PERSPECTIVES

Industrial Age Capacity at Information Age Speed

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Abstract

This article examines the potential for a shift in defense logistics and the DOD's relationship with industry to meet the logistical demands of the modern battlespace. The concept outlines solutions that protect supply chains and manufacturing capabilities through increased agility, adaptability, and resilience. The article uses historical examples and a survey of technologies to make a case for change. It examines enabling technologies and offers an implementation strategy. Artificial intelligence (AI), robotics, big data resources, and ever-improving manufacturing methods comprise the key enabling technologies. The implementation strategy involves establishing a market ecosystem that adequately protects intellectual property and does not jeopardize major contributors to the US economy. The US can evolve its industrial base to meet future logistical demands that spur innovation and sustain competition to emulate industrial age capacity at information age speeds. This change effectively pivots defense logistics from supply management and provision to a deployable, war materiel producing system. The emergent paradigm creates a force structure and manufacturing capability adaptable to the entire spectrum of conflict in an on-demand capacity.

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The future of warfare is as much about manufacturing time as it is about manufacturing war materiel. In other words, great power conflict in the twenty-first century foretells a strategic environment in which the US will not have the luxury of years of industrial mobilization and deployment. Conversely, the US cannot afford to maintain a war-like footing in perpetuity. It must evolve its force structure and manufacturing capabilities to emulate industrial age capacity at information age speeds. Defense logistics must transition from a system of supply management to an organic manufacturing base that leverages advances in production techniques, automation, and AI. Evolving defense logistics and revamping the relationship with industry will create a force structure and manufacturing capability adaptable to the entire spectrum of conflict in an on-demand capacity.

This will allow the US to reduce its standing force structure by creating the ability to generate a force tailored to individual conflicts. The approach will allow the US to respond to any contingency with a hydralike force optimized for the task at hand. Coupling this change with a new acquisition model that leverages force structure in a way that demands from and rewards industry for continuous improvement will help the US remain technologically ahead of adversaries.

This article proposes a radical shift in defense logistics and the underlying strategy of acquisition to meet the demands of the modern battlespace while protecting its supply chains and manufacturing capabilities. First, it makes a case for change; then, it examines the enabling technologies, and, finally, it offers a strategy for implementation. Historical precedents, fiscal constraints, and inherent risks of the current defense industrial base mobilization capabilities comprise the foundation of the rationale for change. The advancing capabilities of AI, robotics, big data resources, and ever-improving manufacturing methods constitute the critical technologies challenging the current framework. The strategy for change involves establishing an appropriate force structure, DOD investment in manufacturing resources, streamlining the defense supply chain, and establishing a market ecosystem that adequately protects intellectual property and does not jeopardize major contributors to the US economy.

As with most transformational change, it should start by leveraging existing technologies in new and innovative ways because invention without practicality offers limited utility. Those who optimize, simplify, or improve often occupy prominent seats in history over those who invent or discover. Henry Ford did not invent the car just as Samuel Colt did not create the gun; however, their paradigm-altering processes made the technology accessible to nearly everyone. Bill Gates and Steve Jobs did not invent the personal computer, but they made them ubiquitous. Innovation in conflict yields similar results. The type of innovation necessary to realize the full potential of the unique technologies at the forefront of the technical revolution requires a shift in focus. Many in the defense enterprise, both industry and the war fighter, recognize new technologies will wield a disruptive influence on the character of war. However, given the state of these technologies today, that vision often narrows in scope. The US may lack the time or ability to recover if it misses this opportunity for adopting and institutionalizing technologies such as AI and additive manufacturing (AM) as it did with the airplane and the submarine. If adaptation is imperative for future ability, then to appreciate the potential for change as well as its complexity, one must bound the problem.

The Case for Change

Today's defense industrial base consists of a rich subset of the economy fueled by the DOD's enduring need to maintain its combat forces and an insatiable desire for new technology in pursuit of advantage over would-be adversaries. An estimated 61,000 companies supply the DOD as prime vendors.[1] The largest companies in the market include Lockheed Martin, Boeing, Northrop Grumman, and Raytheon; known as the "Big 5," they account for the largest share of defense contracts due to their overall size and capacity.[2] Notable programs include the F-35 Joint Strike Fighter (Lockheed Martin), KC-46 Aerial Tanker (Boeing), B-21 Long-Range Strike-Bomber (Northrop Grumman), and BGM-109 Tomahawk Land Attack Missile (Raytheon). Scores of other vendors rest just below the Big 5 in overall market share, providing a myriad of goods and services. Vendors range from large companies, with revenue reaching into the billions, to small businesses providing niche items.[3] The defense industrial base often works collaboratively across the enterprise on a massive program such as those identified above. The prime contractor for an aircraft may select a subcontractor for engines, ejection seats, avionics components, radar, and so on. This abundant ecosystem centered on defense merchants selling arms to the extensive professional forces of the US and its allies did not always exist.

