# Mobilization in an Era of Great Power Competition and Technological Turbulence

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# Table of Contents

# Summary

The 2018 report of the Commission on the National Defense Strategy for the United States[1] was tasked to review the 2018 National Defense Strategy, and the issues of U.S. defense strategy and policy more broadly. The initial paragraph of their final report provides a sobering assessment of these:

> *The security and wellbeing of the United States are at greater risk than at any time in decades. America's military superiority—the hard-power backbone of its global influence and national security—has eroded to a dangerous degree. Rivals and adversaries are challenging the United States on many fronts and in many domains. America's ability to defend its allies, its partners, and its own vital interests is increasingly in doubt. If the nation does not act promptly to remedy these circumstances, the consequences will be grave and lasting*

Given the proliferation of advanced technology and the current rise in tensions with near-peer adversaries, the demands of a protracted major conflict with one of these adversaries would likely exceed the capability of the nation's existing force structure. How should the United States mobilize to meet these demands? We examine previous mobilization efforts, examine the challenges of relying on a similar approach in today's environment, and then recommend changes in force structure to mitigate these mobilization challenges. In the worst case, if left unaddressed, the convergence of these trends has the potential to create a national security crisis for the nation. However, when adequately addressed the nation's improved mobilization capability will increase the deterrent effect of our conventioal military forces.

How, in just a few short years, did the United States go from an almost exclusively civilian economy, to being the "Arsenal of Democracy" as President Franklin D. Roosevelt phrased it? Moreover, would what worked then, work today? From a technological perspective, to what degree is the productive capacity of the modern civilian economy compatible with defense production? Would such a reorientation of the economy, as in the late 1930s and early 1940s, even be feasible today? If so, would that be fast enough?

Our conclusions to the above questions are worrying. Prior to World War II over 20% of the workforce was employed in manufacturing, while the country was a net exporter of


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[1] The National Defense Authorization Act for Fiscal Year 2017 established the Commission on the National Defense Strategy for the United States. The Conmmision is a panel of bipartisan national security experts appointed by Congress to make recommendations for the nation's defense strategy at the outset of an administration.

manufactured goods. Today, less than 8% of the workforce is employed in manufacturing while the country is a net importer of manufactured goods. Furthermore, due to the less complex nature of manufactured goods in the first half of the 20th century, automobile production capacity in the years leading up to WWII was interchangeable with plane and tank production in a manner that is simply no longer the case today.

Concurrently the geopolitical landscape is becoming increasingly tense. As the 2018 National Defense Strategy laid out, "The central challenge to U.S. prosperity and security is the reemergence of long term, strategic competition by what the National Security Strategy classifies as revisionist powers. It is increasingly clear that China and Russia want to shape a world consistent with their authoritarian model—gaining veto authority over other nations' economic, diplomatic, and security decisions."

Simultaneously rapid technological advancements, emanating to a greater extent from the private sector than ever before, are poised to fundamentally change the nature of war. Advancements in artificial intelligence, additive manufacturing, advanced robotics, and autonomy will upend long-held doctrinal assumptions. In particular, the degree to which such technologies diffuse to potential competitors (and every effort should be made to ensure that they don't), quantity and not just quality of systems, will become increasingly critical to maintaining dominance in the battlespace.

# Part I. A review of prior mobilizations

## Introduction

On the eve of World War II, the U.S. possessed one of the smallest standing armies in the developed world, yet in the span of half a decade would become a global superpower. More than anything, this power balance reversal was the result of the U.S. converting its massive underlying industrial base to a war footing. In the years following World War II, the country's leaders sought to develop an international system with American power at its core. Cold War tensions, and the resulting arms race, led to the development of a permanent defense industrial base in order to equip the military with technologically superior weapon systems. Today, as in the 1950s, the U.S. defense industry is composed of for-profit companies that produce the weapons used by the U.S. military services and many allied nations. However, following the Cold War, with the accompanying decrease in defense spending, the DoD encouraged the consolidation of the defense industry (then consisting of some fifty firms) in order to improve industry efficiency through combined operations in sales, purchasing, and overhead allocations. By the start of the new millennium, only a handful of large defense firms remained.

The U.S. military has been forced to continuously adapt to significant strategic challenges from the onset of the 21st century. We entered the new millennium with a military designed for great power conflict yet spent much of the past two decades engaged in counterterror and counterinsurgency campaigns. With the rise of China as a near-peer competitor, and the reemergence of Russia as a significant geopolitical threat, the Department of Defense finds itself once again adapting to a changing strategic environment.

Meanwhile, the defense industrial base in the 21st century has failed to keep up with these changing conditions. High procurement costs and development issues for marquee weapons systems like the F-35 make headlines, but these are simply indicators of an acquisitions system in need of reform. While the U.S. military budget is four times that of China and nearly ten times that of Russia[2], a 2018 report from the National Defense Strategy Commission warned that the

[2] These figures are based on analysis of global military spending by the Stockholm International Peace Research Institute (SIPRI) and are likely misleading for three reasons. Firstly, because the U.S. is rich and has an all-volunteer force, soldiers' wages and fringe benefits must be competitive to attract the needed recruits. In contrast Russia and China can either rely on conscription or inexpensive migrants from the countryside. SIPRI makes the comparisons at

U.S. military advantage in a peer-to-peer conflict is eroding (Edelman, et al., 2018). The defense industrial base powered the U.S. to victory in WWI and WWII, but there are some reasons to worry it could not do so today.

The challenges the U.S. defense industrial base would face in a modern peer-to-peer conflict are significant and varied. The report from the National Defense Strategy Commission warned the DoD is no longer investing enough in new systems and is failing to innovate (Edelman, et al., 2018). In addition, modern weapons systems are more complex, and, as a result, difficult to develop and increasingly expensive. These complex and expensive weapons systems are also often single use, as in the case of missiles and other guided munitions.

Further complicating the picture, the country's military supply chains are increasingly global. For example, China, Russia, and Japan lead the world in titanium production, while the U.S. relies on imports to meet 90% of consumption needs (U.S. Geological Survey, 2016). Possibly of even more immediate relevance, the majority of semiconductors are manufactured in and around the South China Sea. In at least one instance, according to Bloomberg Businessweek and a U.S. government investigation, chips providing backdoor access were inserted by the People's Liberation Army, on Elemental Technologies servers, which provide backend IT infrastructure for federal agencies, such as the CIA and private sector firms such as Amazon (Robertson, 2018).

In Part I of this report, we review how the country responded to World War I & II, and analyze the challenges of planning to use a similar strategy to respond to future major conflicts. We will assess whether these responses will be adequate to keep up in a fast-paced geopolitical arms race, let alone meet military needs in an active peer-to-peer conflict.

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prevailing exchange rates rather than PPP which effectively underestimates China's military spending by 40% and Russia's military spending by 60%. This is because the same amount of funds can go further and buy more in those countries. Second, since World War II the U.S. has assumed strategic responsibility for ensuring stability in Europe, Asia, and the Middle East which requires an inherently different, and more expensive to maintain, force structure. Finally, according to Todd Hudson of the Center for Strategic and International Studies what they (Russia and China) report is not what they actually spend. See https://www.washingtonpost.com/opinions/believe-were-spending-too-much-on-defense-think-again/2019/01/27/4cad190c-20c1-11e9-8b59-0a28f2191131_story.html

## Industrial Base in World War I and II

The framework within which the military and defense industrial base engage with one another was largely created during the interwar period between WWI and WWII. At the turn of the 20th century, the U.S. possessed one of the smallest militaries among rich nations yet became a global superpower less than fifty years later. Reaching that point required the creation of entirely new systems, institutions, and professions to equip and supply a large, global military force.

