers to those with the resources to build or acquire them. Products were generally made locally, and only the most valuable items were traded outside of a region.[25]

Military technologies exhibited a similar dynamic. Weapons were handmade and their capacity was constrained by the availability

of artisans. Skilled soldiers were scarce, as few men would have the time for combat training when human action was required for all agricultural or manufacturing tasks. As a result, military formations often consisted of a large portion of untrained conscripts complemented by relatively few well-equipped, capable warfighters. Although losses in conflict were often substantial, the path to victory usually depended on creating operational dilemmas for an opponent or disrupting its center of gravity; warfare in this era was therefore more decision-centric than attrition-centric.[26]

The decision-centric character of preindustrial conflict reinforced the use of skilled soldiers and their weapons to yield greater diversity in tactics or strategy, which expanded through innovations such as the longbow, armored cavalry, and wheeled cannon. The ability of militaries to sustain their evolution was limited, however, by the need for new weapons to be hand-built by a small number of skilled craftspeople.[27]

Homogeneity at Scale

The emergence of steam- and human-powered machines during the late eighteenth century began to break the paradigm of heterogeneity and scarcity that typified the preindustrial era. Machines emerging from the First Industrial Revolution enabled a single operator or small team to produce many more items per hour or day compared to an artisan and allowed for greater complication in finished goods. Advancements in toolmaking during the Second Industrial Revolution of the late nineteenth century also enabled standardization, creating opportunities for third-party sellers to offer accessories and enhancements to manufactured products and allowing users to collaboratively innovate new use cases.[28]

Manufacturing helped centralize development and production. The machinery and tooling needed to build goods at scale were themselves expensive and required substantial space and steam or electrical power, incentivizing producers to assemble them into large factories. Similarly, scarce technical experts and artisan designers were more effectively employed guiding development of solutions at the factory rather than independently making or modifying products.

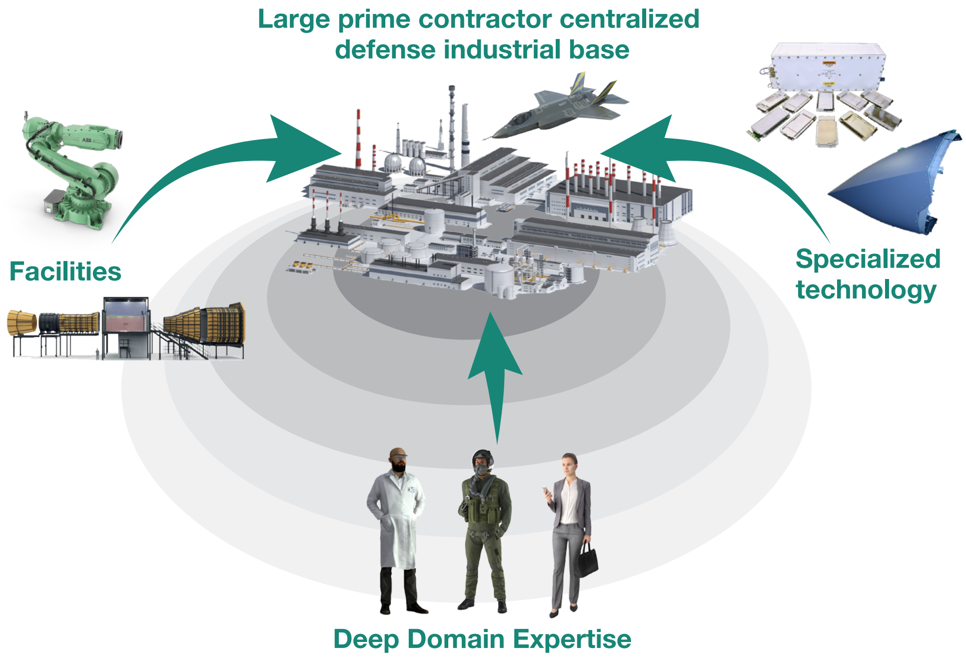
For military forces, the industrial model enabled weapons, vehicles, ships, and aircraft to be manufactured on large scales. Equipment standardization also allowed armed services to apply mass production techniques to military training, including preparing operators to use increasingly sophisticated systems. This approach to military capability and professional development shifted the locus of solution development from the field to central hubs where new technologies and tactics were created and from which they were disseminated.[29]

The commonality in equipment and operational concepts arising from industrial force development enabled military leaders to develop strategies and plan operations with greater confidence in the ways their troops would fight. However, although centralized training and capability development provided commanders with forces that were ready for combat, standardized equipment and training limited the ability of troops to address unanticipated challenges or exploit emerging opportunities.

During World War I, the limitations of a primarily industrial model of conflict came to the fore. With each side having comparable capabilities and training, stalemate ensued on the western front. Innovation intensified to break the impasse, with early versions of chemical weapons, motorized machine guns, fighter-bomber aircraft, and radar and radio reaching operational use.[30]

The centralization of an ecosystem combining experts, equipment, technology development, and training that emerged through the First and Second Industrial Revolutions arguably set the stage for the Third Industrial Revolution's development of electronics, automation, and computing. The co-location of experts and capital-intensive equipment in innovation hubs such as the San Francisco Bay Area for information systems, Boston for electronics and pharmaceuticals, or Los Angeles

Figure 2: Organization of the defense industrial base and DOD during the era of homogeneity and scale



The early development of modern military capability, including tightly integrated platforms and mission systems, favored centralized models to support the integration of unique capabilities in complex problem-solving. During this era, military problems were solved by centralized organizations rather than in the field

Source: Report authors.

for aerospace spurred new solutions that combined emerging technologies with novel use cases.[31]

Centralization in military system development today is typified by large US prime contractors such as Lockheed Martin, Northrop Grumman, Raytheon Technologies, or Boeing. Each encompasses the full range of personnel, equipment, and facilities to design and build sophisticated military systems such as the F-35 Lightning II Joint Strike Fighter or SM-6 multimission missile. Despite frequent concerns about defense industry consolidation, it is the natural architecture for today's mature era of homogeneity and mass in military forces.[32]

Early Networks Reinforce Centralization

As new technologies are fielded at scale, networks often form to exploit the resulting products and facilitate their interaction. The steam engine enabled the steam locomotive, which required an extensive rail network to achieve commercial impact.[33] Harnessing the development of electricity required an electrical distribution network, which in turn, increased the demand for electricity-driven innovation and created a virtuous cycle of growing market size, lower cost, and new applications.

This same trend emerged with the rise of computing during the Third Industrial Revolution. The first computer networks

were used to fully exploit the benefits of computers by allowing collaboration within innovation hubs or government facilities. Despite the physical dispersal of innovation activity they enabled, early networks often promoted centralization by enabling headquarters leaders to oversee, guide, and direct solution development.[34]

The emergence of computerized information networks similarly encouraged centralized control of military operations. Communications over distance have always been an element of effective military action, but until the 1970s and 1980s, senior leaders could only share short messages with distant commanders. For example, high-frequency radios during World War II could connect headquarters with field commanders at transoceanic ranges, but the amount of information that could be passed was small and was often limited to short status messages or high-level strategic direction. Field commanders were largely on their own in terms of operational plans and tactics.[35]

The introduction of datalinks including Link-4 or Link-16 and monitoring systems like Blue Force Tracker starting during the 1970s enabled headquarters to monitor and direct action in near real-time.[36] The ability to coordinate widely dispersed efforts from a distance gave rise to approaches like network-centric warfare that promised more efficient and precise military operations. Proponents of network-enabled operations argued that centrally managed US forces connected by ubiquitous networks and using precision-guided weapons could achieve objectives with fewer troops and less attrition compared to their World War II predecessors.[37]

The networked approach to warfare helped to consolidate US military operational innovation in dedicated organizations and events. Whereas military units during World War II and the early Cold War could experiment with new tactics in the field, the ability and desire of military leaders during the 1980s and 1990s to manage operations on a theater scale required procedural standardization. Moreover, the highly orchestrated nature of net-centric operations constrained concept development outside of experiments or training events where all the relevant participants could be assembled.

The net-centric perspective is so engrained in US thinking that even the DoD's future-leaning science advisory arm, the Defense Science Board, imagines the future as a better version of the past, with centralized networks enabling greater homogeneity at scale. Recently tasked to study multi-domain operations for future warfare, a Defense Science Board task force advocated more extensive preplanning of network structure and operations and a singular, global, open architecture to unite forces across domains.[38] As logical as these recommendations sound, they miss dramatic changes underway in commercial technology and markets that are already reshaping US military force design and C3.

Disruption Drives Decentralization

Despite the economic, technological, and historical incentives behind centralization, a set of countervailing trends are now promoting decentralization. In the centralized production model, manufacturers optimize their products' characteristics to satisfy existing users. However, the standardized interfaces product integrators establish to facilitate their own efforts can also enable competitors to assemble products from components built by third-party suppliers. Although products built in this decentralized approach may not achieve the performance levels of highly integrated systems in prevailing metrics, they are more tailorable, and component suppliers could achieve economies of scale that reduce costs relative to the market leaders.

The lower cost and bespoke characteristics possible through decentralized manufacturing can reveal new categories of users that choose products based on different metrics compared to those favored by the incumbent market of producers and customers. Harvard Business School's Clayton Christenson described this phenomenon as a corollary to his theory of disruption.[39]

Christensen argued that market disruptions can occur when sustaining innovation of an incumbent technology results in its performance exceeding the needs of new users, who may prefer a less expensive alternative they can adapt to their own applications.

Disruption is especially visible in computing technologies and markets, where steadily improving systems are distributed to increasingly less-expert customers who customize products to their own needs through intuitive user interfaces. In this way, technological progress promoted decentralization in which problem-solving capabilities are distributed to users, in contrast to the centralized model in which problems are brought to the solution provider.

For example, mainframe computers integrated and optimized for large businesses to manage processes such as payroll or customer account management were largely displaced by personal computers that were less expensive and offered more tailorable characteristics for smaller business or home users. Today, personal computers are being displaced in part by mobile devices such as smartphones and tablets that provide comparable capability by leveraging cloud services and networks.[40]

Heterogeneity at Scale

After initially encouraging centralized product and operational innovation, improvements in data storage and movement are now fostering decentralization of commercial activities by allowing solution developers to directly engage with users at scale and tailor their offerings to the customer's preferences.[41] Perhaps the most important consequence of increasing network and internet performance is the lower price of computing storage and processing, which dropped by more than seven orders of magnitude since 1980, and information transportation, which decreased in cost by four orders of magnitude since 1998.[42]

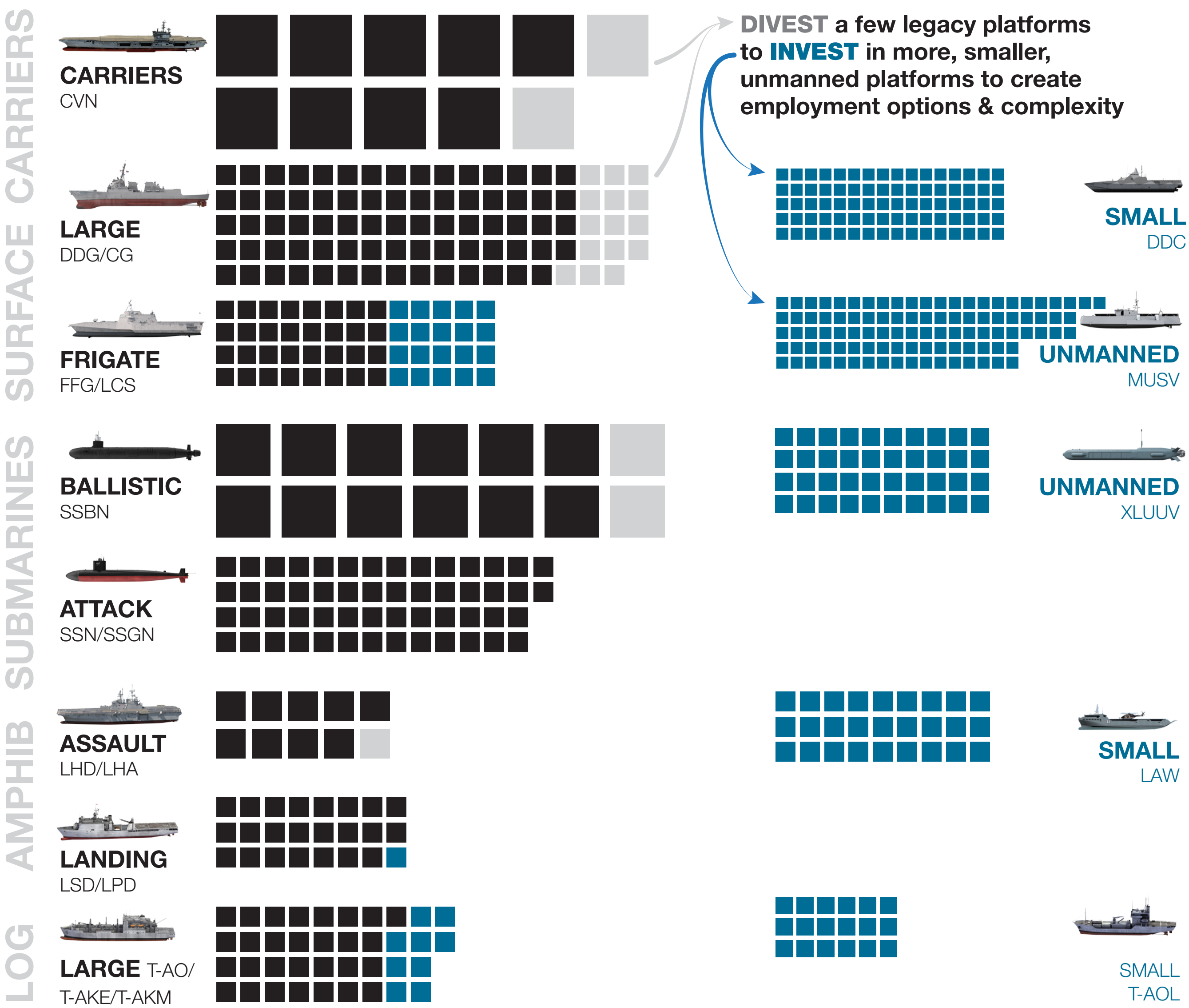
The computing advancements driving commercial decentralization are likely to spur disaggregation and heterogeneity among all militaries. For example, during the 2020 Nagorno-Karabakh conflict, combatants combined commercially derived computing being combined with widely proliferated sensors and guided weapons to form capable reconnaissance-strike kill chains.[43] This decentralized approach to capability composition could disrupt the centralized model of military system development pioneered by US and allied defense contractors during the era of homogeneity and mass. The potential for disruption is likely to grow as the character of warfare becomes more decision-centric and less dependent on the lethality and performance possible with highly integrated weapons systems.

Although prompted in part by budget constraints and the need for distribution, DoD's efforts to rebalance its forces toward a larger proportion of less multifunctional platforms and systems also arise from the emergence of inexpensive computing power that can allow distributed information processing and decision support at the edge. The resulting shift is shown in Figure 3 for the Navy.[44]

The ability to specialize products and military systems is being accelerated by digitization, or the reliance on computer software to provide more of a product's capability, which reduces or eliminates the need for new tooling, logistics, and industrial processes to create customized solutions.[45] Modularity through open architecture hardware and software containers are further expanding the degree of customization achievable in commercial offerings and military systems.[46]

At a greater level of aggregation, software also enables tailoring combinations of products such as the Internet of Things or military systems of systems. In the network layer, DoD tactical datalinks such as Link-16 and the Multifunction Advanced Datalink (MADL) could, in principle, be combined into new virtual networks that would enable greater interoperability between weapon systems using programs like DARPA's Dynamic Network Adaptation for Mission Optimization

Figure 3: Potential rebalance of US naval fleet to reflect heterogeneity at scale



The ability to operate with a heterogeneous, adaptive force could empower the Navy to rebalance toward smaller, less multifunctional ships without additional funding by shifting investment from traditional platforms (light gray) to new systems (blue).

Source: Bryan Clark, Timothy A. Walton, and Seth Cropsey, *American Sea Power at a Crossroads: A Plan to Restore the US Navy's Maritime Advantage*, (Washington, DC: Hudson Institute, 2020), https://www.hudson.org/research/16406-american-sea-power-at-a-crossroads-a-plan-to-restore-the-us-navy-s-maritime-advantage.