The US experience with mobilization evokes images of inauspicious beginnings culminating in the triumph of overwhelming industrial might. From President Wilson's war declaration in 1917 to first combat in 1918, the US took too long to fully mobilize and relied heavily on magnanimous allies. As A. B. Quinton, Jr. summarizes, "industrial activity more than fighting man-power is the determining factor between success and failure of a military effort. . . . Considering the thousands of items required and their high rate of obsolescence due to constantly improved design."[4] The Second World War saw the US only slightly better prepared. Gilbert cites Lt Gen William Knudsen in explaining the national effort, "The first year, he said, was needed for tooling up, the second, for production. At the end of that time, it was his opinion that the United States could 'write its own ticket.' "[5] Great power competition, as described in the *National Defense Strategy* (*NDS*), will consume considerable resources.[6] The only difference between future conflicts of this type and those in the past is that the US cannot expect a period of operational grace for mobilization. Major combat operations with a great power rival will likely occur at an unprecedented pace and consume resources at a rate overwhelming to the existing industrial base.

The changing landscape of the global environment drives the quest for radical change in defense acquisitions and logistics. Leaders focused on national security agree that the international order faces a return to great power competition.[7] In this reemerging geopolitical environment, the US cannot afford for its innovation capacity to languish. The 2018 *Science and Engineering Indicators Report* by the US National Science Board revealed friend and foe nations alike rapidly closing the gap on a US lead in science and technology.[8] In 2018, US spending in research and development (R&D) reached $496 billion with China close behind at $408 billion.[9] In the years leading up to this report, China increased its R&D expenditures at a rate of 18 percent for nearly two decades.[10] In the same period, US expenditures rose by only four percent.[11] Furthermore, China "more than doubled" its market share of technologically advanced manufacturing, including air and space vehicles, semiconductors, computers, pharmaceuticals, and precision measuring and control devices in the last ten years.[12] The steadily dwindling advantage in science and technology held by the US manifests, in part, as growing concern about the stability and reliability of the industrial base.

Unpredictability in defense appropriations raises grave concerns in the industrial base's continued position as a global innovation leader. A recent study by the Center for Strategic and International Studies (CSIS) revealed significant impacts upon the defense industrial base during the period including the Budget Control Act (i.e., sequestration) and unending continuing resolutions.[13] According to Rhys McCormick et al., "Some sectors [of the defense industry] saw continual declines in contract obligations, while others experienced a whipsaw effect, swinging rapidly from growth to decline." In particular, the CSIS report determined that "the data show that across most platform portfolios, R&D took disproportionate cuts when compared to products and services."[14] In the US, the private sector dominates in applied research and experimental development while the university system drives basic research.[15] The central role businesses play in R&D inextricably links the US innovation and industrial bases to marketability. When faced with tough financial decisions and uncertainty in the defense sector, the tens of thousands of vendors who comprise the industrial base opted for tried and true solutions over the internal exploration of new capabilities.

Fielding and maintaining a force ideally suited for the widening spectrum of potential operations will likely prove increasingly cost prohibitive. The all-volunteer force (AVF) already places tremendous strain on the defense budget in personnel expenses. Consequently, this constant pressure increasingly diverts resources from infrastructure and equipment. As the character of war continues to evolve, so do its expenses. Adjusted to 2015 dollars, a single B-17—a reusable bomber with strategic impact—cost \$2.6 million.[16] Conversely, one AGM-158B joint air-to-surface standoff missile–extended range (JASSM-ER)—a single use cruise missile—cost \$1.3 million in 2015 dollars.[17] As technology's role on the battlefield continues to increase, the potential cost of a single volley could render military options economically unviable.

Without considerate appropriation of funds across the portfolio of national interests, the US risks crippling essential sectors of its economy and infrastructure via defense spending. The proposed defense budget for fiscal year 2018 included \$574 billion—less overseas contingency operations funding—and constituted approximately three percent of the US gross domestic product.[18] The principal expenses include health care and services for defense personnel.[19] Furthermore, the US faces the daunting task of simultaneously organizing, training, and equipping a force capable of engaging adversaries across the spectrum of warfare. NDS's 4+1 concept explains the threat environment as one consisting of peer powers, regional disruptors, and nebulous insurgents.[20] Attempting to field and sustain a force capable of responding to the breadth of threats described will likely prove increasingly prohibitive. Without essential changes to force structure and business practices, the DOD risks paralyzing any future NDS by attempting to maintain an impossible level of readiness without relief.

The twentieth century revealed that mobilizing for major conflict requires time, and modern militaries face increasing pressure to prepare for myriad contingencies spanning the entire spectrum of warfare. The intrinsic link between logistics and warfare, the persistence of fiscal discipline in funding the DOD, and the threats presented by adversaries exploiting the changing character of war compel a new approach. Future conflicts will increasingly constrict the time available for mobilization and optimization. To maintain an advantage, the US must explore ways to manufacture time in every facet of its defense infrastructure. In his memoirs, Gen John J. Pershing assessed the American experience in the First World War: "We were called upon to make up in a few months for the neglect of years, during which self-satisfied provincialism and smug complacency had prevented the most elementary efforts toward a reasonable precaution to meet such an emergency."[21] Moving forward, the US should carefully consider and adopt technologies with the greatest potential to stave off calamity as a result of delayed action while presenting would-be adversaries with force—and supporting infrastructure—capable of producing an endlessly variable repertoire of capabilities.