The U.S. procurement system at the beginning of the 20th century retained the same structure it had since it was reorganized by John C Calhoun, in 1824. Then-Secretary of War, Calhoun drew on his experience in the War of 1812 to try and organize a system of national defense that was previously reliant on state militias. The War Department he created relied on a series of powerful but independent bureaus, with the authority to make strategic decisions and budgets to provide for their own acquisitions needs (Maenhardt, 2008).

However when the U.S. entered WWI the decentralized nature of the existing system significantly hindered military efforts. The entire active duty U.S. military force in 1907, numbered only 108,301; by 1918, with the U.S. Expeditionary Force fighting in France, that number grew nearly 30-fold to 2,897,167 (Maenhardt, 2008). Fielding such a large army required coordinated procurement and military logistics efforts that the U.S. was ill equipped to perform. For example, the army and navy neither coordinated supply purchases, or the transportation of those supplies to the front, frequently leading to the two services bidding against each other for supplies and services..

The DoD addressed these challenges in the interwar period with deep structural reforms. The National Defense Act of 1920 tasked the Assistant Secretary of War with establishing a unified procurement plan for the armed services in case of another major conflict. Ultimately, four plans were developed in the interwar period, each building on the last. This effort yielded a number of accomplishments, such as the creation of the Joint Army Navy Munitions Board in 1922 (to coordinate purchases), and the Army Industrial College in 1924 (to train the procurement workforce). The appointment of an Administrator of War Resources in 1930 brought all wartime industrial mobilization efforts under a central authority.

When the U.S. entered WWII, the country was fully prepared for the kind of mass industrial mobilization the war would require. America, in 1941, was a manufacturing powerhouse, with over 20% of the U.S. population employed in manufacturing. Manufacturing hubs in cities like Detroit, New York, and Baltimore allowed for centralized and efficient wartime production. At that time weapons systems' components were easier to build than, for instance, the complex components required by the F-35 or RIM-161 Standard Missile 3. In a speech following the attack on Pearl Harbor, President Roosevelt set staggering manufacturing goals for the next two years: 180,000 aircraft, 125,000 tanks and 55,000 anti-aircraft guns.

The speed and scale with which the nation armed itself immediately prior to, and during, WWII highlighted the latent power the country brought to bear on the task at hand. In 1939, the U.S. still had a 50,000 man cavalry, with horse drawn artillery (PBS, 2007). By 1941, the U.S. was launching annually more ships than Japan did in the entire war. By 1942, U.S. aircraft manufacturers were out producing Nazi aircraft production 3 to 1. This surge in production, from nearly nothing prior to the outbreak of conflict on the continent, was accomplished by completely transforming American private industry to meet wartime needs. For instance, the American automobile industry, which produced three million private cars in 1941, produced only 139 over the course of the war. Instead, that production went to weapon systems. Ford, which built the B-24 Liberator long-range bomber, was able to produce one plane every 63 minutes. In short, the U.S. was prepared to out-build its peer competitors in WWII, and had the systems in place to make full use of those advantages (PBS, 2007).

## Today's Environment

The modern defense industrial base is vastly different from its WWII-era predecessor. While the general structure of contractors coordinated by a central acquisition authority remains, both military needs and the modern economy have changed dramatically.

The U.S. economy has grown from its industrial and agrarian roots. As of 2016, only 7.9% of the U.S. workforce was employed in manufacturing, compared to over 20% prior to WWII (BLS, 2017). In part, this is due to increases in productivity and automation. A substantial portion of the reduction however is the result of manufacturing industries being offshored, frequently to China which for instance employs nearly 1 out of every 2 manufacturing workers worldwide

(Gill, 2017). Today China, not America, is the world's largest exporter of manufactured goods (Our World in Data, 2018). This means that the U.S., in comparison to China, would have a much smaller domestic industrial base from which to arm itself.

The needs of the modern military have changed no less dramatically. Whereas WWII-era General Motors Corporation was able to quickly shift production from cars to airplanes, modern weapons systems require far more expertise and specialized equipment to manufacture. The P-38's engine for example, could easily be manufactured in converted General Motors plants (Carroll, 2018). The F-35 on the other hand, features vastly superior performance in terms of stealth, speed, range, agility, and payload capacity; but at the cost of extraordinary complexity. This complexity means the manufacturing workforce requires specialized training and highly specialized tooling and equipment is required for component production; as a result, existing commercial manufacturing plants cannot be quickly and easily converted to meet wartime production needs. Furthermore, for a variety of reasons, production is distributed between specialized manufacturing facilities located in North America, Europe, and Asia.

The F-35 however is just one example of how production of strategic systems has become increasingly dispersed, while the facilities and equipment required for production have become increasingly specialized and therefore not compatible with potential defense production needs. The semiconductor supply chain, upon which U.S. industry and federal information systems depend, arguably provides another example of this dynamic, dispersion leading to fragility. Historically designed in the U.S., with raw materials sourced from Japan, Taiwan now leads the industry in manufacturing semiconductors themselves; while back-end assembly, testing, and packaging is typically performed in South Asia, due to South Asia's lower cost of labor. The effect of this is a system for producing chips at a fraction of what it would cost to produce them domestically, however at the cost of substantially increased fragility and vulnerability (Platzer et. al., 2016).

Moreover, the industry has consolidated to the point where each juncture in the supply chain is dominated by a few, or even a single corporation. For instance, only one firm makes the current generation of lithography machines, the machines used to transfer integrated circuit pattern designs onto silicon wafers (Clark, 2018). Recently a fire took a key supplier out of operation, delaying the production of state of the art lithography machines, and subsequently slowing down the entire industry's adoption of the next generation of semiconductor manufacturing equipment (Clark, 2018).

The F-35 likewise provides a good example of a globally integrated supply chain, albeit integrated for different reasons. While the stages of semiconductor manufacturing span the globe in search of ever lower cost areas of production, the F-35 incorporates many partners not because it is necessary for the bottom line, but because doing so helps to cement alliances and encourage aircraft sales. Nonetheless, with a flight visor designed in Israel, and parts produced in Norway, South Korea, and Turkey (among others) disruption to our allies could temporarily disrupt production (Sullivan, 2018). Furthermore, parts are often produced using critical commodities, such as titanium and gallium, which are sourced from only a handful of facilities around the world. The aerospace industry, for example, is heavily dependent on titanium sponge imports from Japan (59%), Kazakhstan (17%), and China (13%) (U.S. Geological Survey, 2016). While this arrangement allows for more efficient sourcing, it could prove to be a liability in a major conflict. Because the US government does not have any stockpiles, a serious disruption to sources of supply would cripple aerospace production capacity.

Furthermore, the costs associated with our most commonly used weapons systems have only increased in the modern era. For example, the JASSM-ER, a widely deployed air-to-surface missile, costs about $1.35 million per unit (Sullivan, 2015). By comparison, the P-38 Lightning used in WWII cost about $1.4 million when adjusted for inflation (Statistical Digest, 2004). While a fighter aircraft and a cruise missile may not seem like a perfect comparison, this cost inflation is in line with other modern weapon systems. The projected price per unit in 2019 for the F-35A, a modern fighter aircraft, is around $90 million (F-35 Lighting, 2018). The projected price of a single rocket-guided projectile designed for the Zumwalt-class destroyer--about $1 million per shell (Caves, 2016).

## A changing geopolitical environment

The United States faces a geopolitical landscape that has shifted no less dramatically since World War II. The great power conflict of the Cold War divided much of the world into two opposing camps, with the U.S. and the USSR vying to outpace one another while supporting their various allies and proxies. Following the collapse of the USSR, and the events of 9/11, the U.S. adapted to a new reality of insurgency and asymmetric warfare. However today, with a rising China, and resurgent Russia, actively pursuing their interests around the world, the U.S. faces the return of great power competition.