(DyNAMO).[47] To connect disparate military systems at the application layer, algorithms like DARPA's System of Systems Technology Integration Tool Chain for Heterogeneous Electronic Systems (STITCHES) can automatically build software chains to translate data between the message formats each system or software tool can use.[48]

Realizing the benefits of greater interoperability and customized systems of systems requires the ability to manage data from heterogeneous sources at scale. Graph-based algorithms such as Google's search tool or DoD's STITCHES organize and manage data by identifying relationships and commonalities between disparate information sources and formats rather than attempting to convert all data into a common set of languages or standards.[49] This approach, sometimes described as a data fabric, is also what DoD's JADC2 leaders argue the US military needs to establish as part of its efforts to promote interoperability and flexibility in the force.[50]

The extension of customization from individual systems to systems of systems exchanges the complication of individual sensors, weapons, or platforms for the complexity of a wide variety of changing force configurations. Within the constraints of operators' training and proficiency, this shift could unleash greater operational innovation by field commanders and impose significant uncertainty on enemy decision-making.[51]

Decision-Centric Warfare: The Military Use Case for Heterogeneity at Scale

Heterogeneity could make a military more adaptable while reducing the ability of opponents to predict which capabilities the force will present and how they will be orchestrated. The more complex force could thereby gain a decision-making advantage by having greater options available to it compared to the enemy. In terms of John Boyd's Observe-Orient-Decide-Act cycle, an optionality advantage would improve the likelihood that friendly forces can decide and act on an effective course of action while degrading the adversary's ability to orient.[52]

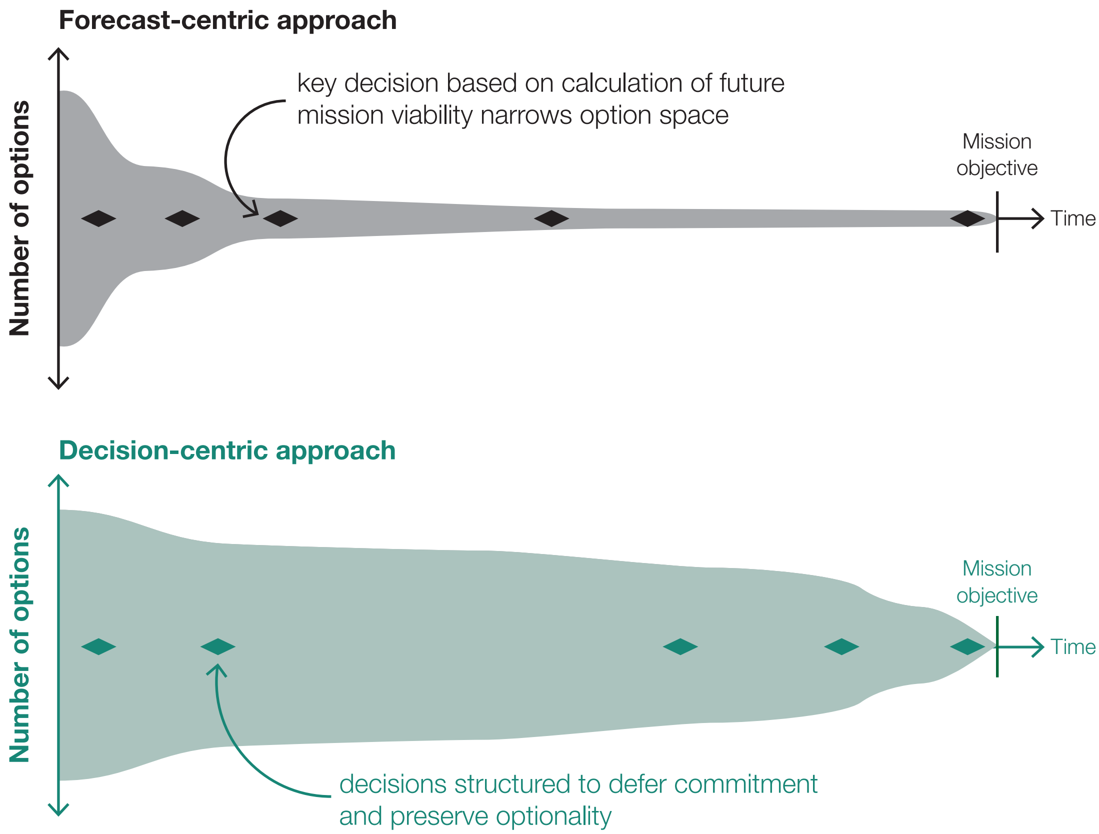
A decision-centric approach to capability planning contrasts with forecast-centric processes like Joint Capabilities Integration and Development System, in which militaries pursue systems to counter predicted adversary capabilities, disposition, and tactics during projected future confrontations. Operationally, the US military's Joint Planning Process is also forecast-centric, relying on commanders' predictions regarding the situation, enemy objectives and capabilities, and actions to be taken by other friendly and neutral forces. Based on these assumptions and the commander's objectives, staffs develop potential courses of action for commanders to consider; after a course of action is chosen, capabilities associated with alternative courses of action are reallocated to other missions or regions in the interest of efficiency.[53]

Because assessing every potential force configuration and situation is not feasible, forecast-centric planning accepts the risk that its assumptions could be wrong. To compensate, planners focus on what they consider to be the most stressing scenarios—usually those requiring the largest number of the most capable troops and platforms. As reflected by US wars in Iraq and Kosovo, this approach worked well during the era of homogeneity and scale when the US military was broadly superior to likely opponents in capability and capacity.[54]

Technology proliferation and economic development now enable a range of potential adversaries including the PRC, Russia, and Iran to field capable and dynamic forces. Whereas during the two decades following the Cold War opponents would need to go all-in to stress the US military, today adversaries operating close to home could bring substantial capacity and capability to bear at various levels of escalation and over a variety of geographic areas or time periods, creating challenging scenarios that are no longer lesser-included cases of theater-level war.

Decision-centric warfare would address the limitations of forecast-centric planning in an era of military parity and geographic disadvantage by prioritizing different metrics

Figure 4: Comparison of forecast-centric and decision-centric option spaces over time



Source: Bryan Clark, Dan Patt, and Timothy A. Walton, *Implementing Decision-Centric Warfare: Elevating Command and Control to Gain Optionality Advantage*, (Washington, DC: Hudson Institute, 2020), https://www.hudson.org/research/16729-implementing-decision-centric-warfare-elevating-command-and-control-to-gain-an-optionality-advantage.

compared to the attrition-centric approaches that typified the period of homogeneity and scale. Whereas forces seeking to win primarily via attrition will focus on offensive firepower and survivability, decision-centric forces will emphasize a combination of adaptability and effectiveness to maximize the useful decision space available to commanders. Increasing the adaptability of military forces should help them address a wider variety of future situations and reduce the reliance on accurate forecasts.

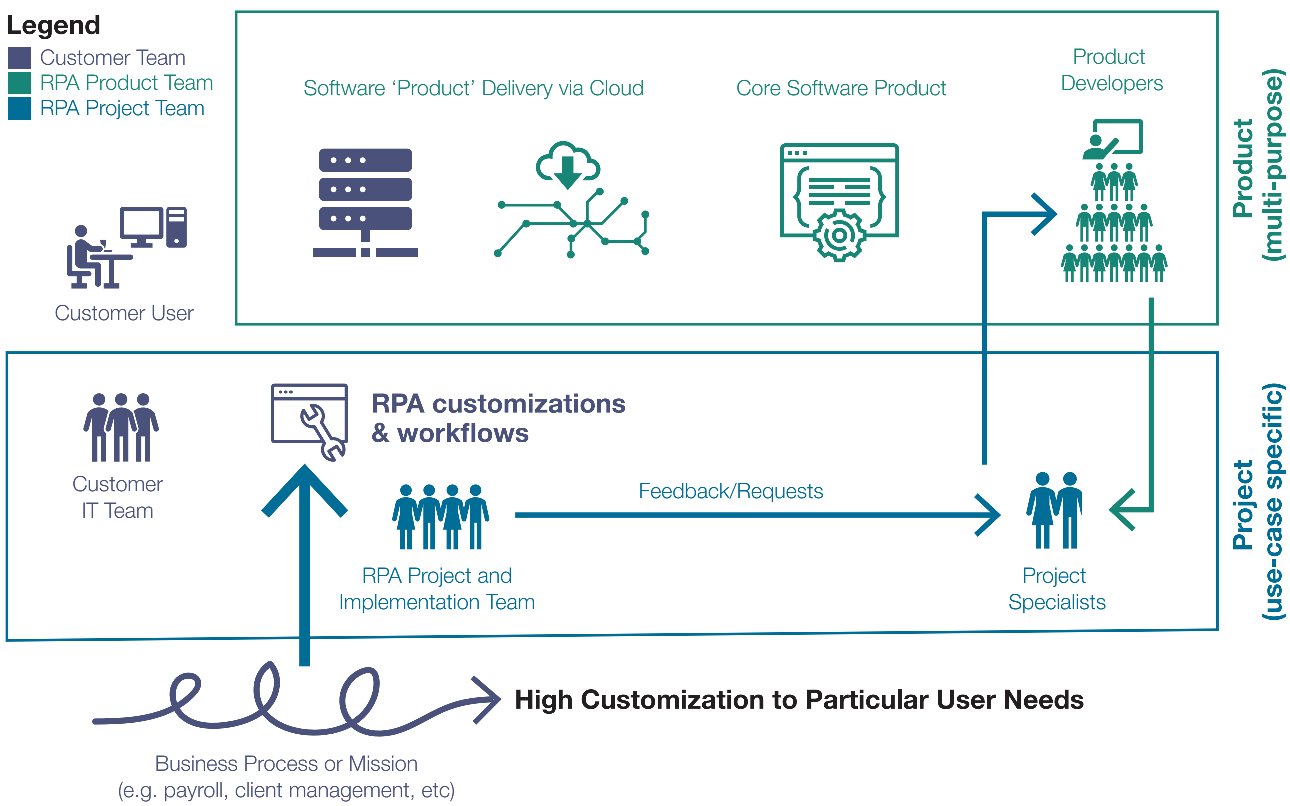
The importance of adaptability is highlighted by today's PRC or Russian gray-zone military and paramilitary operations, which pursue national security objectives while staying below the level of escalation assumed in DoD's scenarios. The monolithic, multimission platforms and troop formations privileged by forecast-centric planning's focus on most stressing situations are ill-suited for gray-zone confrontations because they cannot be easily disaggregated or recomposed into more tailored and proportional packages. PLA or Russian Armed Forces can therefore use their homeland-based long-range weapons and sensor networks to make US commanders choose between deploying valuable and scarce multimission units at substantial risk or aggregating them into more survivable groups that might

be disproportionate to the gray-zone confrontation.[55] Moreover, the multimission units in today's US military are expensive to sustain over the protected periods gray-zone operations are often employed, forcing US commanders to eventually withdraw and leave allies and partners on their own against an aggressive and more powerful neighbor.[56]

Managing Heterogeneity at Scale

Exploiting composability to gain a decision-making advantage will require C2 capabilities that help operators manage complexity and orchestrate disparate force elements in ways that counter adversary actions and enable the employment of unexpected presentations or tactics. Without computer-based modeling and simulation systems and decision aids like DARPA's Adaptive Cross Domain Kill Webs (ACK),[57] commanders faced with an option space of factorial size and complexity will either be unable to manage the force or default to familiar or doctrinal configurations and tactics that could be predicted by an enemy. Creating unexpected force presentations and orchestrations that impose uncertainty on

Figure 5: Enterprise software products are customized using RPA teams and processes



A diverse tool kit and technologies for integration allow RPA developers to compose and deliver mission-specific capability for users. This is accomplished by splitting product and project teams.

Source: Report authors.

the enemy will require C2 tools to look outside doctrine at the whole range of possible options, which will likely grow with the more disaggregated force described above. However, because personnel will not be proficient at new tactics or force compositions, C2 tools will need to build novel courses of action by combining or improving on existing basic tactics that are familiar to the force. For this reason, course of action development tools will likely use analogous reasoning, rather than starting each planning cycle from scratch.[58]

For the near- to mid-term, human operators and their machine assistants will collaboratively develop courses of action, configure interoperable communications, and integrate forces to implement plans. This approach is similar to how developers and implementation teams tailor robotic process automation (RPA) software tools in enterprise information technology systems for functions like payroll, customer relationship management, or other processes specific to a customer's unique business. In contrast to common business use cases like processing a credit card payment, which can be generalized and sold at scale, RPA is used to provide customized business process automation across a variety of use cases that are impossible to predict in advance.[59]

As shown in Figure 5, successful RPA developers use a combination of centralized product development and decentralized project customization to gain the advantages of each. Under this model, development of core RPA software capabilities and version management is centralized, while adaptation to a specific customer mission or business process is accomplished by a forward implementation cell using the RPA tool kit that integrates with a client's existing business processes, IT assets, and software capabilities.

As the RPA deployment model suggests, capability composition and provisioning require significant effort. If each operation is unique and cannot leverage experience from previous customizations, integration teams could easily get bogged down and be unable to support the full scope and tempo of actions needed by the user, or a commander in the military application.

Organizations charged with integrating and composing military forces could balance the benefits of customization with the need for prompt decision-making by focusing on a small set of operational challenges the CCDR views as essential to theater deterrence and operational plans. Force packages for other missions would be employed as provided by the services or allowed to self-integrate into new configurations if appropriate and consistent with the units' training.

Returning Operational Innovation to the Edge

Today, DoD deploys military forces predominantly in the form of multimission platforms or formations such as Navy combatant ships; Air Force fighter, bomber, or support aircraft; Army Brigade Combat Teams; or Marine Expeditionary Units. Their underlying functions are bundled together by design in the form of mission systems and weapons. These integrated units are largely monolithic or self-contained—carrying their own defenses, supplies, technicians, and fuel—to ease the planning burden on operational commanders. However, the operational employment of bundled units is constrained by their observability, size, and need to ensure sustainment and protection.

Adopting a mission integration process would allow the US military to disaggregate service-delivered formations and create new mission-focused force packages in theater. In-theater mission integration would also allow commanders to better leverage less multifunctional systems such as uncrewed vehicles, novel algorithms for intelligence fusion, or specialized satellite payloads that tend to be mission-specific and are less likely to be incorporated into general-purpose service force packages. Exploiting digitization, these lower cost systems could be bought at larger scales compared to monolithic units and, through software containerization and interoperability

toolkits, be more easily composed in theater to address operational challenges and opportunities.

Today, CCDRs convey their capability needs to the military services via a lengthy process of analysis and justification managed by the Joint Staff. This process works when the units are self-contained multimission platforms or formations but affords the CCDR little adaptability or decision space. For example, the Global Force Management system assigns entire carrier strike groups to theaters for months at a time through a low-resolution manual process in which forces are not closely matched to the CCDR's operational challenges. As the US military adopts more disaggregated force designs and machine-enabled decision-support tools, CCDRs could begin to address their needs more precisely and closer to the point of need by assembling new systems of systems in theater. The benefits of composition in theater would increase if US forces implement more decision-centric operational concepts that exploit the composability of planned forces and C2 systems.

The ability of CCDRs to tailor the composition of sensors, weapons, and platforms at scale creates opportunities for DoD to change the way it demands, buys, and organizes new capabilities. For example, requirements should no longer be projected decades in advance to guide capability-development efforts. New defense systems should increasingly be weighed on their ability to improve optionality and effectiveness in a range of potential future force packages and scenarios. Sensors, weapons, and platforms will therefore be more valuable if they have greater interoperability and can adapt and evolve to address changing conditions and adversary capabilities, which may outweigh the system's inherent lethality, reach, or precision.

Fielding systems that can change over time will require a new approach to buying defense capabilities that will be more like the services model used by most commercial and some military software programs today. The adoption of services contracts for acquisition of physical systems would also reflect the growing contribution of software to their capability, as well as the increasingly commoditized nature of hardware like processors, antennas, and weapon or uncrewed vehicle airframes.

The next chapter will describe an approach to mission integration that could be used by CCDRs to tailor the composition of forces in theater, addressing operational challenges by exploiting the trend toward heterogeneity at scale. The implications of these new approaches to force design and capability deployment will be explored in Chapter 4.

CHAPTER 3. COMPETING OPERATIONALLY THROUGH MISSION INTEGRATION

Realizing the optionality possible with a more heterogeneous military will require ways of identifying when recomposing forces would be beneficial and managing the assembly of units from multiple services and domains in theater. Competing operationally with opponents such as the PRC or Russia through decision-centric warfare will therefore depend on organizations and processes for mission analysis and integration.

Today, CCDR and component staffs lack the personnel or technical capabilities to compose forces beyond the integration already performed by the military services. As a result, US military force structure is organized around self-contained or monolithic multimission platforms and formations that can either operate independently or coordinate actions with each other without the intervention of CCDR or component staffs. However, the limited inventory and high value of monolithic units constrains their operational flexibility and ability to create complexity for an enemy.