Enabling Technologies

Three key technologies will enable the US military's transition into an organic, dispersed manufacturing base capable of providing adequate war materiel to the joint force at a much faster rate than today's industrial base. Bolstered by the resilience inherent to dispersion and adaptability, AI, AM, and advanced robotics (AR) comprise the critical technologies capable of ushering in a revolution in military logistics and US force structure.

The eventual force structure change and manufacturing base involved heavily leverage AI as a force multiplier. For this reason, it is assumed that by 2040 AI will reach a technology readiness level that facilitates two essential capabilities. In operations, AI will enable combat employment by human-machine teams. Utilizing the principle of "supervised autonomy," human operators will act as small unit leaders for AI combatants. Recent experiments by the Air Force Research Lab (AFRL) and Army Research, Development, and Engineering Command demonstrated the potential of such collaborations. In collaboration with Lockheed Martin, AFRL recently conducted the Have Raider experiments. In the experiment, a QF-16 aircraft, modified to fly autonomously, joined in formation with a human-operated F-16 in the performance of a series of advanced flight and combat related tasks.[22] Have Raider I proved the autonomous aircraft capable of operating in close formation with the human flight lead in which the "experimental F-16 autonomously flew in formation with a lead aircraft and conducted a ground-attack mission, then automatically rejoined the lead aircraft after the mission was completed." Have Raider II rapidly advanced the concept by achieving the following objectives in an ever-changing environment: first, "autonomously plan[ning] and execut[ing] air-to-ground strike missions based on mission priorities and available assets"; second, "dynamically react[ing] to a changing threat environment during an air-to-ground strike mission while automatically managing contingencies for capability failures, route deviations, and loss of communication"; and third, having "a fully compliant USAF Open Mission Systems software integration environment allowing rapid integration of software components developed by multiple providers."[23]

The second critical component of AI in this endeavor relates to manufacturing. AI and autonomous systems will serve an expanding role in manufacturing operations, as evidenced by the increasing calls for alarm about its impact on the workforce. A recent report by the McKinsey and

Company consulting firm estimates that approximately "fifty percent of current work activities are technically automatable."[24] Consequently, if fully adopted by various industries, automation may displace 800 million full-time employees worldwide by 2030.[25] The potential exists to advance assembly lines and manufacturing processes from machine-assisted operations to fully autonomous activities that exploit the force multiplying and time-saving potential of supervised autonomy.

The next key assumption involves the rapid progress of advanced manufacturing techniques. AM, known colloquially as 3-D printing, appeared in the 1980s; however, its disruptive potential emerged when coupled with advanced computing, new techniques, and previously unusable materials. Today, industries worldwide struggle to grasp the technology's full potential. Emerging AM processes include materials ranging from plastics to metals and will likely touch every aspect of human life in the coming decades.[26] Furthermore, as researchers mature the various AM methods, the processes become ever faster.[27] By 2040, AM technologies will likely overcome the challenges associated with characterizing material and structure reliability, and the lengthy processes of today will see dramatic time reductions.

Discussions on the role of AM in manufacturing often dwell on quality concerns. How can a manufacturer assure a user that an additively manufactured part possesses the same properties as the original produced with traditional methods? The keys to success in improving AM speed and product quality assurance include continued improvement of the machines and their implements. Incorporating sensors to detect and correct anomalies during production improves quality control and assurance. An increasing body of knowledge on the relationship between the AM process, feedstock, and key output properties continually bring AM closer to parity with traditional methods. However, the ultimate success of AM rests in entirely new designs. Those products entirely conceived of and produced with AM in mind will eventually displace comparisons to traditional methods.

AM constitutes a single tool in an expanding catalog of manufacturing resources. R&D at universities, national laboratories, and in businesses continually expand the capabilities of this unique technology. Researchers enjoy steady progress in overcoming challenges related to feedstock materials, improving product reliability and predictability, and continual decreases in the rate of production. AM will likely supplant traditional subtractive (e.g., lathe machining) as the preferred method for manufacturing parts in coming years; however, certain materials will remain best suited for traditional subtractive processes. The key to any successful manufacturing strategy is an appreciation for the holistic value of multiple methods versus placing complete faith in one.

Coupling advances in AI and AM with innovations in robotics lays the foundation for fully autonomous assembly lines. Articulated industrial robots grow increasingly dexterous where *dexterity* is defined as "the variety of tasks that the system can complete, and also how well it can perform those tasks. . . . It is perhaps appropriate to classify the hand and arm as subsystems responsible for tasks of different scales, where the hand performs fixing and fine manipulation and the arm handles gross positioning motions."[28] As developers iteratively advance and couple the individual capabilities of robotic arms and hands, these systems grow ever nearer the ability to duplicate work previously only the purview of skilled human laborers.[29] As the manufacturing tools' abilities progress and their potential becomes increasingly apparent, the feasibility of a transition to widespread implementation across the defense enterprise grows.