While Russia has remained at the center of many international conflicts, China presents the greatest potential threat to the current liberal world order. China currently possesses the second largest national economy (expected to surpass the U.S. by 2032) and spends more on defense than any other country besides the U.S., or about $175 billion in 2018. Barring a major change in China's growth trends, China will soon be as rich as the United States, and with significant military capabilities (Dobbins, et. al., 2017).

A strong China is not a threat in and of itself, but recent moves by China have worrying implications for regional peace. Specifically, China has attempted to greatly expand its maritime border by making territorial claims at the expense of its neighbors; many of them U.S. allies and partners. In the South China Sea, China has attempted to cement their claims there by constructing a series of artificial islands on reefs and atolls far from China's internationally recognized territorial waters. These islands have put them in direct conflict with other claimant nations, such as Vietnam and the Philippines. In addition, China has pressed claims to the Senkaku/Daiyu Islands off the east coast of Taiwan, currently controlled by Japan and also claimed by Taiwan. China has also disputed South Korea's control of Socotra Rock, a submerged rock in the Yellow Sea.

In addition to the current maritime border disputes, China has a number of lingering territorial disputes that increase the risk of conflict breaking out. China currently claims sovereignty over Taiwan, denying the sovereignty of Taiwan's democratically elected government. China's government also claims significant territories held by India, specifically parts of Kashmir and the

Indian state of Arunachal Pradesh. China has also shown a willingness to use force in defense of these claims, fighting a particularly bloody border war with Vietnam in 1979.

As China's wealth and ability to project military force has grown, the threat that China will strongly defend one of these claims has grown as well. In September 2018, a Chinese Navy warship came within 45 yards of the USS Decatur, as the Decatur was completing a freedom of navigation operation around the disputed Spratly Islands. This incident was not the first, as U.S. reconnaissance aircraft have reported being tailed and harassed numerous times by Chinese fighter aircraft, including an incident in May 2017 when a Chinese SU-30 aircraft performed a barrel roll over a U.S. C-135 reconnaissance plane. As the frequency of these incidents, and China's military confidence, grows, the possibility of an incident leading to a major conflict has grown as well (Gompert, et al., 2016).

## Challenges to the industrial base from a Sino-American conflict

According to RAND, by 2030 China's GDP could exceed that of the United States' enabling it to become a more capable adversary than either the Soviet Union or Nazi Germany, at their peak (Dobbins, et. al., 2017). The possibility of a war with China remains remote, but given the tensions detailed above, it is not so remote that it can be ignored. China's improving anti-access and area denial (A2AD) capability means war planners cannot preclude the possibility of very high levels of attrition, particularly at the onset of conflict, before Chinese A2AD can be suppressed (Gompert, et al., 2016). Consequently, the anticipated speed and intensity of a conventional conflict with China would significantly challenge the U.S. defense industrial base to repair and replace battle damaged systems. If the U.S. wishes to remain secure, it is necessary to address these challenges now.

To counter U.S. dominance in the traditional domains of air and sea power, China has invested heavily in asymmetric offsets, particularly surface-to-surface missiles (SSMs), integrated surface-to-air missiles (SAMs) systems, and counter C4ISR. In the last 15 years, China has developed and deployed 1000s of missiles targeted at U.S. forces in Taiwan and Japan along with 100s of missiles capable of striking Anderson Air Force Base in Guam. Since the late 1990s, China has been investing in integrated SAM networks with each battery capable of engaging fighter aircraft at 125 miles or more. Observing the overwhelming advantage U.S.

C4ISR provided the allies in Operation Desert Storm; China since the 1990s has been striving to develop similar capabilities indigenously, in conjunction with the development of anti-satellite and anti-aircraft missiles to degrade and destroy U.S. C4ISR assets (Ochmanek, et al., 2017).

While neither Russia nor China have yet fielded a 5$^{th}$ generation fighter jet, increasing numbers of Su-27s and J-11s will "present a far more formidable challenge to air superiority than any adversary the United States has faced since the Cold War" (Ochmanek, et all., 2017). In a similar manner, the People's Liberation Army Navy has been rapidly modernizing its surface and subsurface fleets, with the most vessels of any navy launched in 2013 and 2014. Chinese nuclear-powered submarines, in particular, will pose a threat to the USN and USAF support aircraft when equipped with Long Range Surface to Surface and Surface to Air Missiles (Ochmanek, et al., 2017).

Chinese doctrine, designed to counter U.S. power projection capabilities, calls for seizing the initiative early in a conflict and prioritizing the destruction of adversary C4ISR capabilities. In any intense conflict, stockpiles of expendable standoff munitions can face rapid depletion. This was demonstrated in NATO's 2011 campaign against Muammar Gaddafi's regime, which found U.S. allies including Britain and France running short of precision bombs. For comparison, Libya spent roughly a billion dollars annually on defense while China is reported to be spending $175 billion a year as of 2018 (DeYoung & Jaffe, 2011).

Should hostilities break out, the DoD would face three major challenges. At the initiation of hostilities, U.S. forces will be dependent on long-range standoff munitions to degrade the adversaries A2D2 systems. The inventory of such munitions would be quickly depleted with the speed and high-intensity of the conflict, preventing allied forces from capitalizing on early wins and seriously impairing the war effort. In a similar vein, should peace prove hard to find, U.S. defense corporations would attempt to ramp up production; however, due to the challenges pointed out previously, this effort would easily prove to be too little, too late.

## Conventional Responses to Mobilization Challenges

The challenges identified above are not new, and have been explored and are well documented. The Department of Defense has responded to these challenges with several recommendations, which very much focus on conventional responses. These responses generally fall into three categories: increasing weapons system inventories, accelerating the procurement process, and increasing funding for research and development. All three should be pursued, but are unlikely to sufficiently address the mobilization needs of a great power conflict. To be successful the DoD must leverage the strengths of the country's industrial base and R&D ecosystem to develop new, more effective weapon systems which can be produced quickly, at scale, and in abbreviated time-frames. In the second part of this report, we will examine key disruptive technologies, and concepts for new weapons that may meet these requirements.

# Part II. Charting a new course

## Introduction

We are entering a period of renewed great power competition. In an interview in March 2019, the Chairman of the Joint Chiefs of Staff, Gen. Joe Dunford, said China and Russia are striving “to establish pre-eminence, if not hegemony, in their respective geographic areas and both are trying to assert greater influence on the world stage.” The increasing military threat posed by these near-peer competitors is driving the U.S., along with allied liberal democracies, to shift their national security focus from terrorism to potential great power competition. And, as discussed in Part I, traditional approaches to mobilization would not be adequate if this competition gives rise to conflict.

During the Cold War, the U.S. strategy was to maintain technological superiority, developing and integrating new capabilities that include stealth, precision-guided munitions, and networked command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR). Should a potential adversary engineer a capability designed to exploit the weaknesses of our technology, the belief was that U.S. innovation could quickly respond and reduce any potential advantage a would be adversary might temporarily enjoy.

Even as technological superiority remains the centerpiece of U.S. military strategy (Garamone, 2018), the ability of ensuring this superiority has changed dramatically over time. Prior to and during the Cold War, U.S. technological innovation often occurred as a result of government research funding for military priorities. However, the end of the Cold War coincided with the start of what would become known as “the information revolution”; research investments now come predominately from the private sector—focused on commercial applications. By the dawn of the new millennium, the vector of technology transfer had reversed. As a result, many militarily applicable disruptive technologies are increasingly being developed by the commercial sector; military systems now strive to adapt the latest, rapidly evolving, commercial technologies and products.

While U.S. military doctrine since the Korean War has been to develop and field small numbers of increasingly expensive, technologicaly advanced weapon systems, current trends in technological trends will render this approach obsolete overtime. For example, as machine intelligence becomes increasingly sophisticated, and sensors become increasingly effective and inexpensive, quantity of force will begin to regain ground from centralized, technological advantaged based doctrines.