As US forces become more distributed and heterogeneous, the military services could create more complexity for

Photo caption: A US Air Force F-15C Eagle assigned to the 67th Fighter Squadron taxis down the flight line in preparation for take-off during surge training at Kadena Air Base, Japan, Feb. 4, 2021. (US Air Force photo by Rebeckah Medeiros)

opponents by establishing a greater variety of force packages. However, more diverse force packages will increase the cost and time to train and certify units before deployment—and the services could still incorrectly forecast the CCDR's needs. Instead, some responsibility for force composition should shift from services toward CCDRs and their domain-based components, which could configure packages closer to the time and location of use. Because services would remain responsible for organizing, training, and equipping their forces, CCDRs should not conduct the majority of force composition, but they will need greater capability for integration than is the case today.

DoD's implementation of JADC2 and ABMS should help CCDRs integrate forces that are not already packaged by services, although the associated course of action development and implementation processes will not be highly automated.[60] Rather than dynamically connecting units as they enter the operating area, in experiments the ABMS network is established and maintained manually, and potential elements of effects chains are scripted and characterized by users in advance. When operations are needed, ABMS proposes a simple course of action such as a weapon-target pairing and a timing or order of engagements, rather than exploring the entire set of course of action options available to a commander.[61]

The limitations of JADC2 and ABMS suggest mission integration in the near term will remain largely manual and conducted well in advance of an operation. This approach, which would constitute Wave 1 of mission integration, could be implemented as an architecture acquisition program that enables a growing number and diversity of options. Wave 2 will require new decision-support systems, interoperability tools, and operational infrastructure that allow CCDRs to integrate forces with greater flexibility and over larger scales closer to the time of operations. In Wave 3 of mission integration, real-time configuration of forces in theater would directly inform capability-development efforts by other organizations in DoD.[62]

Considering Operational Infrastructure

Deployed forces rely on operational infrastructure such as transportation, protection, logistics, energy, and C3 to integrate their actions. The US military's current operational infrastructure is designed to efficiently support multimission platforms and formations that are largely self-contained, carrying their own vehicles, defenses, supplies, battle-management systems, and fuel into theater. Once deployed, today's forces can be efficiently supported from a small number of centralized locations in the CCDR's area of responsibility—provided the units do not widely disaggregate and access is not contested or denied.[63] In contrast, small, less multifunctional units are unlikely to self-deploy. They will need to be transported to and within the CCDR's area of responsibility, resupplied in smaller amounts at a larger number of operating stations, and protected in detail using distributed defensive systems. As a result, the operational infrastructure for a more disaggregated future force may also need to reflect heterogeneity at scale.[64]

Transportation: Today, the military services' force generation organizations arrange for transportation of force packages into theater. In some cases, forces deploy themselves, such as a Navy carrier strike group sailing from the US West Coast to Indo-Pacific Command. In a permissive threat environment, commercial or government civilian transportation can move units into theater at a lower cost compared to military transportation and could afford commanders more options by keeping military units free to relocate units when conditions become contested.

Protection: Smaller, less multifunctional military units may lack defensive systems or only have capacity to ward off a single attack. Larger multimission platforms can provide area defense for smaller units, but this constrains the options for US force package configurations and defeats the purpose of fielding disaggregated forces. To sustain the force's optionality, CCDRs will need to employ attritable (low-cost or expendable) units or combine less multifunctional units in ways that ensure sufficient overall protection of the force package for the environment.

Logistics: The disaggregated units in a decision-centric or mosaic force will lack the combination of fuel storage, on-board ammunition and parts, food and water, and medical support commonly available in their monolithic, multimission counterparts. However, there will likely be too few large logistics platforms such as aerial refueling aircraft and oilers to promptly resupply units distributed through a theater, which will have the effect of reducing optionality. More disaggregated logistics ships, aircraft, and units will be more effective at delivering fuel, ammunition, and cargo to distributed forces but will increase the cost of logistics and reduce efficiency by replacing a single large platform with numerous smaller ones.[65]

The smaller size and more distributed nature of logistics units in decision-centric warfare argues for a shift to demand-weighted support to operational forces, rather than the current supply-based approach. With today's larger, more centralized logistics infrastructure, supported units come to the logistics hub for support, incentivizing the hub to maximize its inventory. In contrast, smaller logistics units will likely offload all their inventory as they resupply distributed forces, incentivizing them to carefully plan their operations to ensure they can meet demand.[66] Commanders' decision-support tools will need to incorporate logistics into their planning constraints, and in turn inform logistics C2 systems of the unit's expected needs.

C3: Perhaps the most important element of operational infrastructure is C3, which includes C2 systems that help commanders develop courses of action and communications networks that issue direction to subordinates and inform decision-making. Since the Cold War, DoD has invested much more on communications compared to C2. This balance reflected an expectation that networking US forces together would reduce the C2 burden by enabling commanders to maintain situational awareness over an operating theater and manage all the friendly forces within it to efficiently accomplish objectives.[67] In contested electromagnetic operational environments (EMOE) against capable peer competitors, however, communications will often be lost between headquarters and field commanders. Junior leaders exercising mission command over the forces with which they can communicate will need to rely on C2 tools to replace the planning staffs available to senior commanders.[68]

The relationship between C2 and communications suggests C3 should be thought of as a unified portfolio. From a planning perspective, C2 system improvements can mitigate communications shortfalls, whereas more resilient and interoperable communications can reduce the sophistication needed in decision-support tools. During operations, C2 systems would need to understand which units are in communication with a commander to develop executable courses of action; conversely, C2 systems could attempt to reconfigure communication networks in support of a commander's desired course of action. In general, improving optionality in a contested EMOE will depend on C2 relationships following communications availability rather than communication networks attempting to sustain a desired C2 hierarchy under all conditions.[69]

The timing and amount of operational infrastructure a CCDR will need to provide in theater can be a useful measure of the cost imposed by disaggregating service-provided force packages and integrating new force compositions in theater. For example, if a modest improvement in decision space requires consuming a large fraction of the available transportation, energy, and communications bandwidth, and thereby foreclosing future options, the course of action may not be worth pursuing.

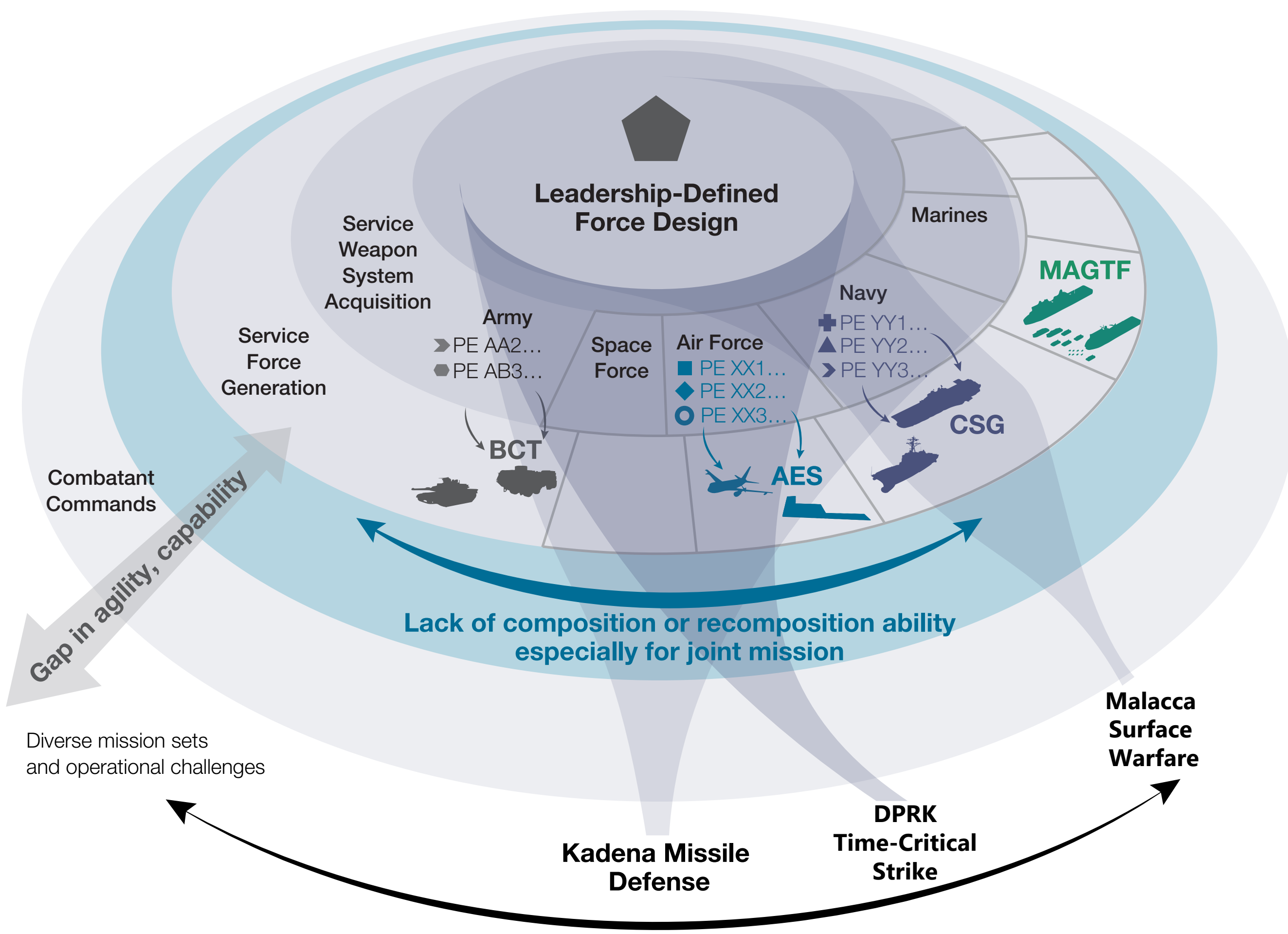
A Federated Approach to Mission Integration

Improvements to interoperability, decision support, and local operational infrastructure could enable CCDRs to create increasingly novel force compositions in theater if they had the organizations and processes to do so, as shown in Figure 6. For missions outside the CCDR's key operational challenges, the lack of mission integration capacity may not significantly impede the CCDR's ability to achieve objectives because force

packages provided by the services will likely be adequate, afford sufficient optionality for future operations, and foreclose few desirable options.

Within the CCDR's operational challenges, the operational infrastructure required to break up and recompose service-integrated forces may outweigh the benefits achieved in terms of effectiveness or adaptability. For example, an Air Expeditionary Squadron (AES) is the smallest unit the US Air Force deploys that incorporates both tactical aircraft and the support capabilities and aircraft needed to sustain operations in theater.[70] A CCDR receiving an AES may choose not to

Figure 6: The US Military's force development and generation process



Force packages could be used as provided by services, as in surface warfare, combined, as in time-critical strike, or broken apart and recomposed, as in missile defense. Today, individual unit commanders are expected to perform this integration.

Source: Report authors.

Figure 7: Capability providers involved in federated mission integration

	MISSION INTEGRATION CELL	MISSION OR SOFTWARE FACTORY	RAPID PROTOTYPING & EXPERIMENTATION	TRADITIONAL SERVICE ACQUISITION
	CCDR DIRECTION	CCDR REQUESTS	CCDR INFLUENCES	CCDR PROVIDES INPUT
SAMPLE OUTPUT	Missionware & novel kill chains to support operations	Mission-tailored systems and algorithms	Novel satellite payload with new sensing mode	Ships, cargo aircraft, hypersonic missiles, HF sensing
INCREASE IN OPTIONALITY	On-demand integration & interoperability tools	Rapid customization and tailoring	New mission systems, concepts, prototypes to build unique kill chains	Support for modular upgrades, open interfaces
FUNDING SOURCE	Combination of mission-based and organizational funding		Combination of mission-based and service funding	Service funding
SUSTAINMENT	Evolutionary development. No extra-mission use anticipated	Focused training & sustainment for CCMD user	Transition to mission use or service inventory	Classic sustainment, training, capacity considerations

Source: Report authors.

split the AES into smaller detachments or recompose the AES' units into other formations because the need for new logistics, transportation, sustainment, and communications arrangements is too high compared with the specialization or adaptability the new configuration would provide. However, the CCDR could choose to align capabilities from AES aircraft such as sensors or weapons with other units in theater because the support requirements for doing so do not differ from the aircraft's already-planned operations.

Larger service-provided force packages may be better suited to disaggregation and recomposition. For example, a Navy carrier strike group comprises an aircraft carrier, carrier air wing, up to seven surface combatants, an oiler, and sometimes a nuclear attack submarine.[71] Although highly multimission and adaptable, a carrier strike group concentrates much of the naval forces in a theater into one package oriented around a common set of missions. For that reason, today's carrier strike groups are often disaggregated in theater and only infrequently assemble for exercises or combat operations. Because the carrier group's constituent force elements are themselves self-contained multimission platforms, when disaggregated they do not require new operational infrastructure to support tasks such as surface warfare.[72]

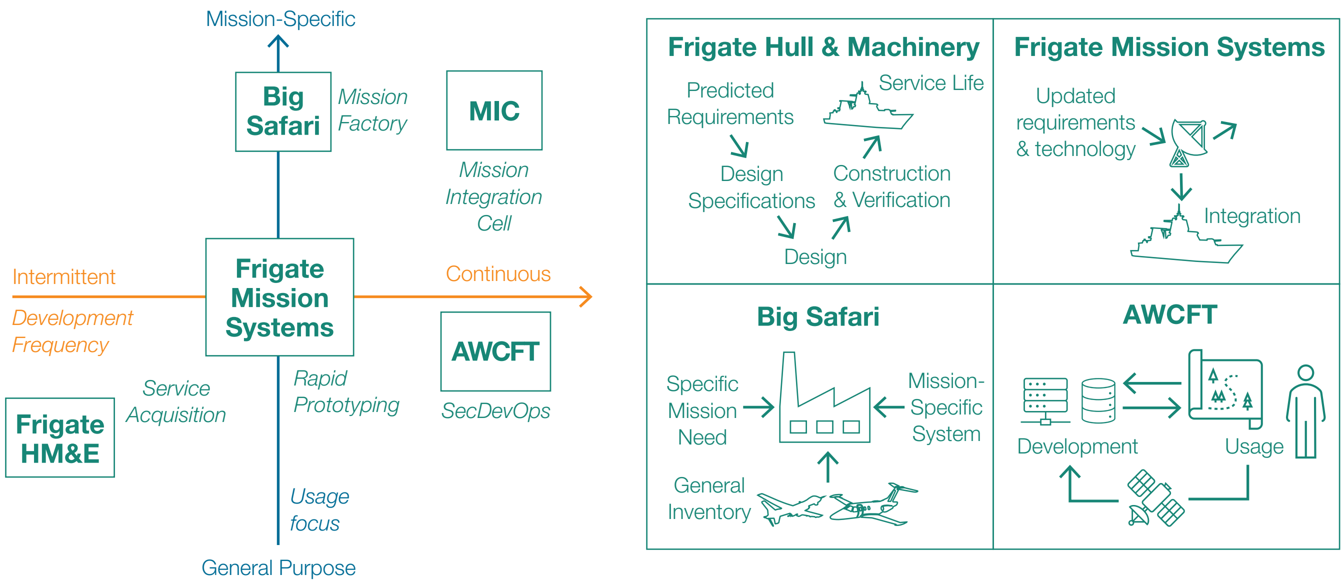
The need for CCDRs to recompose forces in theater in a relatively narrow set of situations suggests DoD should adopt a federated approach to mission integration. In most cases, service-provided

capabilities and force packages will be sufficient, as in the case of the carrier strike group. To address important operational challenges, CCDRs may need to break up existing force packages or assemble individual units deployed by services using operational infrastructure resident in theater. And in the most extreme cases, CCDRs will need to obtain new or modified capabilities on short timelines from service organizations or DoD agencies. The types of capability providers needed for federated mission integration are described in Figure 7, all of which exist in some form today.