Toward Implementation

In application, this concept enables the US to optimize the size of its standing force by simultaneously leveraging the capabilities inherent in a professional corps and the flexibility introduced by rapid manufacturing. The character of war today, and with an eye toward the future, hardly resembles that of the twentieth century; however, new manufacturing and procurement methods renew the potential of an "on demand" force. Consider the fighter squadron: a typical squadron consists of 18–24 aircraft and 20 pilots.[30] The Air Force currently fields 55 fighter squadrons but hopes to expand to 60.[31] For air operations alone, a healthy fighter force requires 990–1,320 aircraft and about 1,100 pilots. Expanding to 60 squadrons would necessitate an additional 100 pilots and 90–120 aircraft. Adopting a force structure that leverages human-machine teams, in which human flight leaders command three semi-autonomous fighters in four-ship formations, yields two possible outcomes for the USAF. First, in the current manpower arrangement, the USAF increases its employable fighter potential (assuming 20 aircraft per squadron) by a factor of three. A single 20-pilot fighter squadron possesses the capacity to launch 80 combat sorties; 55 squadrons suddenly resemble 165. Alternatively, the USAF could maintain 60 fighter squadrons with just a fraction of the current number of fighter pilots. Five pilots and 15 drones maintain the combat potential of current squadrons—a 75 percent reduction in manpower. Furthermore, when considering attrition, and with a three-to-one ratio of humans-to-machines, squadrons will remain combat capable much longer than those comprised entirely of human pilots. The ability to maintain or dramatically increase combat capacity in this way holds great potential for offsetting or reducing the expense of maintaining a high-quality AVF.

Health care was identified earlier as the greatest expense in the annual defense budget, and the DOD routinely seeks opportunities to offset such costs. Proposed flattening or reductions in benefits inflame the sense that the government cannot provide adequately for its forces.[32] In that same vein, base realignment and closure initiatives raise the ire of lawmakers concerned by the economic impacts on their constituents.[33] By leveraging on-demand manufacturing, the DOD could reduce or justifiably offset the stifling expense of providing for its Airmen. Maintaining combat potential with a reduced number of pilots in human-machine teams translates directly to lower force maintenance costs.

Sizing the standing force, including assets and personnel, using the on-demand concept requires careful consideration of the global security environment, national security objectives, and the NDS. Undersized fielded forces may not hold the line until reinforcements can reach the fight. Oversized fielded forces may cripple the economy. Similarly, malaise in the defense industrial base may leave it unable to respond in times of national crisis. Defense mobilization, whether in the historical context of a major industrial endeavor requiring months to years, or one potential future enacted over the course of hours, to days, hinges on the balance of standing force ability and readiness with production speed and capacity. On-demand manufacturing resources must provide the speed to account for expected combat losses and the capacity to generate supplemental war materiel necessary to sustain operations. The worst-case scenario, logistically, of major combat operations versus a peer nation offers an optimal baseline for requirements as any lower-intensity operations should fall within the abilities of the manufacturing base. Once the DOD adequately evaluates the necessary criteria, it can issue requirements for its fielded forces and manufacturing capacity.

The US government and its industrial base should invest heavily in the tools and technologies necessary to improve indigenous resources for AM machines, AR technologies, and AI algorithms. General Electric (GE) currently leads US companies in AM capacity. In 2016, GE purchased controlling shares in the Swedish company Arcam AB and continues to scour the globe for additive and advanced manufacturing technologies to expand its repertoire of capabilities.[34] Despite the presence of a major US company in this sector, the US still lacks the indigenous capacity necessary for overall supremacy. The quest for market advantage by US companies mirrors the necessity of the US military to maintain an advantage over its would-be adversaries. In *Restoring American Power*, Sen. John McCain stated, “If all we do is buy more of the same, it is not only a bad investment; it is dangerous. We must rethink how our military projects power, invest in new capabilities and devise new ways of operating.”[35] Standing at the precipice of major technological change in conjunction with the fourth industrial revolution, the US can position itself to seize the initiative and maintain dominance as the character of war evolves once more.

By procuring manufacturing tools necessary for such production capacity, the US can stave off the operational challenges imposed by delays associated with mobilizing the industrial base. Mark Cancian of CSIS notes the perils of assuming the industrial mobilization schedule that occurred during the Second World War retains any relevance in modern and future conflicts on a major scale. “In fact, after about nine months of intense peer conflict, attrition would grind the US armed forces down to something resembling the military of a regional power. . . . This state of affairs arises because the US government has not thought seriously about industrial mobilization.”[36] It took many months for the US to fully mobilize during the two World Wars without a direct attack on the homeland. The potential for an attack on the industrial base, vital supply chains, or critical infrastructure—in areas previously perceived as sanctuaries—via cyberspace only increases the impetus for a new approach. Integrating manufacturing capacity into the logistics and industrial bases in ways that can substantially bolster the force structure introduces agility and capacity unprecedented in warfare. Furthermore, this research, development, and investment strategy creates opportunities for the US to advance, understand, and protect technologies destined to serve both civil and military utilities.