With the current geopolitical environment, the U.S. will likely not have the luxury of years of industrial mobilization and deployment. Given the current fiscal enviornment, sustaining public support for the alternative of maintaining a war-like footing in perpetuity would be difficult. As a result, future wars will depend on the responsiveness, agility, and production capacity of weapon systems manufacturing (May, 2019). We believe that in order to meet its national security needs, the U.S. will need to leverage the strengths of the entire industrial base, including the innovative technologies coming out of the private sector, to develop weapon systems which can be produced quickly, affordably, and in a manner that optimally leverages the existing, innovative commercial industrial base.

The next section of this paper will examine the disruptive technologies coming out of the private sector which we believe will radically alter future battlefields; these technologies include artificial intelligence (AI), additive manufacturing (AM), advanced robotics, and proliferated sensors. For example, AI or machine intelligence, which is rapidly improving autonomous capabilities, will enable aircraft to be pilot-less, taking the man out of the loop (assuming trust, policy, and ethical issues can be resolved), and allowing for systems to be lighter, simpler to design, cheaper, and potentially expendable. Cheap, proliferated drones and satellite-based sensors will increasingly provide comprehensive and continuous coverage of the battlespace. Machine intelligence will enable nearly spontaneous analysis of data, and acquisition and targeting of enemy systems. The remainder of our paper will address the application of these technologies to the next generation of weapons systems, acquisitions improvements, barriers to change, and enabling factors. We will conclude our paper with recommendations for how they can be employed to develop a more affordable and agile force structure.

## Enabling Technologies

As noted above, in the coming years we expect several technologies to mature that will have a disruptive effect on the development, production, and sustainment of future weapon systems and the industries that produce them. Significantly, these technologies exhibit a dynamic whereby advancement in one, accelerates the capabilities of the others. AI will increase the capabilities of advanced manufacturing robotics and autonomous systems while AM will expand the scope of possibilities regarding AI assisted design and engineering. Advanced manufacturing robotics in turn will drive down the cost of converting raw materials into finished goods. In the long-run however, it is AI that will likely have the greatest impact on the nature of commerce and combat. Similarly, increasingly cheap and effective sensors will enable greater autonomy but will ultimately require machine intelligence or AI to fully leverage the incoming deluge of data.

### *Artificial Intelligence*

Early AI constituted expert systems, tax preparation software being the classic example. Rather than generate any novel insights from data, in the manner that human intelligence is capable of, these systems simply codified expert knowledge electronically. By the early 2010s, per Moore's law,[3] cost per computation had decreased to the point at which machine learning became economically viable. Machine learning algorithms build a mathematical model based on sample data, known as "training data", in order to make predictions or decisions without being explicitly programmed to perform the task. Most prominent amongst machine learning techniques is an approach known as deep learning which leverages artificial neural networks that can be trained to perform a variety of classification and prediction tasks, when adequate data is available. In this paper, AI refers to the most advanced subsets of machine learning, such as deep learning, which, to a degree, is able to replicate human intuition.

All deep learning systems, however, do not require real world data to train their algorithms. Indeed, the biggest breakthroughs in deep learning so far have involved AI producing the requisite training data by playing millions of simulated games against itself. This suggests that while labeled data can be important in some domains, e.g. facial identification; it is less so in other games where the parameters or rules can be specified. In the future, AI systems will likely be able to train themselves, and the key constraints will be programmer talent and computer hardware. In addition to AM and advanced manufacturing robotics, artificial intelligence will

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[3] "In 1965, Gordon Moore made a prediction that would set the pace for our modern digital revolution. From careful observation of an emerging trend, Moore extrapolated that computing would dramatically increase in power, and decrease in relative cost, at an exponential pace. The insight, known as Moore's Law." See https://www.intel.com/content/www/us/en/silicon-innovations/moores-law-technology.html

profoundly revolutionize 4 industries directly impacting the strategic picture, such as strategy, materials research, engineering and design, and automation.

**Strategy development and decision making**

The real time tactical decision-making problem is a difficult military problem. It is generally made more complex due to its high degree of time sensitivity. Not only must a variety of alternative actions be analyzed, the decisions must be made quickly, before the battlefield changes to the point that a decision is no longer viable. This is an area, where AI can make a significant impact.

The commercial sector has been developing real-time strategy (RTS) games; these are a genre of video game which are essentially simplified military simulations. These games are a difficult domain for humans to master. Expert-level gameplay can require performing hundreds of actions per minute in partial information environments. These actions may need to be distributed across a range of in-game tasks (Weber et al., 2011).

AI is ideally suited for these types of tasks. Games can progress from fairly simple to incredible complex, where the complexity cannot be addressed with brute force computational techniques. Take for example Tic-Tac-Toe, where there are a finite number of possible games which can be played, specifically $10^3$. Because there are only approximately 1000 different games that can be played, it is not difficult for a computer to simply attempt every possible combination of moves, i.e. all 1000, to find the dominant or optimal strategy for winning. Consequently, computers were able to reach parity with top Tic-Tac-Toe players in 1952. The most notable example of brute forcing, i.e. calculating all possible moves, however, is probably Deep Blue which defeated the top Chess player Gary Kasparov in 1997 (Piper, 2019).

Chess is not a simple game as there are $10^{47}$ possible moves. The game of Go[4] however, is 123 orders of magnitude more complicated with $10^{170}$ possible moves, and even all the supercomputers on earth, would have insufficient computing power to effectively brute force the game. What sets humans apart from machines is that humans do not have to evaluate every possibility in order to determine a nearly optimal course of action, relative to the space of all

[4] Go is an abstract strategy board game for two players, in which the aim is to surround more territory than the opponent.

possible actions. Rather, with a small training set (data points from which to extrapolate) most humans can become reasonably proficient at a large number of tasks with poorly defined parameters quite quickly (Piper, 2019). Very crudely, this is what intelligence is, the ability to take data points and optimize accordingly to maximize the achievement of an objective or objectives. Among more advanced analytical systems, neither if-then expert systems nor minimax search trees qualify as true artificial intelligence (Russel, n.d.). Rather they are examples of what many in the tech industry refer to as GOFAI or "Good Old-Fashioned Artificial Intelligence", systems which appear intelligent but would never be able to challenge humans in high dimensionality domains, e.g. strategy war games (Haugeland, 1985).

Deep learning, however, is different. Based on artificial neural networks inspired by information processing and distributed communication nodes in biological systems (i.e. brains), deep learning systems use multiple layers to progressively extract higher level features from raw data. For example, in image processing, lower layers may identify edges, while higher layers may identify human-meaningful items such as digits/letters and words. The "deep" in "deep learning" refers to the number of layers[5] through which the data is transformed. These additional layers enable such systems extract causal relationships between actions and results more effectively (Piper, 2019). This technique can be used from everything from facial recognition, to war strategy games and the development and evaluation of force structures. In certain domains, e.g. war games, computers leveraging deep learning are able to make better strategic decisions than human players, by recognizing at a higher level of precision, the relationship between actions and consequences.

Fundamentally, once you have the parameters of a strategy game such as StarCraft[6] or DOTA[7], a map of the battle space and the specifications of the combatant systems in play, developing and executing a strategy to win in a complex simulated war is not necessarily different from developing and executing tactics and strategy applicable to conventional war. Furthermore, we can anticipate that, in spite of increased interconnectedness, compressed OODA (observe, orient,

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[5] More precisely, deep learning systems have a substantial credit assignment path (CAP) depth. The CAP is the chain of transformations from input to output. CAPs describe potential causal connections between input and output. Rather than having just 3 layers as in the example described above, modern deep learning systems can have thousands of layers and millions of 'neurons', with each layer identifying progressively more complex features.

[6] StarCraft is a science fiction real-time strategy game set in a distant sector of the Milky Way galaxy.