The five main capability provider categories in the federated model are described below in order of increasing CCDR influence. For example, CCDR-identified needs and opportunities would have a modest impact on long-lived capital investments like ships, whereas CCDRs would direct the composition of force packages in theater through mission integration. The funding models used in each organization would reflect the degree to which the organization responds to near-term CCDR requirements. For example, long-lived multimission platforms developed under traditional acquisition processes would be funded via program elements as a capital investment by their services. New or modified capabilities needed to support a particular CCDR operational challenge, like maintaining air operations near an Air Force base in the face of a missile threat, would be funded via mission elements in the DoD budget associated with that challenge, combined with organizational funding provided to the mission factories or mission integration cells that create and integrate the capabilities.[73]

- **Traditional service acquisition:** Capital investments such as ships and aircraft are developed infrequently and operate for decades, delivering an evolving set of capabilities using a changing set of mission systems or payloads. This category of capability development would employ a hybrid government and industry R&D and acquisition approach, with the government leading overall design and specification development and industry conducting detailed design and construction. Today ships and aircraft are usually built with their mission systems. However, platform hull, mechanical, and electrical structures will increasingly be decoupled from mission systems, which will be developed via rapid capability processes as described below.[74]
- **Service Rapid Prototyping/Experimentation:** Historically, mission systems such as sensors, electronic countermeasures, and radios were tightly integrated with their host platforms, but they now are frequently modular and use standardized interfaces to enable exchanging systems over the platform's lifetime.[75] Mission systems and payloads such as weapons and UAVs could be therefore replaced or modified more frequently than the underlying ship, aircraft, or vehicle. With new flexible funding and acquisition authorities, US military services have established rapid capability offices that use modularity and open architectures to exploit the changing nature of electronic systems in which hardware is commoditized and software provides a growing portion of a system's capability.[76] These organizations field their capabilities predominantly through a process of prototyping and experimentation.
- **Mission factory:** Some operations or tasks require customization of the current systems within a platform or troop formation. In these cases, DoD would turn to organizations that adapt available capabilities for a unique need, often creating new integrations, algorithms, or equipment to satisfy a specific operation such as the Air Force's Big Safari organization, Navy Warfare Centers, or Army Combat Capabilities Development Command Centers.[77]
- **Software or SecDevOps factories:** Increasingly the capability of a military system is provided by its software, enabling a type of mission factory focused on updating code and algorithms on an ongoing basis. The Undersecretary of Defense for Intelligence Algorithmic Warfare Cross-Functional Team and the Air Force's Kessel Run software factory exemplify this organizational approach.[78]
- **Mission Integration Cell:** As described below, mission integration cells (MICs) will determine when force package

Figure 8: Roles and underlying processes of capability providers in the federated model



An ecosystem of capability providers can provide the spectrum of capability delivery needed to achieve responsiveness in development, long-term capital planning, and customization to the particular needs of missions.

Source: Authors.

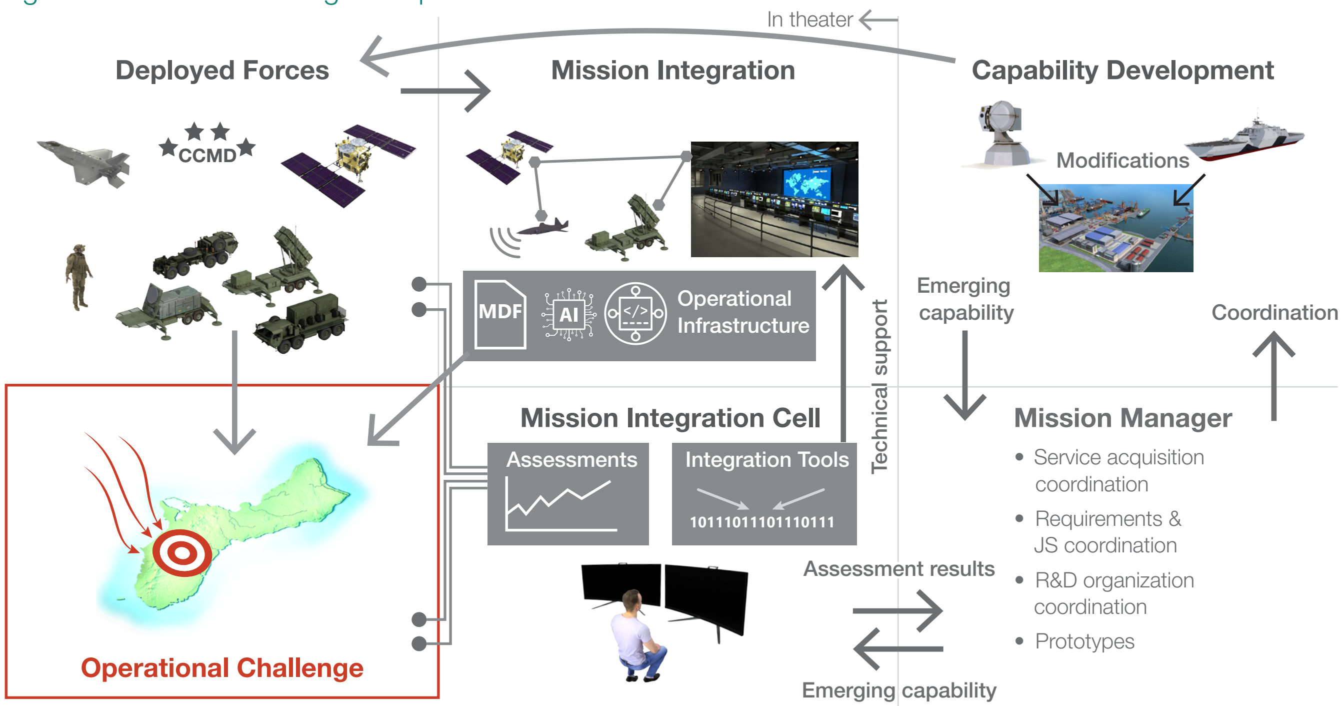
recomposition is warranted and worth the cost and potential impact on optionality. MICs will coordinate with component commanders to manage the recomposition process, including apportionment of operational infrastructure. Through their ongoing assessments, MICs will also identify opportunities where new capabilities could improve their forces' adaptability or effectiveness.

The five different models of capability delivery described above can be considered part of an ecosystem of capability delivery, depicted in Figure 8, each element of which fulfills a unique role. The diversity of capabilities delivered reflects the military's growing heterogeneity, which cannot be adequately sustained through industrial processes designed primarily to support long-lived capital investments like crewed combat aircraft or ships.

The Mission Integration Process

The central node of the federated mission integration model would be the MIC within a CCDR's staff. Although mission integration suggests the real-time assembly of forces and operational infrastructure in response to an emerging challenge, force packages recomposed by the MIC will draw upon capabilities already in theater. Therefore, MICs will need to anticipate their capability needs in advance and collaborate with component commanders to ensure required forces and operational infrastructure are in place in time to conduct missions.

Figure 9: The mission integration process



The mission integration process creates a fast feedback loop for combining deployed forces with operational infrastructure, supported by a mission manager to oversee fielding of emerging military capability.

Source: Report authors.

As shown in Figure 9, MICs would assess the ability of current and anticipated forces to address the CCDR's key operational challenges during the coming one to two months to determine whether recomposition of service-provided force packages is appropriate. As detailed further in Chapter 3, MICs would mitigate the risks of this essentially forecast-centric assessment process by pursuing both adaptability and effectiveness in their analyses.

When new force packages are needed, MICs will direct recomposition by component commanders using local operational infrastructure. If assessments suggest available or anticipated forces will not provide sufficient effectiveness or optionality, MICs can request modified or new capabilities from the providers shown in Figures 7 and 8. The necessity of focusing MIC actions on the near term—months down to days—would shape the MIC's interaction with capability providers. For example, MICs will have significant influence on mission factories and rapid prototyping organizations but less impact on services that are developing platforms and systems with much longer development timelines.

MICs will need assistance navigating their varying relationships with capability developers. The Joint Staff will help MICs collaborate with capability developers for most mission areas. Because the Joint Staff lacks funding authority, mission managers in the Office of the Secretary of Defense would be established for CCDR operational challenges to direct

capability-development efforts using mission element funding as described in Chapter 4.[79]

In contrast with the Joint Capabilities Integration and Development System's goal of determining future capability gaps, the mission integration process is focused on identifying near-term opportunities to pursue improved effectiveness or adaptability. The CCDR's familiarity with local conditions, relationships, and threats will in some cases provide the MIC with additional insight regarding new systems or operational concepts that could improve the outcomes achieved by US forces. These opportunities would be evaluated in excursions to MIC assessments, with the results being provided to capability developers via mission managers or the Joint Staff.

A Case Study in Mission Integration: Resilient Air Base Operations

Although the US military operates as a joint force overall, there is currently no integration activity beyond the services' force generation organizations. As a result, most missions are performed by units from a single service; if multiple services' units are involved, they merely deconflict their actions rather than attempting to integrate their capabilities around a new set of tactics. As described above, the mission integration process is designed to achieve improved outcomes by providing a mechanism for identifying and managing the composition of joint force packages in theater.

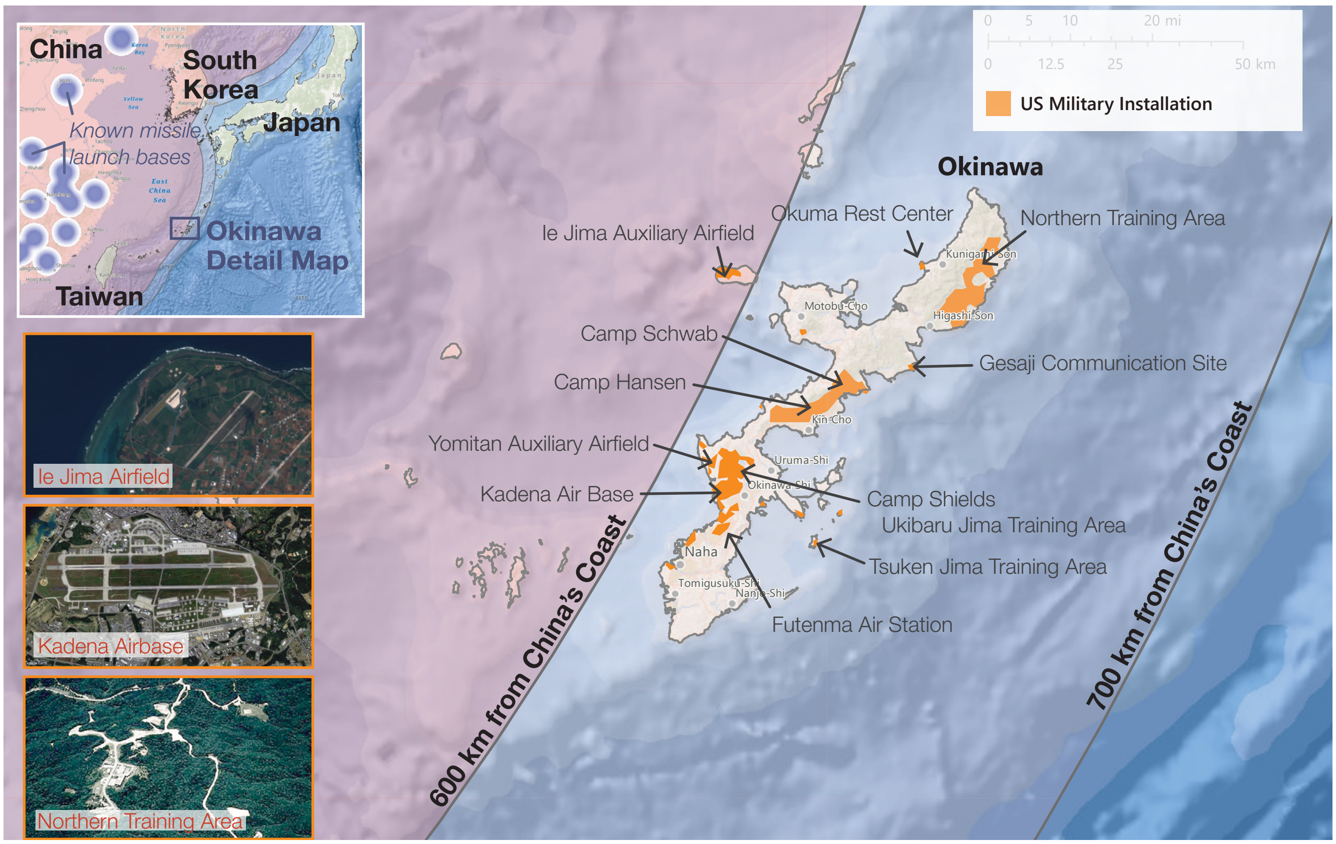
The operational challenge of sustaining air operations from Kadena Air Base on Okinawa in Japan provides a good case study for mission integration.[80] In the absence of a mission integration cell or any other integration activity beyond the service level, this mission is addressed independently by forward-stationed Air Force base operation and support units, including rapid runway repair teams; forward-deployed Marine units employing auxiliary airfields; Navy Aegis-equipped surface combatants; and Army Patriot air and missile defense batteries. Stationing these units in theater on a permanent or semi-permanent basis allows operators over time to integrate their procedures, communications, logistics and other operational infrastructure in advance of an attack. This approach, however, also presents an opponent with well-defined forces and predictable tactics that reduce the attacker's uncertainty.

In a hypothetical military confrontation, an adversary's ability to suppress air operations from Kadena would substantially reduce the options for US commanders, increase the predictability of US actions, and expand the decision space available to an attacking force. Although the proximity of Kadena to potential threats would make large-scale air operations challenging during a conflict, continuing even a modest number of sorties would introduce uncertainty into the attacker's decision-making and reduce the options available to the enemy.

Sustaining some level of Kadena's functions will rely on creating adaptable and unexpected schemes for air defense and sortie generation. For example, defenses could be augmented, distributed, and made more relocatable by adding Army or Marine Corps maneuverable short-range air defense systems, including the Indirect Fires Protection Capability and powder guns using hypervelocity projectiles, to protect priority targets such as fuel or C2 facilities.[81] Physical and electromagnetic decoys could help dilute attacks by simulating likely targets such as radars, communication systems, or runway repair vehicles; the effectiveness of decoys could be enhanced by using electronic warfare systems such as the Army's Terrestrial Layer System (TLS) to obscure enemy attempts to surveil Kadena's defenses using radar.[82] Defensive operations could also be augmented with offensive actions when appropriate and authorized.

Alternative capabilities for vital base functions could make air operations around Kadena more adaptable and less predictable. Staging areas, ramps, taxiways, and roads could be employed as runways, especially for smaller jets, managed by mobile air traffic controllers in vehicles. Aircraft on the ground could be dispersed on Okinawa or off-island prior to hostilities to reduce

Figure 10: Okinawa's geographical proximity to the People's Republic of China



The proximity of Okinawa to the PRC makes it especially vulnerable to attack.

Source: Report authors, with base information drawn from Okinawa Prefectural Government.

their vulnerability but could remain fully fueled so they could take off and use airborne Air Force or Navy tankers rather than relying on Kadena's fuel farms, which are likely to be attacked.[83]

Coordinating the actions of numerous units from multiple services before imminent hostilities and during conflict will require substantial recomposition and integration of traditional force packages, which today's CCDR staffs are ill-equipped to manage. Moreover, enabling this approach to an operational challenge will require some new or modified systems and capabilities to connect disparate units and help commanders effectively orchestrate their activities. To reduce the cost and complexity of integrating forces in support of resilient Kadena air operations, the MIC would conduct the following tasks continuously in advance of potential hostilities:

- **Assess:** The Indo-Pacific Command (INDOPACOM) MIC would maintain real-time awareness of force readiness, using tools like DARPA's LogX,[84] and analyze a range of potential

scenarios during the next one to two months in which Kadena's air operations could be constrained. In the context of these situations, the MIC would assess the effectiveness and optionality afforded by a wide variety of joint force packages that could be brought to bear using units that are already in theater or could be quickly redeployed to Okinawa. Balanced against the operational infrastructure needed and the impact on other missions, the MIC would identify new courses of action that provide substantially improved outcomes.

- **Recompose:** Drawing upon the force packages already deployed or expected in theater, the MIC would coordinate with component commanders to recompose forces in support of one of the desired courses of action. These forces may have been destined for another INDOPACOM location or mission, but their use in the Kadena air operations mission could provide a larger benefit in terms of theater-wide effectiveness and optionality. For example, additional Patriot batteries or TLS units would be beneficial at other air bases in Japan. The MIC's analysis, however, may suggest placing these systems at Kadena creates a greater impact on enemy decision-making and affords more options to US commanders. Similarly, intelligence, surveillance and reconnaissance (ISR) aircraft may be useful identifying potential targets in the South China Sea but could afford more benefit to the CCDR's decision-centric operations if used to improve intelligence and warning of impending attacks on Kadena.
- **Modify:** Some existing systems may require modification to support the advantageous courses of action identified by the MIC. Changes are unlikely to be needed for communications interoperability, which could be afforded by software-defined networks like DyNAMO or automated software tool kits like STITCHES. However, the new force package's adaptability may depend on system changes such as new or improved algorithms for the Army's Integrated Battle Management Command and Control System to coordinate air defense fires between new combinations of units; updated electronic warfare system mission data files to address new threats and employ new techniques; or artificial intelligence-based processing systems and programs to fuse data from a changing collection of regional commercial sensors. Modular software and hardware will facilitate these changes, which would be conducted by mission factories.
- **Evolve:** Some modifications would be more substantial. For example, decoy air defense systems and sensors could be assembled relatively quickly by the services' rapid prototyping and experimentation organizations. These organizations could also quickly procure additional runway repair capabilities to enable fighting through attacks and construct necessary personnel bunkers and other fortifications. The mission manager would direct these efforts, which could be funded with mission element funding or by services.