The idea of the government assuming responsibility for production invariably raises flags over potential technology stagnation or wilting competition in a critical national sector. However, regarding the resultant manufacturing enclaves as deployable entities rather than factories or business competitors offers one way of assuaging such concerns. This construct alleviates much of the uncertainty that disrupts the industrial base, such as up-front expenses incurred by companies to tool factories for specific production lines despite the risks of reduced or discontinued orders. If manufacturing is procured and maintained like other major defense programs, the DOD can leverage its experience in sustaining and improving fielded designs. Additionally, weaponizing the industrial base in this way introduces an entirely new sector for competition as companies compete to provide, and the DOD strives to field, subsequent generations of manufacturing capabilities. Sharing the workload in this construct enables the industrial base to continue developing manufacturing tools. Perhaps most importantly, this approach frees critical resources within the industrial base for increased and uninterrupted R&D pursuits.

Weaponizing the tools of manufacturing fuels competition among the defense industrial base. According to the 2018 CSIS report analyzing the impact of sequestration, "the number of prime vendors was reduced by roughly 20 percent or about 17,000 vendors."[37] When uncertainty strikes, many suppliers of military goods cannot endure. The current market resulted from decades of asset consolidations as the United States navigated the Cold War, its aftermath, and the conflicts that shaped the decades bridging the twentieth and twenty-first centuries. If the DOD maintains the major industrial resources for production, the cost of entry into competition lowers. A defense vendor with a winning design and viable production requirements does not require the massive industrial footprint necessary to manufacture hundreds of thousands of units. Conceivably, a small start-up capable of producing a quality prototype could compete as an equal with any of the Big 5 vendors.

Incentivizing private industry in this model requires a shift in the types of goods produced and the nature of defense contracts. Today, the companies that comprise the defense industry operate on the expectation that they will win a contract then produce the hardware associated with that contract. Such contracts include major weapons systems with intended service lives spanning decades, and the winning supplier pours tremendous resources into production. Adapting to an on-demand force means significant changes to this paradigm. First, weapons system designs would transition to something more akin to "software as a service." The DOD will still award contracts, but rather than winning the opportunity to produce a set number of units, the supplier commits to a number and frequency of updates or design improvements for a set period. Instead of buying 1,000 F-35As, the Air Force buys Lockheed Martin's time and resources to mature the F-35 from models A through H over 20 years. The success of companies like Amazon and IBM that offer software as a service prove how lucrative this model can be. Private industry production of goods shifts toward the exquisite. Line replaceable units (LRU) including radios, radars, engines, and myriad components intended to feed the supply system provide ample opportunity for defense vendors to profitably sustain their current business ventures while expanding operations in support of the new model. As the entire system evolves to leverage overlapping components across weapons systems, the potential growth and market opportunities offset the disruption of traditional production expectations.

The necessity of pursuing near perfection in a major system wanes with an on-demand force structure. With only a handful of opportunities and an expectation of long service lives, the DOD and the defense industry face the antithetical challenges of simplicity and requirement creep. An on-demand force deposes both of these problems because it allows for continual improvement. Hardware solutions can experience the same types of rapid prototyping, testing, and certification as software; the design plan for the wartime manufacturing configuration enjoys constant improvement. This evolution of today's sustainment infrastructure also contributes to the viability of the business model and potential for cultivating growth.

Incorporating manufacturing capacity into the DOD force structure further expands competition by increasing the potential of Federally Funded R&D Centers (FFRDC). According to Federal Acquisition Regulations, "FFRDCs are unique nonprofit entities sponsored and funded by the US government to meet some special long-term research or development need which cannot be met as effectively by existing in-house or contractor resources."[38] The Manhattan Project stands out among the most readily identifiable examples of FFRDC programs and their potential to yield tremendous capability.[39] The national laboratories, under the purview of the US Department of Energy and its subordinate, the National Nuclear Security Administration, constitute the enduring legacy of innovation and cutting technological development marked by that auspicious beginning.[40] Today, FFDRCs serve a variety of purposes for numerous organizations throughout the federal government, such as the RAND Corporation's Project Air Force. However, the national lab infrastructure and roles as centers of excellence for both science and weapons design hold the greatest potential benefit to the nation. Consider the BLU-129 carbon-fiber bomb body: experts at Lawrence Livermore National Lab designed the weapon, and the US government retains the intellectual property rights to its design. Unfortunately, since the labs lack significant manufacturing capability, the DOD must contract production of the weapon to Aerojet Rocketdyne.[41] With an organic manufacturing capability in the DOD, the US can effectively extend competition among defense vendors and expand its innovation potential by increasing the ability of its FFRDCs to contribute.

The fundamental elements of the relationship between the DOD and the industrial base do not change, but their best practices evolve. The DOD will continue to set requirements based on its operational needs, expected operating environments, and threats posed by adversaries. The industry continues to propose design solutions for those requirements and operational challenges competitively. Once the DOD declares a winner, contracts ensure sustainment for purposes of design improvements, software sustainment, weapons integration, and so on. Newly selected systems still face rigorous evaluation by developmental and operational testing communities. The services still scrutinize any selected systems and continuously improve them like they improve today's force. The manufacturing shift outlined here enables change by enabling leaders to adjust the size of the standing force according to the global security environment.