[7] DOTA is a multiplayer online battle arena video game.

decide, act) loop cycles, the speed and volume of data, and adversary deception and misinformation will result in increased ambiguity in future conflict (White, 2016, p.4).

This murky situational awareness will feed decision cycles, which will be compressed by pervasive data and near-instantaneous communications. Decision events will increase in frequency and speed. The OODA loop decision cycle – must be compressed in the short term to RDA – (recognize, decide, act). Observation and orientation as discrete actions will be a luxury that the future battlefield will not allow. Superiority will be predicated on further evolving the decision cycle to PDA (predict, decide, act) – with the goal of reducing (or ultimately eliminating) the time to decide – PA (predict, act) – through automation and AI (White, 2016, p.4).

AI decision aids will be a critical capability on future battlefield. Considering their potential, Eric Schmitt the former CEO of Google and current chair of the DoD innovation board, argued at a recent Center for New American Security conference that the DoD and RAND corporation should begin to incorporate AI into war gaming, strategy and operational concept development (Schmidt, 2017).

**Materials Research**

From fighter jets to semiconductors, performance in most physical systems is limited by the properties of the molecules from which the systems are constructed. In the pharmaceutical industry, an industry based largely around the development and testing of novel molecules, companies develop and screen millions of compounds for the potential to serve as new drugs. Even with robotics and lab-automation tools, this screening process is slow and yields relatively few hits. Of the more than $10^{30}$ theoretically possible molecules, only between $10^{7}$ and $10^{8}$ have been developed and screened (Carbeck, 2018).

With AI, algorithms can analyze all known past experiments that have been attempted—those that worked and, importantly, those that failed, to discover and synthesize substances of interest. Based on the patterns they discern, the algorithms predict the structures of potentially useful new molecules and possible ways of manufacturing them. Outside of pharmaceuticals, ventures such as Citrine Informatics are using approaches similar to those of pharmaceutical makers and are partnering with large companies, such as BASF, to speed innovation. The U.S. government is also supporting research into AI-enabled materials research, investing more than $250 million in the Materials Genome Initiative[8] since 2011 to accelerate the development of advanced materials (Materese, 2019).

The key takeaway here is not just that AI holds promise for the development of novel materials, some of which have important strategic implications; but also that the development of novel materials will lead to existing systems becoming obsolete at a much more rapid clip as improved materials enable increasingly advanced systems. In such a world, flexibility and nimbleness in the defense industrial base will be critical.

**Engineering and Design**

Artificial intelligence promises to remove much of the drudgery from design work. Despite the space of all possible designs being nearly infinite, product development historically has been painfully iterative and ridged. Given requirements, engineers would develop and experiment with possible designs informed by intuition and experience, testing them virtually and then physically to determine viability in various conditions, iterating until the design meets specifications. While this process can be adequate for simpler designs, at higher levels of complexity and in domains where the marginal value of improved performance is extremely high, this process is also inherently limiting.

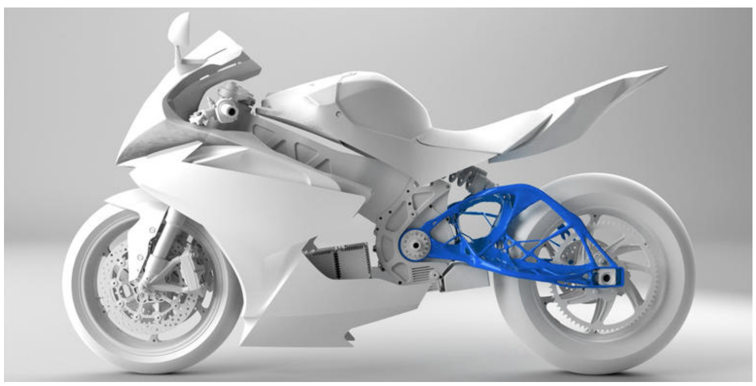
Computer-Aided Design (CAD) augmented with AI enables intelligently searching through a vast space of possible structures to optimize according to desired specifications, e.g. minimum weight at a given strength. Critically though, rather than relying on brute force computing, i.e. attempting to calculate the viability of every possible design down to the molecule, artificial neural networks enable CAD programs to develop what might be analogous to human intuition but with much greater computational power, speed, and working memory.

An engineer seeking to design a frame for a quadcopter, for example, might specify the internal hollow volume needed for the motor, batteries, etc., the weight of those components, and the forces that will act on the drone. Furthermore, when integrated into a firm's enterprise resource planning system, the AI could further optimize according to expected availability and cost of

[8] The Materials Genome Initiative is a multi-agency initiative designed to create a new era of policy, resources, and infrastructure that support U.S. institutions in the effort to discover, manufacture, and deploy advanced materials twice as fast, at a fraction of the cost.

different construction materials, cost of manufacturing with different materials, demonstrated performance of different materials in the field, etc. In other words, AI enables automatically optimizing against a larger number of variables and to a greater degree of precision than humans do.

Frequently the result of AI assisted design is a highly intricate design which maximizes the structural integrity of the component at a given mass, but which would also be nearly impossible for a human machinist to build. The graphic below illustrates a rear assembly developed with an AI assisted CAD program and then instantiated via AM. The structure is highly unusual and almost certainly could not be produced easily and to spec without the aid of either AM or robotic manufacturing systems (Condon, 2019).



### *Additive Manufacturing*

Unlike conventional manufacturing process, which rely on either milling, drilling, or cutting processes, AM is a "printing-like" process that can be used to make three-dimensional objects from computer models (GAO, June 2015, pg. 5). With AM, successive layers of melted or partially melted material are bonded together until the final object is formed (General Electric, n.d.). Additive manufacturing (AM), commonly known as 3D printing, has matured at a rapid pace and is now being used for a wide variety of industrial applications.

The promise of AM is that it enables mass customization at nearly no increase in cost, due to its ability to make an almost limitless variety of parts with the same machine. Concretely, AM offers the opportunity to revolutionize three specific domains of interest to the national security community: design and development, production, and sustainment. Economy of scope enables rapid prototyping, facilitating accelerated development timelines while also driving down costs by obviating the need for new tooling for each iteration of a design.

When applied to production, AM (and AI) will substantially reduce the cost of complexity or customization (Connor et al., 2014). Deploying AM in the field will also enable on-site production of spare parts reducing dependency on supply chains and required levels of inventory. The technology promises to enable "on demand production" of military equipment using any suitable AM machine in the world; reducing the DoD's need to maintain large inventories. Such applications are already becoming more prevalent, for example, the 31st Marine Expeditionary Unit based in Okinawa, Japan recently reported the successful test of a printed plastic bumper on one of their F-35B Lighting II aircraft (GAO, 2018). Not only does AM offer the potential to ease the burden on overtaxed logistics networks; it will reduce the cost of maintaining legacy systems. With AM, spares (those that are suitable for AM techniques) need not be stockpiled, as long as the technical data packages (TDP) are still available.

Of course, with new technologies, come new risks and AM is no exception. In the case of traditional manufacturing, even if the blueprints are stolen, tacit knowledge is required for production. Without the requisite tacit knowledge, the thief is unlikely to be able to replicate the technology in question. For example, China stole either portions of, or the entire set of drawings for the F-35 but they have not been able to come anywhere close to replicating the plane itself. Contrastingly, with the right AM technology, all that is required to replicate a given component would be the TDP. With AM, sabotaging critical supply chains could be accomplished by hacking into an adversaries' network and compromising the TDPs, or potentially manipulating the printer firmware to adversely impact the properties of the manufactured component. As a result, cyber security will be critical for protecting and maintaining the integrity of TDPs.