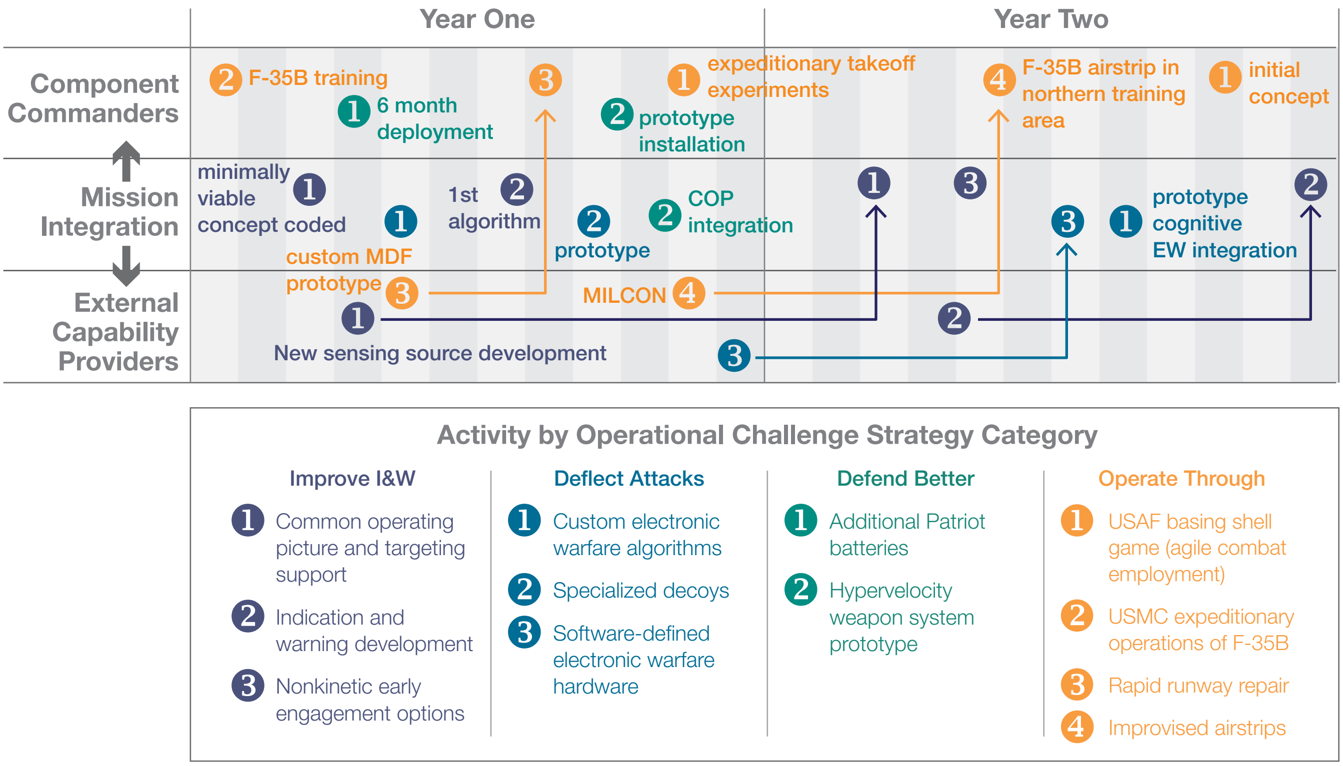
In addition to these activities focused on protecting and sustaining air operations, the MIC could assess and identify opportunities made possible by offensive action against an attacker. These missions may be integrated into the courses of action developed by the MIC or coordinated separately across the CCDR staff.

Although the MIC is focused on a near-term window of the new one to two months, as shown in Figure 11 the mission manager would direct actions over a one- to two-year time horizon. Some tasks involve operational demonstrations and experimentation by INDOPACOM component commanders, whereas others require capability modification by mission factories or rapid prototyping organizations. Notably, none of the capability delivered constitutes a new weapon system, and the depicted process occurs well within the Pentagon budget preparation cycle. Therefore, mission integration will require a stable source of mission-based funding even as to support a set of activities that are unpredictable and adaptive by design.

Restoring the Customer to Capability Development

The mission integration process could enable a new approach to establishing requirements for future military systems. Today, services supply forces to CCDRs that act as the customers or

Figure 11: The mission manager support process for combatant commander mission integration based on a two-year model



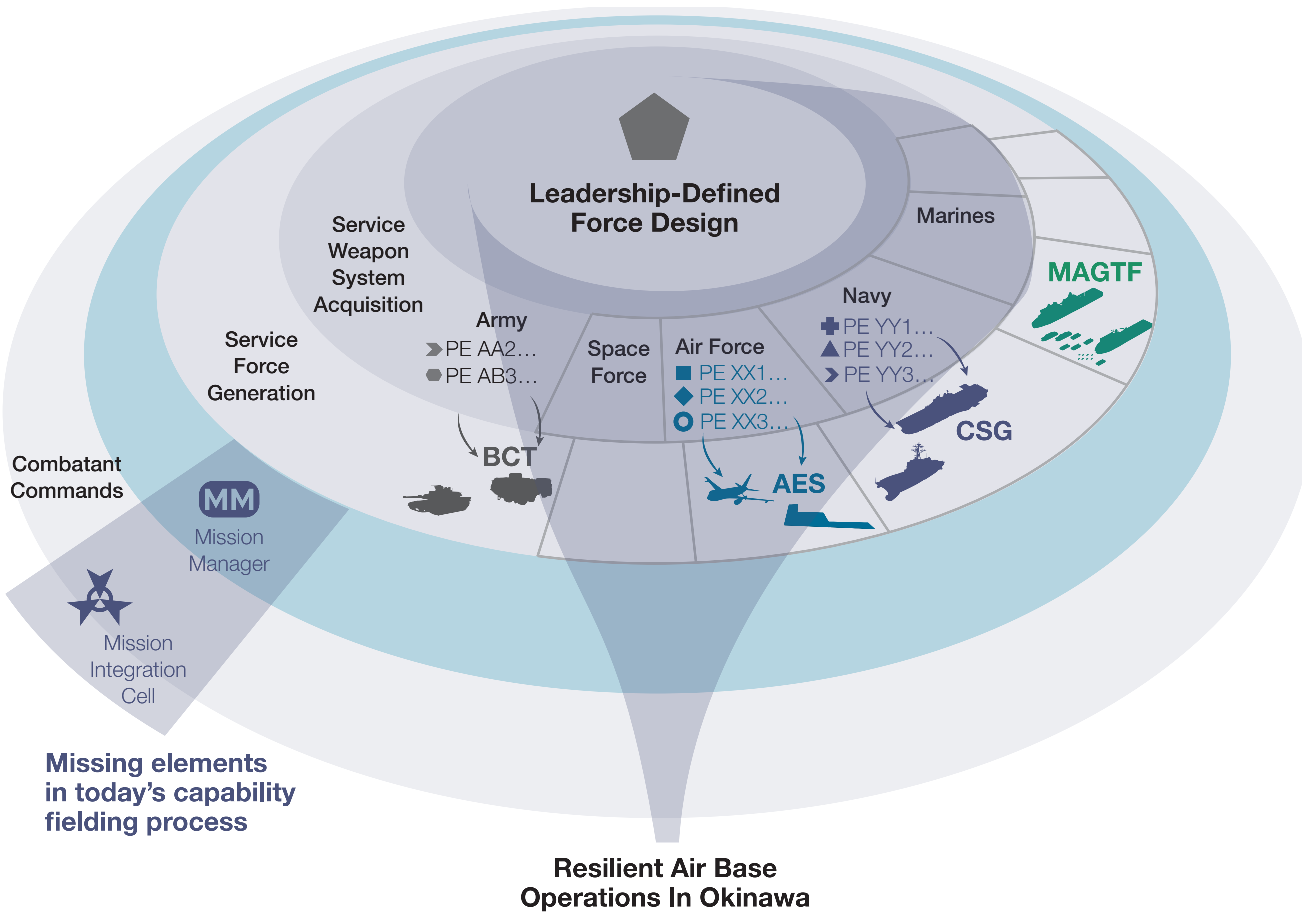
The mission manager for an operational challenge like resilient Kadena air operations would help coordinate action and integration between operational commanders and external capability providers.

Source: Authors.

users of defense capabilities. Unlike customers in a commercial market, however, CCDRs do not have a strong influence on their suppliers, the military services. CCDRs participate, but do not lead, in the Joint Capabilities Integration and Development System process that sets requirements for future capabilities and are generally not part of R&D decision-making bodies such as the Defense Acquisition Board. In large part, the diminished CCDR role in capability development results from an expectation that they are focused on current operations, not projections of future needs.[85]

CCDRs should have a greater role in setting capability requirements and guiding R&D given the pace of technology development and near-term operational demands created by adversary innovation. For example, as noted by INDOPACOM's commander, the PRC may be in a position to invade Taiwan before the end of this decade.[86] And as US military force designs move toward a model of heterogeneity at scale, CCDRs will have a greater ability to compose forces in theater to support their ability to address operational challenges.

Figure 12: The US Military force development and generation process including joint force integration in the field



DoD needs a layer of composition and recomposition to achieve the optionality and complexity needed for decision-centric warfare.

Source: Report authors.

As shown in Figure 12, the MIC and its associated mission managers would help CCDRs exercise greater responsibility for capability composition and development and provide a system for joint integration missing in today's service-driven force generation processes. Although CCDRs would continue to have a limited role in defining needs for capital investments such as aircraft and ships, in the context of their operational challenges MICs would increase the CCDRs' influence on mission system development and modification through rapid prototyping organizations and mission factories.

The US military is evolving like the rest of the US economy toward heterogeneity at scale. At the same time, trends in

information and communication technology are driving mission systems to be more software-defined, enabling them to be continuously developed and decoupling mission systems from hull, mechanical and electrical structures developed using industrial models. DoD is making some reforms to embrace these changes with the introduction of its Adaptative Acquisition Framework and new software appropriation category. However, the US military lacks organizations and process to use these new authorities to address needs and opportunities identified by CCDRs. By introducing MICs and mission managers and formalizing the roles of existing mission factories and rapid prototyping organizations, DoD could enable CCDRs to increase their role in force composition and improve the US military's adaptability.

Whether the federated model described above is adopted in whole or part, technological and operational trends are driving the US military force design toward heterogeneity and its capability-development efforts toward more rapid introduction of new systems and platforms. As a result, some type of mission integration process is likely to emerge. Perhaps more importantly, the importance of adaptability implies changes are needed in DoD's budgeting and innovation processes. These changes will be described in the following chapter.

CHAPTER 4. COMPETING STRATEGICALLY THROUGH INSTITUTIONAL AGILITY

During the Cold War, net assessments from strategists like Andrew Marshall concluded that preventing the Soviet Union from gaining a strategic advantage over the United States and its allies would require the US government to compete institutionally, militarily, and economically with its Soviet counterpart.[87] The preceding chapters describe the evolution underway toward heterogeneity and scale in US military forces and how DoD could exploit these trends to better compete operationally. However, improving DoD's ability to compete institutionally with adversaries including the PRC or Russia will require changes to the department's resource allocation and innovation processes, and most importantly the metrics DoD uses to define success. This chapter will highlight some of these changes, which will be further explored in future research.

New Metrics and Analytics

Similar to the PC's displacement by mobile computing devices, the emergence of heterogeneity at scale and virtualization of mission systems will privilege new metrics compared to the monolithic platforms and formations of today's US military. Like

Photo caption: A logistics unmanned air system (UAS) prototype, called Blue Water UAS, approaches to deliver cargo on the aircraft carrier USS Gerald R. Ford's flight deck during a supply demonstration, Feb. 21, 2021. (US Navy photo by RJ Stratchko)

other forms of maneuver warfare, forces in decision-centric operations succeed primarily by using their composability to achieve an optionality advantage that can create an insoluble set of dilemmas for the enemy or overwhelm opposing defenses to allow attacks on enemy centers of gravity. The effectiveness of heterogeneous US forces will therefore depend more on their interoperability and adaptability than on their individual performance according to traditional measures.

The rising importance of interoperability and adaptability implies changes to the context in which a force's effectiveness should be measured. The utility of an individual unit of a disaggregated force is irrelevant when evaluated in isolation, requiring assessments to instead consider force packages as a whole. The optionality advantage a force can achieve will also depend on the opposing force's capabilities and disposition, requiring assessments to be conducted in an adversarial setting.

Assessing force packages in predicted operational situations, however, incurs the problems inherent in forecast-centric planning. Assumptions regarding adversary actions and systems could be incorrect and projections of US or allied force posture and performance could fail to come to fruition. To reduce the risk of choosing an inaccurate set of future scenarios and force configurations, capability assessments by mission integration cells should consider multiple configurations of US and adversary forces in a variety of plausible situations that include competition and conflict.

The need to assess an array of force configurations, scenarios, and adversary dispositions suggests MIC analyses should be stochastic rather than deterministic. By using scenarios with probabilistically generated characteristics, DoD planners could better assess the robustness of existing or potential future force configurations. Chaos engineering is a form of this assessment approach used by information technology companies such as Netflix to assess the robustness of infrastructure to a range of possible challenges.[88]

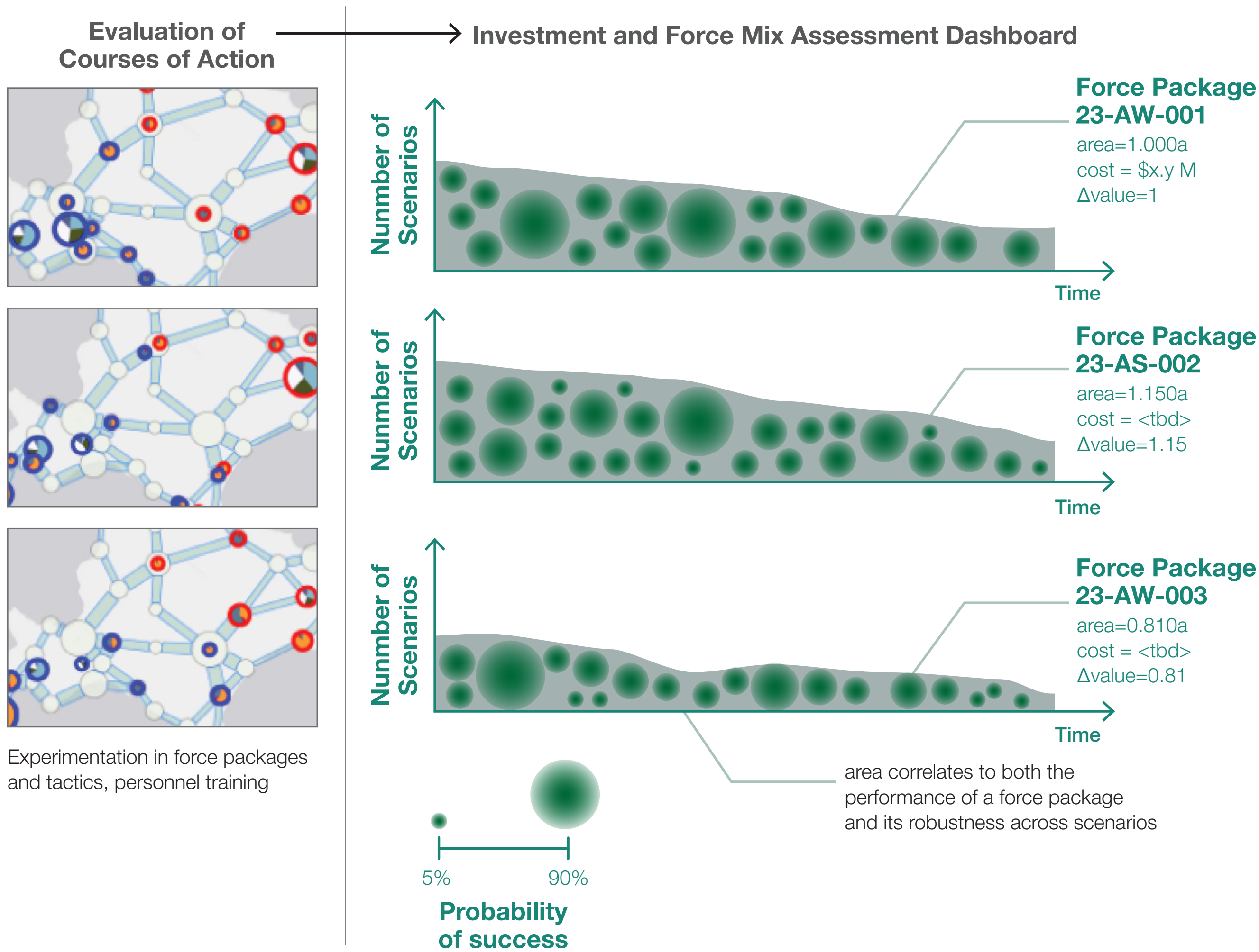
In the DoD version of chaos engineering, each potential combination of force package and tactics would be assessed against a probabilistic set of situations and enemy dispositions, with the scenarios evolving from competition toward conflict to evaluate the force package's optionality over time. As shown in Figure 13, force packages and tactics that yield a higher probability of success will yield a larger bubble for that scenario, leading to a wider cone of results for force configurations that have greater effectiveness over more situations. Force packages that perform well in a narrow set of scenarios would have a smaller cone than those that perform adequately in a wider variety of situations.