Professional service members still train regularly leveraging live and virtual constructive environments as well as a handful of manufactured and maintained systems. For example, two tank platoon leaders embark on a field exercise with each of their human-operated vehicles, one machine-operated vehicle apiece, and two virtually represented vehicles round out the eight-deep formation. Rather than maintaining the personnel necessary for eight tanks plus all accompanying logistics, the Army maintains four tanks, two crews, and possesses the manufacturing capacity to meet wartime requirements. Conversely, the services may dramatically increase their capacity by maintaining the current number or increasing the number of personnel. In both cases, on-demand manufacturing creates a means of offsetting expenses.

An on-demand force does not necessitate a shoddy force. Continuous design improvement means continual product improvement. As mentioned earlier, incentivizing the private sector highlighted changes to the types of contracts awarded. This approach effectively incentivizes and rewards companies for conducting and implementing initiatives currently in the realm of internal R&D, leveraging private capital in hopes of securing government contracts in the future. Furthermore, on-demand manufacturing does not mean single use quality. Instead, engineers can design unmanned equipment for a service life on par with expected operating conditions. Considerate design and production of a system with a service life of 100 combat sorties or a single year instead of decades would be tremendous, especially when compounded with a force structure that can delay production of that system until needed. Those assets designed and intended for human operators can include the same margin of safety and human performance enhancing features while benefiting from the continuous improvement concept. With contractors constantly engaged and rewarded for improving their products, shortened weapon system service lives mean even manned assets can enjoy refreshed technologies at a greater frequency than today. Many serving platforms today (e.g., B-52, F-15, and UH-1) testify to the prowess of their designers; however, the average age of systems serving every branch of service should represent notable exceptions—and failures of other acquisition efforts—rather than some gold standard of success. In this new structure, the DOD can provide its combatant commanders with the same vanguard of professionals as today but malleable in ways previously unimaginable. If, for example, a conflict begins as high-intensity peer-to-peer but devolves into a simmering counterinsurgency operation, the overall force seamlessly transitions along with the fight. An on-demand force can strike a harmonious nexus between quality, quantity, and value.

New manufacturing capabilities point to a bright future capable of enabling a revolution in how the services organize, train, and equip, but one can expect complex components to persist in supply. Certain LRUs such as specially configured electronics or aircraft engines may require prohibitively pristine conditions or consume too much time in production. This reality may change; however, the DOD can exploit the need to maintain a supply of such components by increasing commonality. Classes of aircraft or vehicles that share engines or wheels create efficiency. Common LRUs like radios, controls and displays, or basic operating software further simplify the supply chain and create opportunities for flexibility.

Advanced manufacturing tools and techniques also possess tremendous utility in nonmilitary applications and, therefore, the potential for cost offsets. Consequently, any investment in such equipment for military purposes enables the US to repurpose such equipment to other sectors when not necessary for the support of combat operations. The Global Positioning System (GPS) perfectly illustrates the potential of contributions from military systems to the civilian enterprise. The abandoned policy of "selective availability" in which the US would intentionally degrade GPS position accuracy for national security reasons offers a precedent for such a relationship.[42] Consider the value of military manufacturing equipment contributing to civil works projects at home or in collaboration with US-led aid operations abroad. The DOD may establish the performance specifications and generate the initial orders for the government; however, the US government could find ways to share this manufacturing potential beyond the defense sector. The potential value to the nation of manufacturing resources procured to provide for defense but applied to initiatives supporting the other instruments of national power both domestically and abroad could significantly, and favorably, alter the makeup of the national budget.

Furthermore, the potential to lease manufacturing tools not actively supporting the production of war materiel could bolster the economy while attacking national debt. In 1953, President Dwight D. Eisenhower delivered the speech known as "The Chance for Peace," and, in 1961, he warned against "the Military-Industrial Complex" in his farewell address. In the former he stated,

> This world in arms is not spending money alone. It is spending the sweat of its laborers, the genius of its scientists, the hopes of its children. The cost of one modern heavy bomber is this: a modern brick school in more than 30 cities. It is two electric power plants, each serving a town of 60,000 population. It is two fine, fully equipped hospitals. It is some 50 miles of concrete highway. We pay for a single fighter plane with a half million bushels of wheat. We pay for a single destroyer with new homes that could have housed more than 8,000 people. This, I repeat, is the best way of life to be found on the road the world has been taking.[43]

In the latter, Eisenhower acknowledged, "Only an alert and knowledgeable citizenry can compel the proper meshing of the huge industrial and military machinery of defense with our peaceful methods and goals."[44] The specific figures changed, but the principal issue remains. Sustaining a large, fielded force places a strain on other areas of the nation and the economy. Adapting the defense industrial base to meet the needs of a force structured and postured to field combat capability on-demand creates the opportunity to address the challenges Eisenhower put forth decades ago. Consider the potential applications of dual-use technologies, procured for the manufacture of war materiel in defense of the nation and applied to the needs of national infrastructure, energy, education, or medicine in times of peace.