### *Advanced Robotics*

While AM promises to enable greater economies of scope, particularly for individual components, it is unlikely in the near term that we will move away from conventional assembly lines for large systems such as planes and tanks. However, as machine intelligence increases, assembly lines will become increasingly automated. Such automation in turn will drive down the cost of processing materials and the cost of mass customization, in a manner similar to AM. In contrast to AM, advanced robotic manufacturing systems will not substantially change manufacturing applications. Production facilities will still be large and centralized, just faster, operating 24-7, and require less human labor.

As noted previously, in the modern age, the balance of power between states is primarily a function of industrial capacity and technological capability. At the present date, robotic manufacturing systems are limited largely by intelligence than by the physical ability to manipulate objects in space. As the intelligence of machines increases, we should expect to see a corresponding decrease in the cost of complexity. For example, rocket fuel represents only ~0.4% of launch costs, while material costs for constructing the rocket constitute a similarly small percentage of total expenses. Rather, the bulk of marginal expenses are for the skilled labor required to construct or refurbish the rockets (Shanklin, 2013). Overtime, advanced manufacturing robots will inevitably drive down the cost of handling materials, plausibly to the point where the primary cost of a tank or rocket will just be the raw materials and the energy required to assemble the system.

Recognizing this, the DoD is currently leading a $250 million venture with Carnegie Mellon University and over 220 partners in industry, academia, government and the nonprofit sector nationwide to advance the frontier of manufacturing leveraging AI, AM and other emerging technologies (Carnegie Mellon University, n.d.). Briefly, in the coming decades, extraordinarily complex high-end systems such as the RIM-161 Standard Missile 3 (SM3 missile) may not cost substantially more than their technologically simpler, but physically similar rocket artillery cousins. In such a world, industrial capacity, technological advantage, and access to shear quantities of raw materials will be more important than ever before.

### *Autonomous Systems*

As AI and advanced robotics mature, and are combined with increasingly capable sensors, autonomous systems will become more and more effective. "Autonomy is the power of self-governance — the ability to act independently of direct human control and in unrehearsed conditions. An automated robot, working in a controlled environment, can place the body panel of a car in exactly the same place every time. An autonomous robot also performs tasks it has been 'trained' to do, but it can do so independently and in places it has never before ventured" (Tung, 2018). In the very near future (assuming trust, policy, and ethical issues can be resolved) deep learning and analogous AI systems will enable drones to rapidly orient themselves in space, decide on the correct course of action, and potentially act in less time than it takes a pilot to blink.

These types of systems are rapidly advancing from futurists' musings to engineering laboratories, and will increasingly be on the battlefield. These new capabilities raise many questions, particularly when weapons can perform increasingly advanced functions, such as targeting and application of force, with little or no human oversight. This is not without precedent. The U.S. Navy has deployed the MK 15 Phalanx Close-In Weapons System on Navy ships since the 1980s. This system can detect, track and engage enemy aircraft and anti-ship missiles without any human commands (Etzioni and Etzioni, 2017).

Such developments may seem revolutionary and they are, just not necessarily in the U.S.'s favor. Historically, the U.S. has enjoyed a monopoly on most strategically relevant innovative technology. Certainly, this may continue to be the case for some technologies, e.g. cutting edge LIDAR systems. In the grand scheme of things however, the overall drivers of enhanced autonomous systems (cheaper sensors and better AI) will be broadly available to all sophisticated actors. Even if the U.S. government was to classify AI research, something which would be nearly infeasible absent an AI national emergency, considering the majority of research is done in the private sector and academia; current deep learning programs today are sufficiently powerful to provide for full autonomy (Scharre, 2017). In other words, the underlying technologies, cheap sensors and AI are already out in the wild.

The U.S. can reasonably expect to maintain a technological advantage over adversaries, but almost certainly not to the degree to which it enjoyed during Operation Desert Storm and Operation Iraqi Freedom. In such a world, where adversaries also have access to these commercially available technologies, mass will be increasingly important (Scharre, 2015).

## Next Generation Systems and the Quality of Quantity

### *The Return of Mass*

"Quantity can have a quality of its own" (quote often attributed to Stalin). In WWII for example, frequently superior German tactics and weapons systems were no match for overwhelming Allied quantities:

> “By 1944, the United States and its Allies were producing over 51,000 tanks a year to Germany’s 17,800 and over 167,000 planes a year to the combined Axis total of just under 68,000.” (War on the Rocks, n.d.)

U.S. systems may be exquisite, but the quantities the country can afford to deploy are shrinking, as noted by “Norm” R. Augustine, almost 40 years ago (Augustine, 1983). The most recent Marine Corps Commandant’s Planning Guidance makes a similar point:

> “We must continue to seek the affordable and plentiful at the expense of the exquisite and few when conceiving of the future amphibious portion of the fleet.” (Berger, 2019)

Simultaneously, great power competitors are developing increasingly expansive and effective A2/AD systems. Furthermore, because the cost exchange ratio of missile defense almost always favors the attacker, it will be increasingly difficult to avoid airframe and ship losses in future conflicts.

As demonstrated during both World Wars, mobilizing for major conflict requires time, which in today’s environment will not be available. It is anticipated that in any future conflict, the time available for mobilization will be increasingly limited. The increasing commercial development and dispersion of technology, the continued downward budgetary pressure, and the rapidly evolving threat environment will require a shift to new types of weapons. Weapons that can be quickly and affordably developed and manufactured and require minimum logistics support will minimize human capital requirements to operate and maintain, and have a small footprint when deployed.

In the previous section, we investigated the technological trends, which will influence the development of future weapon systems and the dynamics of armed conflict. The U.S. should make maximum use of these technologies to develop systems that will take advantage of the nation’s entire innovative industrial base (commercial and defense) to produce “… an endlessly variable repertoire of capabilities” (May, 2019). Of course, these new systems will drive changes in operational doctrine and optimal force structuring. Immediately below we provide an overview of possible next generation weapon systems.

### *Air Systems*

Disaggregating expensive multi-mission systems into a larger number of smaller, lower cost distributed platforms will be one solution to increasingly effective and proliferated adversary A2/AD systems. This concept, commonly referred to as swarming , involves disaggregating expensive multi-mission systems into a larger number of smaller, dispersed, lower cost systems. Such dispersion creates more targets for the enemy, forcing them to reveal their positions earlier, complicating their targeting, and forcing them to expend more munitions to achieve a similar effect. Analogously, larger quantities of disaggregated systems degrade more gracefully in the face of attrition. As adversaries' abilities to detect and engage those aircraft from longer ranges have improved, DARPA has developed concepts such as Mosaic warfare, combining manned and autonomous systems, and system prototypes such as 'Gremlins' to address these challenges.

Mosaic warfare broadly refers to distributed, disaggregated systems of systems. An in-depth analysis by Dr. John Stillion at the Center for Strategic and Budgetary Analysis suggests such "teams of manned and unmanned aircraft could have a major impact on air-to-air exchange ratios." (Stillion, 2015). In one scenario, unmanned combat air systems serving primarily as sensor platforms with modest weapon payloads could detect adversaries at range while teamed with bombers or other large capacity aircraft loaded with very long-range air-to-air missiles. In another scenario, unmanned combat systems would be the first to enter contested air space, either to draw out enemy fire to force the enemy to revel themselves or even attack adversary air defense installations directly.

In the longer term, technological advances will push combatants towards large numbers of fully automated systems. In the short term, however we are more likely to see systems such as the loyal wingman concept, which would leverage the advanced sensing and communications abilities of the F-35 and the expendability of drone systems such as the XQ-58A Valkyrie (Mizokami, 2019). Drones such as the XQ-58A Valkyrie may be well suited for reconnaissance missions but it, and any semi-expendable platform will ultimately lack the capacity to rapidly deliver large munitions payloads.