In addition to evaluating available force packages, the MIC analytic process could assess the impact of new capabilities and operational concepts. By introducing the notional new system or tactic into existing force packages, the assessment process would yield cones of probability showing the revised force's effectiveness across a range of situations. These insights could be fed to capability-development organizations via the mission manager or Joint Staff to guide efforts to field new capabilities that improve effectiveness and optionality.

Assessing force configurations for adaptability and effectiveness implies changes to DoD's common analytic processes. To evaluate a wide range of situations, DoD planning scenarios will need to be less detailed and more varied, addressing events during both competition and conflict. This is very different from the small number of large-scale canonical warfighting scenarios currently used in DoD force planning.[89] Moreover, the analysis conducted of force packages in these scenarios will by necessity need to be of lower fidelity than is commonly employed in current DoD campaign analysis.[90]

The shift from extensively analyzing a narrow set of situations to assessing a wide range of circumstances with lower fidelity is a significant adjustment to DoD operations research practices but is consistent with the advent of decision-centric operations.

Figure 13: An illustration of the notional effectiveness of three force packages in the same set of scenarios over a timeframe from competition to conflict



Size of bubble indicates probability of success of force package in a specific situation or scenario. Each force package is assessed in the same broad range of scenarios that take place over a given confrontation or competition. The number of possible scenarios narrow over time due to proximity, losses, and improved situational awareness. The area covered correlates to both the effectiveness of a force package and its robustness across scenarios.

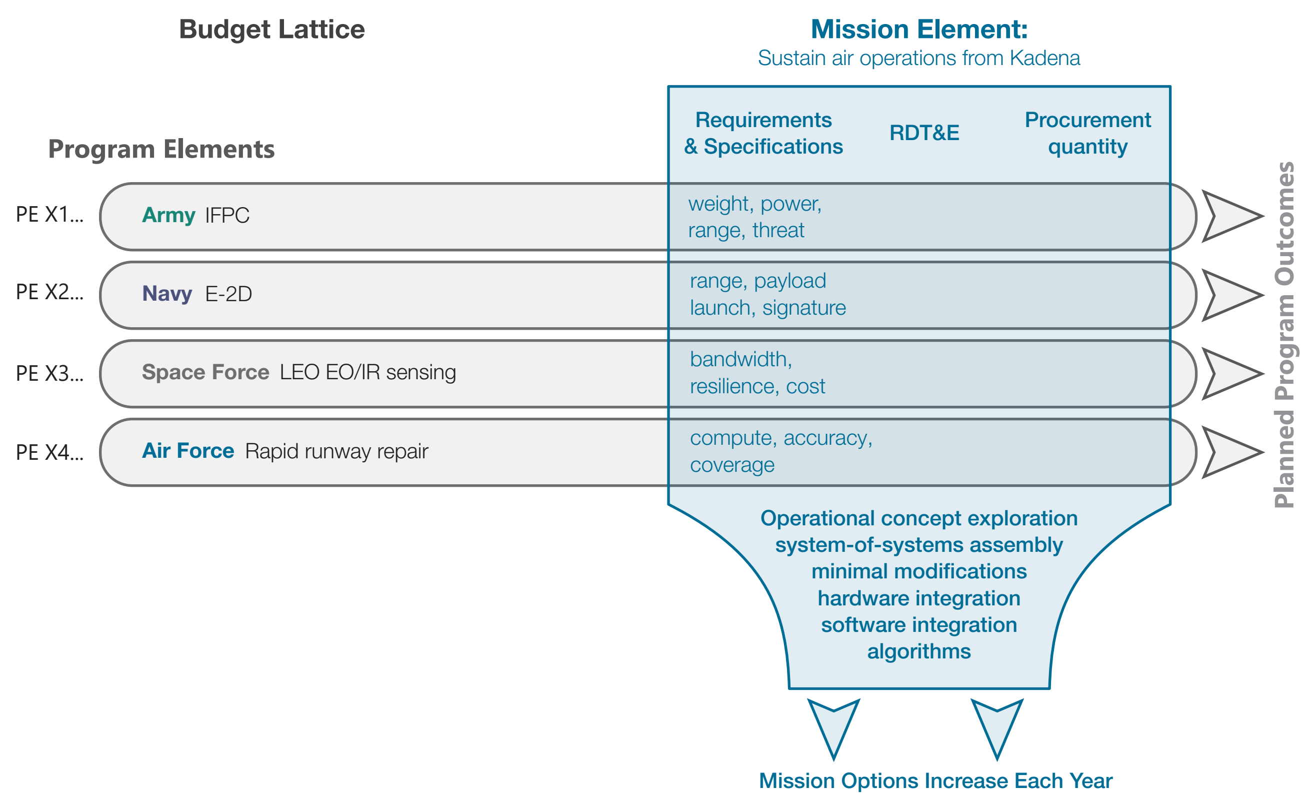
Source: Report authors and analysis taken from the DARPA CASCADE program.

By pursuing capabilities that address a variety of situations with acceptable effectiveness, the US military could reduce an opponent's optionality and likelihood of success.

Increasing Budget Agility

DoD's resource allocation processes are arguably the most significant constraint on its ability to realize the benefits of heterogeneity at scale and develop forces balancing adaptability and effectiveness. Today, funding for defense activities is allocated via program elements that reflect an industrial planning model: Money for platforms and systems such as aircraft, ships, weapons, or sensors is narrowly prescribed for purchases or R&D of specific equipment; funding for compensation or operations and maintenance is defined more broadly but cannot be moved between categories. Once appropriated by Congress, changes in resource allocation require bureaucratically cumbersome reprogramming or a delay of two to three years to make the change in a future defense budget.[91]

Figure 14: Relationship between program elements and mission elements in DoD budget structure



DoD budget structures should change to incorporate mission elements managed by CCDRs that can fund integration of capabilities developed by services through investments made via existing program elements. The mission elements deliver combined capability against emerging operational challenges, while the program elements deliver against weapon system requirements on schedule.

Source: Authors.

Metrics are also a problem in defense budgeting. Return on investment is measured in terms of production outputs, rather than operational outcomes. And while a great deal of effort is devoted to justifying operational utility and value when establishing requirements and funding levels, these decisions are rarely revisited during the life of an acquisition, even as threats and scenarios change.

The static nature of defense budgeting and its focus on outputs vs. outcomes could prevent DoD from implementing a federated mission integration model like that described in Chapter 3. For example, mission managers would need to buy new or additional existing operational infrastructure on relatively short timelines to enable MICs to compose a greater variety of force packages. Less multifunctional units could adapt by taking advantage of their modular and software-defined mission systems, but mission factories or rapid prototyping organizations would lack the authority to promptly start new programs. Perhaps most egregiously, systems that yield an inadequate combination of effectiveness and adaptability based on MIC assessments cannot be stopped and their funding reallocated for years thereafter.

DoD could help address the inflexibility and industrial focus of its current budget process by changing its resource allocation model to fund missions alongside programs. In this new approach, shown in Figure 14, today's program elements would be joined by mission elements for high-priority operational challenges that require complex combinations of service-provided forces and local operational infrastructure. These operational challenges, such as resilient air operations from forward bases on Guam or Okinawa, time-critical strikes against missile launchers in North Korea, or anti-submarine warfare in the Greenland-Iceland-United Kingdom gap would be addressed by a mission manager and MIC as described in Chapter 3.

In addition to coordinating the efforts of capability providers as requested by MICs, mission managers would control funding associated with mission elements. Mission managers would use mission element funding to support mission factories and rapid prototyping organizations in providing new or modified systems to CCDRs, as well as pay for operational infrastructure such as additional logistics platforms, decision-support system updates, or interoperability tools.

Moving from Cost to Value

The revised analytic process described above could be combined with mission-based funding to evaluate new capabilities on the basis of their value instead of only on their cost. The range of scenarios against which force packages are assessed would essentially create a "market" in which defense capabilities are employed. The aggregate effectiveness of a force package against the range of scenarios, or the area covered by bubbles in Figure 13, represents the operational benefit it could provide. If this benefit were divided by the force package's cost, it could provide a measure of a force package's value.

The use of value to assess changes to force packages across a broad range of scenarios would provide capability providers and DoD decision-makers a comprehensive way to assess their programmatic tradespace. Although this approach would be too cumbersome to use for every mission and context, it would be feasible for the small number of key operational challenges identified by DoD leadership and for which a mission manager is assigned.

A significant benefit of comprehensive tradespace analysis would be highlighting the most beneficial additional elements that could be added or removed from force packages that address operational challenges. In today's DoD programming process, a new capability has to be affordable in its own resource portfolio—such as land-based fighter aircraft or naval surface combatants—and fill a well-documented gap in the effectiveness of a narrow set of force packages and scenarios. In addition to requiring substantial assumptions and predictions about future scenarios and capabilities, this approach will tend

to undervalue new capabilities that could improve effectiveness rather than solve a projected shortfall.

In the value-based assessment approach, the predominant existing force package for an operational challenge is considered the baseline. As described above, the area covered by bubbles represent the baseline force package's effectiveness in various scenarios for that operational challenge and dividing effectiveness by cost yields its value. Alternative force packages incorporating new elements or capabilities can be assessed in terms of their value by comparing them to the baseline. DoD leaders could determine which new or modified capabilities to develop based on which provide the greatest improvement in value.

A value-based, rather than cost-based, approach to prioritizing new capabilities could allow contracting officials to justify pricing for new capabilities that would better incentivize new vendors to enter the defense market, including commercial firms accustomed to higher margins on their products. Implementation of value-based decision-making will be addressed in future research.

Implications for the Defense Industrial Base

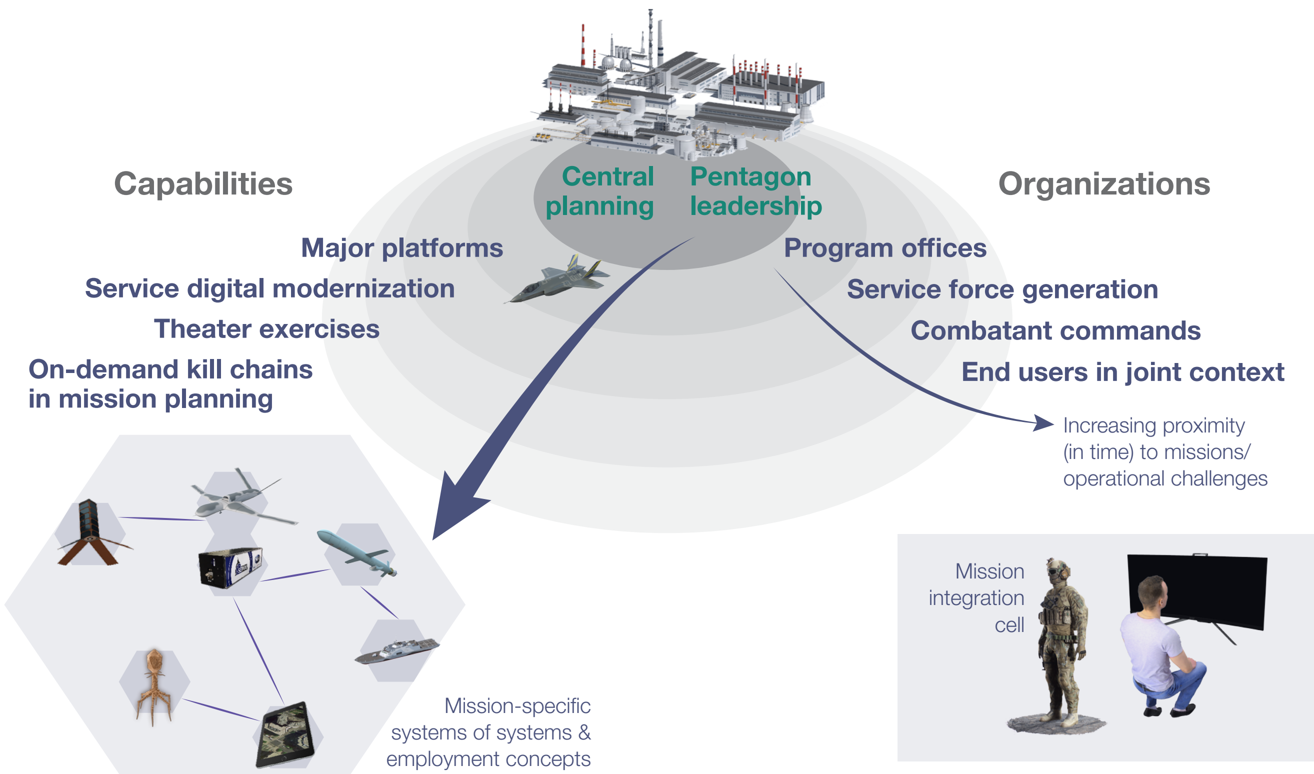
The trends toward heterogeneity at scale and modular capabilities are already driving changes to the defense industrial base. For example, mission system providers are consolidating or being acquired by platform builders seeking the faster development cycles and higher margins possible in sensors, communication systems, C2 tools, weapons, and countermeasures compared to aircraft or ship construction.[92] DoD is growing the number of commercial providers it relies on for services like software development or satellite ISR and expanded its use of new contracting arrangements such as Other Transaction Agreements to sponsor mission system development and procurement. [93]

By adopting a federated mission integration approach like that described in Chapter 3, DoD could accelerate this trend. Legacy prime contractors will remain the most cost-effective providers of long-lived platforms and systems built under the current industrial acquisition model, which would host a changing set of payloads. A growing ecosystem of smaller vendors would continue providing mission systems through rapid prototyping organizations or mission factories using new acquisition pathways for Middle Tier of Acquisition, Urgent Capability Acquisition, and Software Acquisition.[94]

This model of the defense industrial base suggests that the solution to excessive defense industrial base consolidation may not be encouraging new competitors to bid on major defense acquisition programs. Instead, as shown in Figure 15, disruptive entrants could drive cycles of decentralization by focusing on new and underserved customers like the mission manager or CCDR who could benefit from a solution tailored to a particular operational challenge. Similarly, aligning some budgetary authority under mission managers and promoting service experimentation could create opportunities for companies who can modify hardware under the mission factory model or develop better algorithms like service software factories, or otherwise support the military's sprawling heterogeneous demand.

If DoD goes further than simply riding the ongoing trend toward disaggregation and embraces changes to its metrics and budgeting processes, it will incentivize greater emphasis on adaptability and interoperability in defense programs. Although platforms will continue to be defined by predictive analyses of their utility over decades of service life, mission systems will experience shorter cycle times, which DoD can exploit by building them outside of the legacy acquisition process using agile funding mechanisms such as mission elements or software appropriations. Flexible funding and acquisition will erode the advantages of incumbency, allowing DoD to more easily favor mission systems that deliver greater value by driving larger increases in aggregate effectiveness across a wider array of situations.