Intellectual property and International Traffic in Arms Regulations (ITAR) may raise concerns for proliferation or espionage—this risk is not unfounded. International trade laws often lag behind technology, and a recent dispute over digital data highlights the issue. The US International Trade Commission faced the task of determining whether or not digital design data transmission (related to orthodontic devices) constituted a physical "article" and therefore violated patent law.[45] Furthermore, one needs only a glance at images of Chinese J-20 and J-31 aircraft in comparison to our US F-22 and F-35 aircraft to notice similarities. By leading with initiatives in this space, the US can establish regulations and guidance on how nations should deal with manufacturing technologies capable of civil and military applications without any significant reconfiguration. Furthermore, the US can establish safeguards and methods capable of protecting intellectual property inherent to the software packages used to produce a given weapons system.

Adjusting the acquisitions and force structure paradigms of the industrial era to meet information era demands not only paves the way for continued US superiority in industry and war, but it also expands the collective war-fighting potential of allies and partners. The US ability to rapidly coalesce and lead international coalitions with disparate positions in pursuit of common objectives routinely stands out as, arguably, its greatest strength. Coupling team-building capacity with rich cultures of innovation and skilled industrial bases can elevate the group to its maximum potential. The 2017 National Defense Authorization Act (NDAA) included language that expanded National Technical and Industrial Base (NTIB) status to "include persona and organizations in the United Kingdom and Australia as well as those in the United States and Canada."[46] Adding two additional allies to the existing international collaboration with Canada expands the innovation and production potential of the four nations. While Congress did not set forth specific stipulations, deadlines, or criteria for success in the 2017 NDAA, the potential for continuous improvement and growth is evident upon even cursory examination. Codified NTIB collaboration in conjunction with amendments or exemptions to ITAR would ease the flow of concepts, designs, and products among the allies. Paired with the organic manufacturing concept presented in this article, this strategy enables each of the four nations to effectively extend the footprint of its industrial base to the countries and bases of its allies. Operating on this manufacturing strategy, the alliance effectively crowdsources its war materiel needs among members. The entire war production effort automatically achieves resilience via geographic dispersal and redundancy.

Implementation of this strategic vision begins with simultaneous analysis and physical experimentation. Proving the concept on an experimental scale leverages the existing capabilities of the technologies in question while testing their potential. With empirical evidence, the DOD can determine whether the key technologies, in concert with an R&D campaign, can swell manufacturing operations to the scale and speed necessary to meet anticipated demand. In parallel, the DOD should analyze its requirements for production in various operating environments and conflicts. Such research will inform decisions concerning replenishment of expendables, replacements due to attrition, and necessary supplemental materiel. Conquering the technical challenges of implementation alone will result in an incomplete solution—the DOD must couple this aspect of implementation with its efforts to prepare its forces for future operating environments.

The subject of future conflict and the evolving character of war weighs heavily on each of the services. How will they best organize, train, and equip to face emerging challenges? New technologies and operating environments will ceaselessly challenge military leaders to embrace the adage that "doctrine is not dogma." The USAF extensively researched the future of air superiority as it prepared its plans for its penetrating counterair platform.[47] The US Navy consistently re-evaluates its force structure as the maritime operating environment evolves. Increasing interest in acquiring a new class of frigate versus relying exclusively on the littoral combat ship illustrates the dynamic nature of each domain.[48] The US Army recently established Futures Command, charged with researching the future battlespace and ensuring "overmatch."[49] The US Marine Corps has already established AM initiatives for its logistical needs and appears intent on further integrating the technology to support its concepts of operations.[50] Integrating operations across domains, replacing tried and true tactics with those defined by swarm algorithms, or questioning the continued viability of long-held principles of warfare will require careful consideration—and willingness—to change across the force. How do war fighters achieve mass in the narrow confines of a megacity? How does a combatant commander integrate across domains without communications considered essential for unity of command? As the DOD grapples with these doctrinal questions, increasingly divergent alternatives should receive consideration. The hydralike adaptability of an on-demand force in perpetual development and improvement between the DOD and industry, capable of deploying forces tailored to individual operating environments, and optimized for the application of force suitable to the conflict's place on the spectrum of warfare may solve such problems.

Conclusion

Each of the service secretaries and chiefs of staff laud innovation and tout the importance of new technologies to future war-fighting capabilities. However, experience shows that technology alone cannot guarantee successful employment. In parallel with calls to embrace emerging capabilities, the services lament the ossified bureaucratic processes and resistance to change that dominates defense acquisitions. This is not a new problem. Dorothy Leonard-Barton and William Kraus summarized the challenges of adopting new technologies in *Harvard Business Review*:

> Many implementation efforts fail because someone underestimated the scope or importance of such preparation. Indeed, the organizational hills are full of managers who believe that an innovation's technical superiority and strategic importance will guarantee acceptance. Therefore, they pour abundant resources into the purchase or development of the technology but very little into its implementation. Experience suggests, however, that successful implementation requires not only heavy investment by developers early in the project but also a sustained level of investment in the resources of user organizations. . . . No one in the user organization had prepared the way for the innovation, so there was no one to whom developers could hand it off.[51]

Barton and Kraus highlighted a problem in 1985 as personal computers proliferated in offices around the world. This issue persists and grows increasingly acute as technology infiltrates more and more aspects of daily life. The inability to successfully implement these technologies among its fighting forces may pose grave consequences to the US as evidenced by history.