**Autonomous Systems in the Desert Storm – "Scathe Mean"**

The Iraqi air defense system circa 1990 concerned Pentagon air planners greatly. Consisting of Soviet, British, and U.S. radars and missiles linked together through a sophisticated French-built command, control, and communications system, it posed a serious threat to coalition pilots. The U.S. quickly developed a program, operation Scathe Mean, to mitigate the threat by luring the Iraqi radar systems and SAM sites into revealing themselves for targeting. Using modified Navy BQM-74 aerial target drones, Ground-Launched Cruise Missile (GLCM) crews launched the BQM-74s towards Baghdad. Along with tricking the Iraqis into reveling their positions for targeting, the decoys launched by Operation Scathe Mean were able to absorb Iraqi SAMs in the place of manned USAF aircraft. (Vriesenga, 2002).

Certainly, in many instances, modern stealth jets such as the F-35 and F-22 can play the quarterback role, fusing, processing, and communicating information while also delivering munitions. However, in a high intensity conflict, such a role (specifically munitions delivery) may not be the best use of such expensive and limited assets. Furthermore, as adversary A2/AD and point defense systems become increasingly numerous and capable, larger and larger salvos of missiles will be required to achieve the same effect. So-called arsenal planes could step in to satisfy this need. When armed with long-range missiles, such systems could deliver overwhelming firepower on demand from secure airspace. Furthermore, such systems would substantially reduce the cost of salvos (due to economies of scale) while increasing the percentage of munitions that make it to the target (due to economies of force).[9]

### *Space and C4ISR*

U.S. preeminence in space provides American military forces an overwhelming advantage in C4ISR. Unfortunately current American dominance in C4ISR rests disproportionally on a small number of highly capable but extremely expensive satellites, which can cost upwards of a billion dollars and take a decade or so to design, build, and launch. Increasingly peer competitors are developing the capabilities to neutralize U.S. space assets, at scale. The implication of these developments is twofold. Firstly, U.S. conventional forces must be ready to fight without reconnaissance, GPS, and even possibly communications satellites if need be. Secondly, the U.S. must develop the capability to rapidly, and inexpensively, redeploy space assets as existing systems are attrited. Here again, the private sector is advancing new strategies, and the DoD needs to quickly move to similar approaches.

Historically, developing and launching satellites has been a challenging task, often costing hundreds to billions of dollars, on timelines measured in years. However with continual improvements in and miniaturization of sensors and communications hardware, costs and timelines are quickly shrinking. While there were 730 Earth observation satellites launched over the last decade, it is anticipated that in the next 10 years, nearly three times as many will be launched into orbit. In addition to cameras, these satellites will be equipped with a wide array of sensors that include infrared, hyperspectral, and radar. These small, private sector satellites, cost approximately $3 million and weigh less than 10 pounds, but can produce sharper imagery than the 900-pound behemoths costing hundreds of millions, built in the late 1990s. Firms are launching dozens of satellite, focusing on specific regions or types of data. The large numbers of sensors will produce incredible amounts of data, and advances in AI will allow fusion and analysis of this data at greater speed and greater accuracy (Metz, 2019).

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[9] A major advantage of arsenal planes vs ships is that planes can release their munitions payloads at ~650mph and at 50,000 ft. of altitude. In contrast, ships provide nearly no inertial or elevation endowment to their rocket and missile payloads. This is significant because booster rockets, the systems used to deploy cruise missiles from the Mk 41 and bring them up to cruising speed, are highly inefficient compared to a turbo-fan jet engine and therefore missile salvos with ship launched munitions require 20%-40% more mass to achieve the same affect. Additionally due their speed, bombers have the ability to intrude further into contested spaces without being held at risk by enemy systems, than due ships. (On the other hand, a bomber may be within line of sight of adversary radar installation sooner than a ship would be. This issue however could be mitigated by decreasing altitude as necessary to stay below the adversary's radar's line of sight, at the cost of increased fuel burn and decreased altitude upon munitions release.)

AM is also being used to reduce the cost of launch vehicles. German researchers have developed a reusable rocket engine, designed specifically for the launch of small satellites. The complex injector heads for these engines are “3D printed which unlocks additional performance, reduces the part count, speeds up production time, and reduces weight and costs…thermal, mass and hydraulic performances can all be independently optimized and are no longer contingent on the selected fabrication methods.” The ability to quickly “print” and prototype a variety of designs significantly reduced the development time (Schulz, 2019).

When the cost of producing and launching these critical assets is sufficiently reduced, an attacking adversary will have to expend nearly as much to disable the systems, as they cost to build in the first place. Considering the above, the Defense Advanced Research Projects Agency has multiple projects in the works to meet developing needs for rapidly deployable, cost effective C4ISR solutions. Project Blackjack, for example, seeks to leverage forecasted decreases in the cost of “buses” and launch services to develop networks of smaller, less expensive spy satellites (Wall, 2018).

Of course, at a certain point, LEO (Low-Earth Orbit) may be filled with older on-orbit satellites and increasing amounts of space junk. There are concepts to use low-cost, small autonomous satellites for n-orbit operations. It is envisioned that these small satellite “robots” will be able to autonomously complete complex tasks, such as inspection, repair, and on-orbit assembly of modular systems. Perhaps, most importantly, they could be used for active debris removal, reducing the risk to critical space assets and helping to maintain access to specific orbits. (Nanjangud, et al., 2018).

### *Ground*

According to Pentagon figures, in 2013 alone, some 60 percent of US combat causalities were related to convoy resupply. At the height of the Afghan war, the U.S. was incurring one death or severe injury for every 24-fuel convoys brought in (Army Technology, 2018). While it is not clear if fully autonomous convoys are yet suitable for deployment, Oshkosh Corporation, a major provider of trucks for the U.S. military believes they can take humans out of the loop altogether. Indeed, many major tech companies have had fully autonomous vehicles on the road for years; they have just not been approved to operate without a human observer (Pegoraro, 2019). Advances in AI and machine learning should improve these systems to adapt to new and novel environments from actual experience operating in these situations. The technology also exists, or will soon exist, to develop and deploy armed autonomous ground systems. These introduce a host of policy and ethical issues, which are unlikely to stop adversaries from using them—changing not only the "how", but the "who" of warfighting.

The Army is slowly moving to adopt these systems and expects to begin deploying at scale limited autonomous capability. These are limited to convoys led by a manned truck, followed by up to eight or so autonomous "follower" trucks. Safety certification tests will occur through 2019 and by 2020 the Army expects to have 60 trucks converted "self-driving" status (Freedberg, 2018).

### *Cyber*

In an increasingly interconnected world dependent on electronic systems, cyber vulnerabilities will pose threats and opportunities to both sides. Dr. Martin Libicki, a RAND cyber expert, has defined two types of cyberwarfare: Strategic and operational, with strategic being "a campaign of cyberattacks one entity carries out on another", while operational cyberwarfare "involves the use of cyberattacks on the other side's military in the context of a physical war" (Libicki, 2009). When used in military operations, operational cyberwarfare can be used to replace, support, or amplify kinetic operations (e.g. degrade command and control systems). Strategic attacks, or their threat, may be useful to deter conflict, or used to support a broader military campaign. With a strategic cyber-attack, the objective is to cripple an adversary's banking systems, electricity generation plants and distribution grids, communications networks and so forth to achieve a strategic objective. Today most countries have both offensive, as well as defensive capabilities.

Unfortunately, for the U.S., the dynamic will be asymmetric. Although the U.S. is suspected of having a significant offensive capability, the U.S. and its industrial base utilize a largely open internet while Russia and China are increasingly developing their own closed systems (Jee, 2019). With fewer access points by design, even with superior 'cyber warriors,' the U.S. will find itself in the unusual and unenvious position of being disproportionately vulnerable to adversary intrusions.