Figure 15: The decentralization of DOD solution development



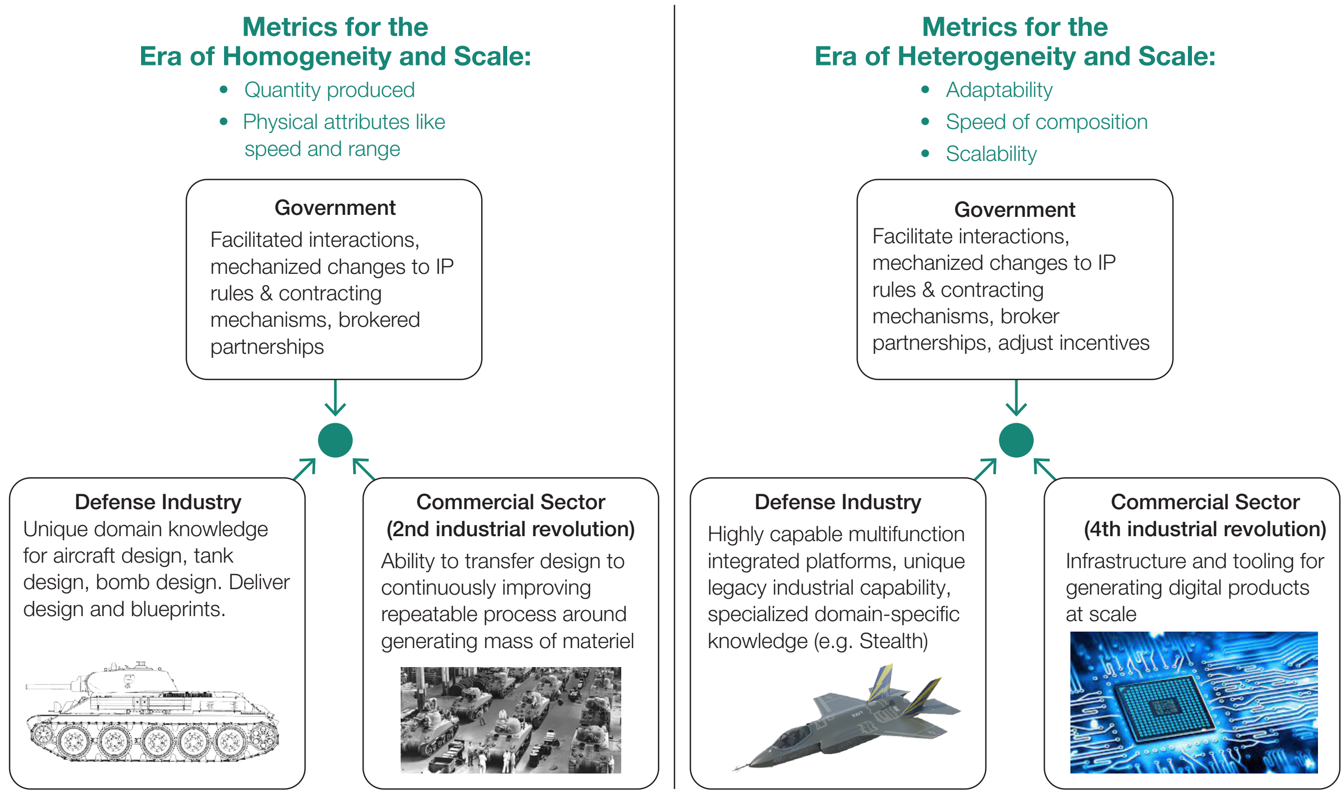
Mission integration could unleash decentralization and a wave of new industrial base entrants that provide capabilities for organizations other than service program offices. In the era of heterogeneity and scale, military problems are being solved in the field.

Source: Authors.

With new mechanisms for more easily buying and replacing mission systems and an emphasis on value rather than cost, DoD could further incentivize commercial product builders to enter the defense industry, as shown in Figure 16. During the industrial era of World War II, shown on the left, the government acted as an intermediary between defense contractors and the commercial sector, with commercial providers supplying extra capacity to build equipment using the defense contractor's or government's intellectual property. Today, as shown on the right, the commercial sector can provide some capabilities directly to the government, such as satellite ISR. More importantly, commercial participants can provide the digital infrastructure to allow rapidly adapting defense capabilities that derive an increasing amount of their capability from software or commercially derived information and communication technology hardware such as processors and electromagnetic sensors or countermeasures.

The trend toward heterogeneity at scale will continue to foster an emerging ecosystem of defense providers including

Figure 16: The relationship between the government defense industrial base and commercial sector during different eras



The changing metrics for military capability development will create new incentives for the defense industrial base.

Source: Authors, based on Arthur Herman, *Freedom's Forge*, (New York, NY, Random House, 2013).

traditional prime contractors for integrated multimission platforms, defense-facing mission system manufacturers, commercial services providers that support digital adaptation of mission systems, and a growing number of defense companies transitioning commercial technology into military mission systems. DoD can further encourage and take advantage of this trend with changes to how it measures value in military systems, funds capability development, and engages with the defense industry. These areas will be addressed in future research.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

Emerging technologies and new use cases are driving consumer products, services, and military forces toward a combination of heterogeneity and scale. In commercial applications, the internet, mobile communications, modular products, and algorithm-enabled transportation are enabling the distribution of tailored products and services to users. Military forces are able to similarly exploit networks, C2 tools, modular mission systems, and operational infrastructure to compose force packages that provide a combination of effectiveness and adaptability to CCDRs.

Whereas many commercial technology companies built their businesses around the ability to tailor offerings to global customers, DoD has largely been a bystander to the trend toward heterogeneity at scale. Although the Pentagon established a growing collection of capability-development organizations and acquisition pathways to field more diverse systems faster, the goal of these efforts was to get capabilities more quickly to the warfighter rather than change its force development paradigm to harness fundamental technology trends.

Photo caption: Capt. Adam Schinder, commander of the Expeditionary Cyber Support Detachment, 782nd Military Intelligence Battalion, provides command and control for ECSD cyberspace operations specialists supporting training for the 3rd Brigade Combat Team, 1st Cavalry Division at the National Training Center in Fort Irwin, CA, January 14, 2019. (Photo by Steven Stover)

The US military needs operational and institutional decision-making advantages to effectively deter opponents such as the PLA or Russian Armed Forces. Operationally, achieving a larger decision space depends on having military units and decision-support tools able to compose force packages that are effective in a wide range of situations. Strategically, DoD's institutional processes will need new metrics and analytic approaches, more agile resource allocation structures, and a more responsive defense industrial ecosystem to adapt its capabilities for operational advantage.

As a first step, DoD should more proactively exploit the evolution of defense technology by explicitly adopting a federated model for mission integration. Today's approach of services integrating deploying units and affording CCDRs little ability to recompose force packages in theater denies US commanders their most effective opportunity for adaptation and fails to leverage ongoing advances in networking and interoperability. In addition to yielding greater operational optionality, providing CCDRs the tools and operational infrastructure to compose forces would also enable feedback for capability developers that are already organizing along the lines of the mission factories, rapid prototyping organizations, and platform industries proposed in Chapter 3.

To fully exploit the opportunities in heterogeneity at scale, DoD should go further and begin to reform some of its decision processes. By prioritizing adaptability and effectiveness as metrics for capability assessment, force planners could privilege systems that improve outcomes across a range of situations while basing decisions on value instead of cost. Performing these assessments will require new methods and tools for analysis that can quickly examine many situations at a lower level of fidelity compared to today's deep analysis within a narrow set of canonical scenarios. And to provide CCDRs the operational infrastructure to integrate forces in theater or the new and modified capabilities needed to achieve acceptable effectiveness and adaptability, DoD will require budget categories with more flexibility than is found in today's program element structure.

DoD should engage the defense industry as a partner in its effort to compete operational and strategically with the PRC and Russia. Technology and conceptual trends are driving commercial and defense ecosystems toward new models of delivering capability and engaging with the government as a customer. Measuring the utility of new capabilities based on value rather than cost, DoD may be able to incentivize greater commercial contributions to defense capabilities.

The Pentagon should stop letting the evolution of technology pass it by. By embracing new models for capability development, integration, and decision-making, DoD could gain the organizational flexibility to compete effectively with its PRC and Russian counterparts. If it doesn't, the US military runs the risk of ending up like the IBM PC—a great capability for its time but disrupted into irrelevance by more agile competitors.

ENDNOTES

1 Scott Galloway, *Post-Corona* (New York, NY: Penguin/Random House, 2020), 16-24.

2 Office of the Chief of Naval Operations, Deputy Chief of Naval Operations (Warfighting Requirements and Capabilities—OPNAV N9), "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels" (Washington, DC: US DoD, 2020), 9, https://media.defense.gov/2020/Dec/10/2002549918/-1/-1/1/SHIPBUILDING%20PLAN%20DEC%2020_NAVY_OSD_OMB_FINAL.PDF; Charles Q. Brown, "Accelerate Change, Or Lose," US Department of the Air Force (August 2020), https://www.af.mil/Portals/1/documents/csaf/CSAF_22/CSAF_22_Strategic_Approach_Accelerate_Change_or_Lose_31_Aug_2020.pdf; Headquarters, US Marine Corps, "Force Design 2030," US Department of the Navy (March 2020), https://www.hqmc.marines.mil/Portals/142/Docs/CMC38%20Force%20Design%202030%20Report%20Phase%20I%20and%20II.pdf?ver=2020-03-26-121328-460; Jen Judson, "US Army's $7 billion wish list would boost multidomain units and wartime funding," *Defense News* (February 21, 2020), https://www.defensenews.com/smr/federal-budget/2020/02/21/armys-7-billion-wish-list-would-boost-mutlidomain-units-and-wartime-funding/.

3 Bryan Clark, Dan Patt, and Harrison Schramm, *Mosaic Warfare: Exploiting Artificial Intelligence and Autonomous Systems for Decision-Centric Operations* (Washington, DC: CSBA, 2020), https://csbaonline.org/research/publications/mosaic-warfare-exploiting-artificial-intelligence-and-autonomous-systems-to-implement-decision-centric-operations.

4 PLA doctrine describes Systems Confrontation Warfare as an approach to implement Informationized Warfare, or with the advent of AI, Intelligentized Warfare; see US OSD, "Military and Security Developments Involving the People's Republic of China 2020," (Washington, DC: US DoD, 2020), https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.PDF.

5 James Derleth, "Russian New Generation Warfare: Deterring and Winning at the Tactical Level," *Military Review* (September/October 2020), https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/September-October-2020/Derleth-New-Generation-War/; Jeff Engstrom, *Systems Confrontation and System Destruction Warfare* (Santa Monica, CA: RAND, 2018), https://www.rand.org/pubs/research_reports/RR1708.html.

6 David Kilcullen, *The Dragons and the Snakes: How the Rest Learned to Fight the West* (Oxford University Press, 2020).

7 Chris Dougherty, "Moving Beyond A2/AD," Center for a New America Security, December 3, 2020, https://www.cnas.org/publications/commentary/moving-beyond-a2-ad.

8 Evan Montgomery, "Unpacking Overmatch: Three Crucial Questions About U.S. Military Superiority," *War on the Rocks* (July 6, 2018), https://warontherocks.com/2018/07/unpacking-overmatch-three-crucial-questions-about-u-s-military-superiority/.

9 Theresa Hitchens, "Exclusive: J6 Says JADC2 Is A Strategy; Service Posture Reviews Coming," *Breaking Defense* (January 4, 2020), https://breakingdefense.com/2021/01/exclusive-j6-says-JADC2-is-a-strategy-service-posture-reviews-coming/.

10 Theresa Hitchens, "ABMS Demo Proves AI Chops For C2," *Breaking Defense* (September 3, 2020), https://breakingdefense.com/2020/09/abms-demo-proves-ai-chops-for-c2/.

11 Mark Schauer, "Project Convergence a generational shift for Army," US Department of the Army (October 7, 2020), https://www.army.mil/article/239770/project_convergence_a_generational_shift_for_army.

12 David Larter, "The US Navy's 'Manhattan Project' has its leader," *C4ISRNet* (October 14, 2020), https://www.c4isrnet.com/naval/2020/10/14/the-us-navys-manhattan-project-has-its-leader/.

13 John Hoehn, "Joint All Domain Command and Control (JADC2)," Congressional Research Service (September 28, 2020), https://fas.org/sgp/crs/natsec/IF11493.pdf.

14 Mallory Shelbourne, "Services Looking for 'Synergy' in JADC2 Efforts," *USNI News* (November 13, 2020), https://news.usni.org/2020/11/13/services-looking-for-synergy-in-jadc2-efforts.

15 Bryan Clark, Dan Patt, and Timothy A. Walton, *Implementing Decision-Centric Warfare: Elevating Command and Control to Gain An Optionality Advantage*, (Washington, DC: Hudson Institute, 2021), https://www.hudson.org/research/16729-implementing-decision-centric-warfare-elevating-command-and-control-to-gain-an-optionality-advantage.

16 The joint force component commanders associated with most combatant commanders are air, maritime, and land.

17 See US Air Force, US Air Force Warfare Center, Nellis Air Force Base, October 26, 2016, https://www.nellis.af.mil/About/Fact-Sheets/Display/Article/284150/us-air-force-warfare-center/; US Navy, "Warfare Centers," US Naval Sea Systems Command, https://www.navsea.navy.mil/Home/Warfare-Centers/Who-We-Are/.

18 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, 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;

19 See Statement by Barbara McQuiston to the U.S. Senate Appropriations Committee Subcommittee on Defense Innovation and Research, April 13, 2021, or the DoD Mission Engineering Guide found at https://ac.cto.mil/wp-content/uploads/2020/12/MEG-v40_20201130_shm.pdf.

20 Office of the Under Secretary of Defense for Acquisition and Sustainment, "DOD INSTRUCTION 5000.02: Operation of The Adaptive Acquisition Framework," January 23, 2020, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2020-01-23-144114-093.

21 Office of the Under Secretary of Defense for Acquisition and Sustainment, “Budget Activity (BA) “B A-08”: Software and Digital Technology Pilot Program,” Defense Acquisition University, September 28, 2020, https://www.dau.edu/cop/it/DAU%20Sponsored%20Documents/SW%20APPROPRIATION%20BA-08%20FAQ.pdf.

22 François-Xavier Meunier, “F. (2019). Construction of an Operational Concept of Technological Military/Civilian Duality,” *Journal of Innovation Economics & Management*, 29(2), (2019): 159-182. https://doi.org/10.3917/jie.029.0159.

23 Klaus Schwab, “The Fourth Industrial Revolution: What it means, how to respond,” World Economic Forum, January 14, 2016, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

24 Jan Verloop, “Insight in Innovation: Managing Innovation by Understanding the Laws of Innovation” (New York: Elsevier, 2004), 18.

25 Shekhar Aiyar, Carl-Johan Dalgaard, Omer Moav, “Technological progress and regress in pre-industrial times”, *Journal of Econonmic Growth* 13, 2008, 125–144, https://doi.org/10.1007/s10887-008-9030-x.S.

26 Robert Leonhard, *The Art of Maneuver: Maneuver Warfare Theory and AirLand Battle* (New York: Ballantine Books, 1991).

27 Brian Cotterell and Johan Kamminga,. *Mechanics of Pre-industrial Technology: An Introduction to the Mechanics of Ancient and Traditional Material Culture* (Spain: Cambridge University Press, 1992).

28 Joel Mokyr, “The Second Industrial Revolution, 1870-1914” (Evanston, IL: Northwestern University, 1998), https://faculty.wcas.northwestern.edu/~jmokyr/castronovo.pdf.

29 Jim Garamone, World War I: Building the American Military,” DoD News (March 29, 2017), World War I: Building the American Military > U.S. DEPARTMENT OF DEFENSE > Defense Department News.

30 Hubert Johnson, *Breakthrough!: Tactics, Technology, and the Search for Victory on the Western Front in World War I*, (San Francisco: Presidio Press, 1994).

31 Seth Center and Emma Bates, “Tech-Politik: Historical Perspectives on Innovation, Technology, and Strategic Competition,” Center for Strategic and International Studies, December 2019, https://www.csis.org/analysis/tech-politik-historical-perspectives-innovation-technology-and-strategic-competition.

32 Andrew Philip Hunter, Rhys McCormick, “What Comes after the ‘Last Supper’?,” Center for Strategic and International Studies, June 2019, https://www.csis.org/analysis/what-comes-after-last-supper.

33 Leland H. Jenks, “Railroads as an Economic Force in American Development,” *The Journal of Economic History* 4, no. 1 (1944): 1-20, http://www.jstor.org/stable/2113700.

34 Computer History Museum, “Timeline of Computer History,” CHM.org, https://www.computerhistory.org/timeline/networking-the-web/, accessed April 20, 2021.

35 Max Marshall, Ed., *History of the U.S. Army Signal Corps*, (New York, NY: Franklin Watts Inc.,1965), https://cybercoe.army.mil/AC/WWII/WWIIINTR.html.

36 National Research Council,. 1997. *The Evolution of Untethered Communications*, (Washington, DC: The National Academies Press, 1997), https://doi.org/10.17226/5968.

37 Arthur K. Cebrowski and John H. Garstka, “Network-Centric Warfare: Its Origin and Future,” *Proceedings* (January 1998): 1139, https://www.usni.org/magazines/proceedings/1998/january/network-centric-warfare-its-origin-and-future; Mark Pomerleau, “How the Army and Air Force are linking comms,” *C4ISRNET* (January 22, 2020), https://www.c4isrnet.com/it-networks/2020/01/23/how-the-army-and-air-force-are-linking-comms/.

38 Defense Science Board, Executive Summary of the Report of the Defense Science Board Task Force on 21st Century MultiDomain Effects, US Department of Defense, September 2020, https://dsb.cto.mil/reports/2020s/MDE_ExecutiveSummary.pdf.

39 Clayton Christenson and Michael E. Raynor, *The Innovator’s Solution: Creating and Sustaining Successful Growth*, (Cambridge, MA: Harvard Business Review Press, 2013).

40 Ric Telford, “The disruptive nature of cloud computing,” *ZDNet* (August 11, 2009), The disruptive nature of cloud computing | ZDNet; Rokon Zeman, “Smartphone’s Evolution as Creative Destruction,” The Waves, July 7, 2020, https://www.the-waves.org/2020/07/07/smartphones-evolution-as-creative-destruction/.