The role of highly capable platforms in war will not end anytime soon; however, a handful of wonder weapons will not yield decisive results in a campaign. In *Joint Force Quarterly*, T. X. Hammes correlates the current rate of technological advance to the interwar period: "This creates the potential for disruptive shifts by creative applications, especially by combinations of these advances. The key question is whether we will invest in . . . battleships or aircraft? Will our investments prove exquisite and irrelevant or change the face of conflict?"[52] The Japanese Zero and German Tiger possessed superior performance characteristics over their American counterparts. Nevertheless, superior employment by American operators and rugged designs by US companies often carried the day. Similarly, the employment of atomic bombs against Japan at Hiroshima and Nagasaki led to Japanese capitulation, but historians credit the suffocating interdiction campaign by US submarine forces with setting the conditions for success.[53] AM, AR, and AI pose the same kinds of disruptive threats to manufacturing, and the industrial base as aircraft and mechanization posed to the certainty of battleships and horse cavalry in the past. The difference, in this modern situation, centers on the fact that the technologies challenging industrial norms simultaneously threaten the status quo of how militaries organize, train, and equip.

Leveraging rapid manufacturing, iterative and continuous design improvement, and human-machine teams effectively operationalize the industrial base. Rather than simply providing the means of procurement and the tools of production, the industrial base, and its potential becomes a component of the joint force commander's (JFC) campaign plan. During shaping operations, the JFC works with apportioned human-machine teams to influence the theater in a way supportive of national objectives. Because operationalizing the industrial base brings manufacturing capacity closer to the fight, the JFC can leverage this concept as circumstances escalate. Deterrence today might include deployments of new assets into theater or shows of presence activities. The resultant shell game played to ensure limited resources meet worldwide demands often results in precarious solutions and potentially risky gaps. With an operationalized industrial base, a JFC may make a public display of reapportioning manufacturing resources for war materiel or requisitioning additional production capacity from outside the theater. The US can demonstrate readiness and resolve without redistributing combat forces or risking excessive build-up for one crisis at the expense of another. Seizing the initiative and dominating the adversary with an operationalized industrial base means rapid production of precisely tailored forces suited for the exact nature of the operation underway. JFCs executing with such resources maintain the capacity to produce combat forces optimized for exploiting emerging circumstances in a conflict. Additionally, this model provides a ready reserve—in manufacturing potential—capable of adapting to and countering enemy actions. Lastly, because part of the force apportionment strategy includes manufacturing tools and raw materials, the JFC prepares for stabilization and transition operations before hostilities commence. The ability of an operationalized industrial base to cease production of combat hardware and begin producing things necessary to assist civil authorities postbellum offers a unique opportunity for the US to assure victory from pre-hostility to the ensuing peace.

Today there exists the necessity for a radical change in thinking regarding how the military views the industrial base and manufacturing, but additionally, the matter of force size and structure demands further investigation. The size of the force appropriate for day-to-day operations worldwide requires careful consideration by the DOD. Employing too few professionals only exacerbates the demands placed on service members while potentially introducing an asymmetric vulnerability for an adversary to exploit. Conversely, employing too many fails to exploit the potential of on-demand manufacturing fully. This question warrants examining the security environment and considering how to balance the active duty, Reserve, and National Guard forces most effectively. The composition of human-machine teams requires further examination of how much equipment to sustain versus how much to produce when needed.

All signs point to the ability of new manufacturing capabilities to increase the rate and quality of production dramatically, but the specific needs of an engaged military require careful consideration. Determining the rate of production necessary to satisfy force deployment and crisis response marks a key first step. Identifying acceptable and achievable replenishment rates for combat losses during large-scale, sustained operations will serve as the benchmark for this concept's efficacy. The specific demands on force structure and manufacturing resources point, finally, to economic impact and viability.

Experts recognize that AI, AM, and AR will dramatically impact the workforce and have a disruptive effect on the global economy. Ignoring these challenges or attempting to negate their effects without an accompanying revolution on how the economy organizes and operates will only erode US status as an economic and military superpower. The US government should work collaboratively with industry to determine the best courses of action to maintain combat capability, encourage competition, and assure economic growth. Despite these potential obstacles to implementation, the potential for a dramatic increase in capability demands further research.

The US can leverage technologies already in existence and champion the advancement of those just emerging in ways that can secure its preeminence in power projection and assured force sustainment. By evolving the character of the defense industrial base, the US can field and maintain a military that proves both economically viable and combat capable. Investing in advanced manufacturing capabilities will enable the US to continually evaluate and evolve its equipment and force at a faster pace and at a lower cost than an industrial era model allows. SSQ

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