41 Matt Burgess, “What is the Internet of Things? WIRED explains,” *WIRED* (February 16, 2018), https://www.wired.co.uk/article/internet-of-things-what-is-explained-iot.

42 See various references studying cost trends, including https://drpeering.net/white-papers/Internet-Transit-Pricing-Historical-And-Projected.php, https://techpolicyinstitute.org/2018/07/19/cloud-computing-co-invention-for-the-masses/ and https://aiimpacts.org/trends-in-the-cost-of-computing/.

43 Jack Watling and Sidharth Kaushalm, “The Democratisation of Precision Strike in the Nagorno-Karabakh Conflict,” RUSI, https://rusi.org/commentary/democratisation-precision-strike-nagorno-karabakh-conflict, October 2020.

44 David Berger, “Force Design 2030” (Washington, DC: Headquarters, US Marine Corps, March, 2020), https://www.hqmc.marines.mil/Portals/142/Docs/CMC38%20Force%20Design%202030%20Report%20Phase%20I%20and%20II.pdf?ver=2020-03-26-121328-460; Office of the Chief of Naval Operations Deputy Chief of Naval Operations (Warfighting Requirements and Capabilities—OPNAV N9), Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels, December 9, 2020, https://media.defense.gov/2020/

Dec/10/2002549918/-1/-1/1/SHIPBUILDING%20PLAN%20 DEC%2020_NAVY_OSD_OMB_FINAL.PDF; Charles, Q. Brown, "Accelerate Change of Lose," (Washington, DC: US Department of the Air Force, August 2020), https://www.af.mil/Portals/1/documents/csaf/CSAF_22/CSAF_22_Strategic_Approach_Accelerate_Change_or_Lose_31_Aug_2020.pdf.

45 Gary Chen, "The Role of Virtualization in the Era of Containers and Cloud," Red Hat, December, 2018, vi-virtualization-role-era-containers-cloud-idc-analyst-paper-f15570bf-201812-en.pdf (redhat.com).

46 Red Hat "What's a Linux container?," https://www.redhat.com/en/topics/containers/whats-a-linux-container; Defense Standardization Program, "What is MOSA," US DoD, https://www.dsp.dla.mil/Programs/MOSA/.

47 Carlos Munoz, "DARPA's DyNAMO connects incompatible datalinks under electronic attack," *JANES* (December 2018), https://www.janes.com/defence-news/news-detail/darpas-dynamo-connects-incompatible-datalinks-under-electronic-attack.

48 DARPA, Creating Cross-Domain Kill Webs in Real Time, DARPA, September 17, 2020, https://www.darpa.mil/news-events/2020-09-18a.

49 Eric Roberts, "The Google PageRank Algorithm," Computer Science 54 Curriculum, November 9, 2016, https://web.stanford.edu/class/cs54n/handouts/24-GooglePageRankAlgorithm.pdf.

50 Theresa Hitchens, "EXCLUSIVE: 'Do-Or-Die' JADC2 Summit To Crunch Common Data Standards," *Breaking Defense* (January 12, 2021), EXCLUSIVE: Do-Or-Die JADC2 Summit To Crunch Common Data Standards « Breaking Defense - Defense industry news, analysis and commentary.

51 Martin Weitzman, "Recombinant Growth," Quarterly Journal of Economics, 1998.

52 See Frans Osinga, *Science, Strategy, and War: The Strategic Theory of John Boyd*, (New York, NY: 2007, Routledge); also, the theory and practice of decision-centric warfare is detailed in Bryan Clark, Dan Patt, and Harrison Schramm, *Mosaic Warfare: Exploiting Artificial Intelligence and Autonomous Systems for Decision-Centric Operations* (Washington, DC: CSBA, 2020), https://csbaonline.org/research/publications/mosaic-warfare-exploiting-artificial-intelligence-and-autonomous-systems-to-implement-decision-centric-operations.

53 US Joint Staff, Joint Publication 5-0: Joint Planning, (Washington, DC: DoD, 2020), III-66-67, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp5_0.pdf?ver=ztDG06paGvpQRrLxThNZUw%3d%3d.

54 Michael Mazaar, Katharina Ley Best, Burgess Laird, Eric V. Larson, Michael E. Linick, Dan Madden, *The U.S. Department of Defense's Planning Process: Components and Challenges* (Santa Monica, California: RAND, 2019), https://www.rand.org/pubs/research_reports/RR2173z2.html.

55 The escalation dynamics associated with gray-zone operations are addressed in Bryan Clark and Jesse Sloman, *Winning in the Gray Zone: Using Electromagnetic Warfare to Regain Escalation Dominance* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017), https://csbaonline.org/research/publications/winning-in-the-gray-zone-using-electromagnetic-warfare-to-regain-escalation.

56 Euan Graham, "U.S. Naval Standoff With China Fails to Reassure Regional Allies," *The Diplomat* (May 4, 2020), https://foreignpolicy.com/2020/05/04/malaysia-south-china-sea-us-navy-drillship-standoff/.

57 DARPA, Creating Cross-Domain Kill Webs in Real Time, DARPA, September 17, 2020, https://www.darpa.mil/news-events/2020-09-18a.

58 See Br*yan Clark*, Dan Patt, and Timothy Walton, *Implementing Decision-Centric Warfare: Elevating Command and Control to Gain and Sustain an Optionality Advantage in Military Conflict and Competition* (Washington, DC: Hudson Institute, 2021).

59 Tom Taulli, *The Robotic Process Automation Handbook: A Guide to Implementing RPA Systems* (Germany: Apress, 2020).

60 Theresa Hitchens, "Exclusive: J6 Says JADC2 Is A Strategy; Service Posture Reviews Coming," *Breaking Defense* (January 4, 2020), https://breakingdefense.com/2021/01/exclusive-j6-says-JADC2-is-a-strategy-service-posture-reviews-coming/.

61 Theresa Hitchens, "ABMS Demo Proves AI Chops for C2," *Breaking Defense* (September 3, 2020), https://breakingdefense.com/2020/09/abms-demo-proves-ai-chops-for-c2/.

62 For more detail on the waves of mission integration and decision-centric C3, see Bryan Clark, Dan Patt, and Timothy Walton, *Implementing Decision-Centric Warfare: Elevating Command and Control to Gain and Sustain an Optionality Advantage in Military Conflict and Competition* (Washington, DC: Hudson Institute, 2021).

63 US Department of Defense, "Supply Chain Metrics Guide," Office of the Undersecretary for Acquisition, Technology, and Logistics, March 2016, 147, https://www.acq.osd.mil/log/SCI/.policy_vault.html/Supply_Chain_Metrics_Guide_signed_3Mar2016.pdf.

64 Bradley Cooper, "Precision Logistics: Sustainment for Multi-Domain Operations," Institute for Land Warfare, Association of the US Army, September 2019, https://www.ausa.org/sites/default/files/publications/SL-19-4-Precision-Logistics-Sustainment-for-Multi-Domain-Operations.pdf.

65 Miranda Priebe, Alan J. Vick, Jacob L. Heim, Meagan L. Smith, *Distributed Operations in a Contested Environment* (Santa Monica, CA: RAND, 2019), https://www.rand.org/pubs/research_reports/RR2959.html.

66 DARPA, "Making DoD's Vast Logistics Enterprise More Resilient," DARPA.mil, May 20, 2019, https://www.darpa.mil/news-events/2019-05-21a.

67 Arthur K. Cebrowski and John H. Garstka, “Network-Centric Warfare: Its Origin and Future,” *Proceedings* 1139, (January 1998), https://www.usni.org/magazines/proceedings/1998/january/network-centric-warfare-its-origin-and-future; Mark Pomerleau, “How the Army and Air Force are linking comms,” C4ISRNET, January 22, 2020, https://www.c4isrnet.com/it-networks/2020/01/23/how-the-army-and-air-force-are-linking-comms/.

68 Mission Command: Command and Control of Army Forces, US Department of the Army, 2020, https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN19189_ADP_6-0_FINAL_WEB_v2.pdf.

69 Bryan Clark, Dan Patt, and Timothy A. Walton, *Implementing Decision-Centric Warfare: Elevating Command and Control to Gain and Sustain an Optionality Advantage* (Washington, DC, Hudson Institute, 2021).

70 US Air University LeMay Doctrine Center, “Annex 3-30 Command and Control: Organizing Air Force Forces,” US Air Force, January 7, 2020, https://www.doctrine.af.mil/Portals/61/documents/Annex_3-30/3-30-D35-C2--AF-Org-intro.pdf.

71 Chief of Naval Operations, “OPNAV INSTRUCTION 3501.316C: FORCE COMPOSITION OF AFLOAT NAVY AND NAVAL GROUPS,” US Department of the Navy, November 10, 2017, https://www.secnav.navy.mil/doni/Directives/03000%20Naval%20Operations%20and%20Readiness/03-500%20Training%20and%20Readiness%20Services/3501.316C.pdf.

72 Michael Hettinger, “21st Century Anti-Scouting for Carrier Strike Groups—Countering Detection in the Anti-Access/Area Denial Environment,” (Newport, RI: US Naval War College, 2019), https://apps.dtic.mil/dtic/tr/fulltext/u2/1077931.pdf.

73 For more details on the structure and use of mission elements in DoD budgets, see Bill Greenwalt and Dan Patt, *Competing in Time: Ensuring Capability Advantage and Mission Success through Adaptable Resource Allocation* (Washington, DC: Hudson Institute, 2021), https://www.hudson.org/research/16717-competing-in-time-ensuring-capability-advantage-and-mission-success-through-adaptable-resource-allocation.

74 Jonathan Greenert, “Payloads over Platforms: Charting a New Course,” *USNI Proceedings* (July 2012), https://www.usni.org/magazines/proceedings/2012/july/payloads-over-platforms-charting-new-course.

75 US Department of Defense, Defense Standardization Program Office, “Modular Open Systems Approach (MOSA),” https://www.dsp.dla.mil/Programs/MOSA/; Open Group FACE Consortium, “Future Airborne Capability Environment (FACE),” https://www.opengroup.org/face; Office of the Under Secretary of Defense for Research and Engineering, Director of Defense Research and Engineering for Advanced Capabilities, “Modular Open Systems Approach (MOSA) Reference Frameworks in Defense Acquisition Programs,” May 2020, https://ac.cto.mil/wp-content/uploads/2020/06/MOSA-Ref-Frame-May2020.pdf.

76 Office of the Under Secretary of Defense for Acquisition and Sustainment, “DOD INSTRUCTION 5000.02: OPERATION OF THE ADAPTIVE ACQUISITION FRAMEWORK,” US DoD, January 23, 2020, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2020-01-23-144114-093; Jared Serbu, “Pentagon teeing up nine programs to test new ‘color of money’ for software development,” *Federal News Network* (March 4, 2020), https://federalnewsnetwork.com/acquisition/2020/03/pentagon-teeing-up-nine-programs-to-test-new-color-of-money-for-software-development/.

77 See US Air Force, “U.S. Air Force Warfare Center,” Nellis Air Force Base, October 26, 2016, https://www.nellis.af.mil/About/Fact-Sheets/Display/Article/284150/us-air-force-warfare-center/; US Navy, “Warfare Centers,” US Naval Sea Systems Command, https://www.navsea.navy.mil/Home/Warfare-Centers/Who-We-Are/.

78 US Air Force Kesselrun, “What is a DevSecOps Unit?,” (Jan. 2021), https://kesselrun.af.mil/news/What-is-a-DevSecOps-Unit.html; Robert Work, “Establishment of an Algorithmic Warfare Cross-Functional Team (Project Maven),” US DoD Chief Information Officer, April 26, 2017, https://dodcio.defense.gov/Portals/0/Documents/Project%20Maven%20DSD%20Memo%2020170425.pdf.

79 For more details on the purpose and use of mission element funding, see Dan Patt and Bill Greenwalt, *Competing in Time: Ensuring Capability Advantage and Mission Success through Adaptable Resource Allocation* (Washington, DC: Hudson Institute, 2021), https://www.hudson.org/research/16717-competing-in-time-ensuring-capability-advantage-and-mission-success-through-adaptable-resource-allocation.

80 The term “operational challenge” is used here to denote a mission being conducted in a specific geographic and temporal context.

81 See Andrew Feickart, “U.S. Army Short-Range Air Defense Force Structure and Selected Programs: Background and Issues for Congress, Congressional Research Service, July 23, 2020, https://fas.org/sgp/crs/weapons/R46463.pdf; Jared Keller, “The Pentagon used a hypersonic bullet to shoot down a mock cruise missile for the first time,” *Task and Purpose* (September 4, 2020), https://taskandpurpose.com/news/air-force-hypervelocity-projectile-test/, and John Hamilton, “Soldiers get hands-on with new air defense system,” US Army, November 18, 2020, https://www.army.mil/article/240995/soldiers_get_hands_on_with_new_air_defense_system. Aegis guided-missile destroyers (DDG) and aircraft from nuclear-powered carriers (CVN) or amphibious assault ships (LHA/D) could supplement air defenses but would be vulnerable to attack as well and are less easily repaired compared to dispersed ground facilities.

82 Sydney Freedberg, “Army Explores Robot Decoys & Cannon-Fired Jamming Pods,” *Breaking Defense* (August 23, 2019), https://breakingdefense.com/2019/08/army-explores-robot-decoys-cannon-fired-jamming-pods/; John Haystead, “US Army Lays Out Plans for Terrestrial Layer Systems,” *Journal of Electronic Defense* (March 2019), https://www.jedonline.com/2020/05/20/us-army-lays-out-plans-for-terrestrial-layer-systems-jed-march-2019/.

83 See Miranda Priebe, Alan J. Vick, Jacob L. Heim, and Meagan L. Smith, *Distributed Operations in a Contested Environment*, (Santa Monica, CA: RAND, 2019), https://www.rand.org/pubs/research_reports/RR2959.html.

84 DARPA, “Making DoD’s Vast Logistics Enterprise More Resilient”, DARPA, https://www.darpa.mil/news-events/2019-05-21a, May 21, 2019.

85 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, D-1–D-3, 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.

86 Mallory Shelbourne, “Davidson: China Could Try to Take Control of Taiwan In ‘Next Six Years’,” *USNI News,* March 9, 2021, https://news.usni.org/2021/03/09/davidson-china-could-try-to-take-control-of-taiwan-in-next-six-years.

87 Andrew Marshall, *Long-Term Competition with the Soviets: A Framework for Strategic Analysis*, (Santa Monica, CA: RAND, 1972), https://www.rand.org/pubs/reports/R862.html.

88 Rosenthal, Casey., Jones, Nora. *Chaos Engineering: System Resiliency in Practice*. United States: O’Reilly Media, 2020.

89 Eric Larson, *Force Planning Scenarios, 1945–2016: Their Origins and Use in Defense Strategic Planning* (Santa Monica, CA: RAND, 2017), https://www.rand.org/pubs/research_reports/RR2173z1.html.

90 More detail on the shift from large, detailed campaign analyses toward less specific and more numerous tactical situations is described in Brian L. Morgan, Harrison C. Schramm, Jerry R. Smith, Jr., Thomas W. Lucas, Mary L. McDonald, Paul J. Sánchez, Susan M. Sanchez, Stephen C. Upton,   Improving U.S. Navy Campaign Analyses with Big Data,” *Informs* (September 6, 2017), https://doi.org/10.1287/inte.2017.0900.

91 The limitations of the current DoD budget process are detailed further in Bill Greenwalt and Dan Patt, *Competing in Time: Ensuring Capability Advantage and Mission Success through Adaptable Resource Allocation*, (Washington, DC: Hudson Institute, 2021), https://www.hudson.org/research/16717-competing-in-time-ensuring-capability-advantage-and-mission-success-through-adaptable-resource-allocation.

92 Andrew Hunter and Rhys McCormick, “What Comes after the ‘Last Supper’?,” Center for Strategic and International Studies, June 19, 2019, https://www.csis.org/analysis/what-comes-after-last-supper; Jill Aitoro, “Raytheon-UTC merger wins approval, pending divestitures,” *Defense News* (March 27, 2020), https://www.defensenews.com/industry/2020/03/27/raytheon-utc-look-to-shed-segments-to-win-merger-approval/.

93 DoD News, “DIU Making Transformative Impact Five Years In,” *Defense.gov* (August 27, 2020), https://www.defense.gov/Explore/News/Article/Article/2327021/diu-making-transformative-impact-five-years-in/; Rhys McCormick, “Department of Defense Other Transaction Authority Trends: A New R&D Funding Paradigm?,” Center for Strategic and International Studies, December 8, 2020, https://www.csis.org/analysis/department-defense-other-transaction-authority-trends-new-rd-funding-paradigm.

94 Office of the Under Secretary of Defense for Acquisition and Sustainment, “DOD Instruction 5000.02: Operation of The Adaptive Acquisition Framework,” US DoD, January 23, 2020, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2020-01-23-144114-093.

Notes

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