If we consider a major conflict with China, a key consideration is that the U.S. will depend on an extended logistics tail, and, in large part, an unclassified logistics network. These will be vulnerable to disruptive attacks, negatively impacting support for military forces. The DoD, along with the country's industrial base actors, must therefore work to counter this developing asymmetric threat by working to implement necessary cyber security defensive measures, to ensure that they will be able to maintain production, and continue to support the forces, in the face of concerted cyber-attack (Ausherman, 2019).

### *Missile Defense*

Effective and economical, short-range A2/AD systems will become increasingly critical as near-peer competitors stockpile missiles. China, for example, can use these to strike out to the second island chain. As Mark Gunzinger highlights, "in future conflicts America's opponents can be expected to employ large numbers of sea-, air-, and ground-launched guided weapons to overwhelm limited defenses now protecting the U.S. military's forces and bases." (Gunzinger, 2016) In such salvo competitions, it is critical that missile defense systems be both effective and sufficiently economical that the U.S. does not have to choose between leaving Pacific Rim bases unprotected and bankruptcy.

An effective, albeit "white knuckle" strategy to keep the cost exchange ratio favorable is to leverage large numbers of smaller, short-range anti-missile missiles. Such systems when combined with forward based sensors; either air, sea, space, or ground based, would greatly reduce the cost of protecting not just high end assets such as air-craft but also supporting infrastructure (Gunzinger, 2018). Additionally, as highlighted above, AM offers the potential to substantially reduce the cost of producing the previously machined portions of a rocket engine. Raytheon and Northrop Grumman for example have recently partnered to produce a scramjet made entirely via AM. Once the bugs are worked out, such production systems will reduce the cost of such engines to just the materials required for constructing the engine and the depreciation/wear and tear on the AM machine (Insinna, 2019). Finally, on the more futuristic side, electromagnetic railguns[10] and directed energy systems[11] (lasers) may revolutionize A2/AD if certain (substantial) technical details can be worked out.

## Barriers to Change

The need for more easily producible, adaptive, and compact weapons systems has been a common theme in acquisitions reform for decades. Unfortunately, high institutional barriers within the acquisitions process impede the Department of Defense in adopting the kind of reforms necessary to produce weapons systems that fit those needs. Three main barriers exist: budgetary inertia, political interests, and cultural resistance to change. In order to create the kind of military that can maintain American battlefield superiority going forward, the DoD will have to overcome these barriers to reform.

### *Budgetary Inertia*

As noted before, the Department of Defense is a large ship, and does not turn easily. Long lead-times for the development of new weapons have long plagued the Department of Defense. Programs develop constituencies in the public and private sectors, and as a result, often continue, notwithstanding, poor program performance or changing mission requirements.

There are the competing priorities and incentives for stakeholders, with varying abilities to influence the regulatory and legislative processes. These stakeholders include Congress, the DoD (and all the subordinate organizations), other executive agencies, government employee unions, major defense contractors, and foreign and commercial firms, all of whom have parochial interests and a variety of perspectives on the best approach to provide for national security. For example, in Congress, Senators and Representatives have vastly different incentives based on who their constituencies are, and the sizes and locations of military and industrial facilities within their districts and states. Additionally, differences arise within the DoD; the services may

[10] Electromagnetic Railguns offer three substantial advantages over traditional artillery; the rounds are smaller, weigh less, have greater range and travel much faster and therefore transfer more kinetic energy into the target upon impact. After spending hundreds of millions of dollars and years of development, the Navy is planning to finally test the electromagnetic railgun aboard a warship. A Critic, Bryan Clark, an expert with the Center for Strategic and Budgetary Assessments and former US Navy officer, argues that the money may be better spent "on missiles and vertical launch system cells than you are on a railgun" (Pickrell, 2019).

[11] Long the domain of science fiction, directed energy or lasers are becoming increasingly effective and in the not so distant future may play a vital role in missile defense. Indeed, in a series of tests on April 23rd 2019 the USAF successfully engaged and destroyed a series of air-launched missiles (Pickrell, 2019).

be at odds over control of resources and program requirements and their impact on service interests and force structures, while civilian leadership within OSD often have different priorities (e.g. the Air Force resisted the introduction of unmanned systems). These barriers often make it difficult to make the necessary budgetary changes.

When a program may no longer be needed or useful, slow changes within the Department of Defense lead to budget inertia, or the repeated funding of programs known to be wasteful or ineffective. This inertia leads to spending on lower-utility systems, cutting into the funds DoD has for adaptation.

### *Political Resistance*

In addition to budgetary inertia, changes to acquisition priorities can be impeded by the parochial concerns of elected politicians. With military bases and contractors in every state, funding for nearly every weapons program is closely guarded by a bipartisan and diverse group of interested politicians. For instance, during the 2011 sequestration fight, Ohio's congressional delegation collectively pushed to save five weapons programs the Department of Defense aimed to cut: the Global Hawk, the C27 Spartan, upgrades to the M1 Abrams tank, funding for the Air National Guard and an East Coast missile defense system. Ultimately, all five programs continued to receive funding (Sweigart, 2012). More recently, Marine Corps General David H. Berger highlighted the extent to which the corps is burdened down by old, decaying, and excess infrastructure:

> "We are encumbered by 19,000 buildings, some of which are beyond the scope of repair and should instead be considered for demolition. These excess structures spread limited facilities, sustainment, restoration, and modernization (FSRM) resources thinly across the enterprise, impeding our ability to focus efforts and achieve desired outcomes." (Berger, 2019)

Yet another political consideration is that while many military planners perceive a future that is more autonomous and less reliant on personnel, services providing for those personnel constitutes a significant portion of the US economy. With a large standing military, the US has committed itself to considerable personnel costs that will only continue to grow. While this may be bad for the military, it may, be good for individual congressional districts. To put this into perspective, personal costs for the U.S. military impose a greater burden on the DoD's budget than procurement and R&D combined (Rugy, 2014). The Military Health System alone is expected to grow to $70 billion, or roughly 10% of the defense budget annually, by 2022.

A recent attempt to bring down personnel costs illustrates how difficult a problem this can be. In 2013, Speaker Paul Ryan forged a budget deal to end 'budget sequestration', which was an across the board cut to discretionary spending passed in 2011 designed to motivate recalcitrant legislators to consider difficult spending reductions. As part of the deal, leaders aimed to maintain deficit reductions while increasing funding for military readiness and modernization, so they proposed a cut to personnel costs. Specifically, the compromise included a reduction in the cost of living adjustment to 1% below the consumer price index for retirees under 62. While the budget compromise ultimately passed, the Senate voted to restore the military benefits less than a year later (Wright, 2014).

### *Cultural Resistance*

Perhaps the greatest barrier to modernizing the acquisitions process for this new age of warfare lies within the military itself. The established norms, practices, and culture of the DoD acquisitions workforce has a direct impact on what weapons we buy and how quickly the military adapts to changing needs. While an acquisitions officer who has spent her career working on the M1 Abrams may wonder, "What should the next generation of tank look like?" A more valuable question might be, "Do we need tanks?"

The mid-90's development of an "Arsenal Ship" as part of the Navy's Surface Combat for the 21st Century (SC-21) initiative is a good example of the effect the acquisitions workforce can have on the development of new weapon system concepts. An arsenal ship is a large capacity missile destroyer intended to replace some of the function of aircraft carriers in a land invasion scenario. The concept arose from a RAND study, which suggested a single ship of this type would significantly reduce the time needed to degrade an enemy's land force vis-a-vis fighter aircraft. Chief of Naval Operations at the time, Jeremy Boorda, championed the idea, suspending the SC-21 program and using Other Transaction Authority to quickly begin design work on a US arsenal ship (Leonard, 1999).

Sadly, CNO Boorda's untimely death in 1996 proved to be dire for the fate of the arsenal ship program as well. In April 1997 the arsenal ship was re-designated the Maritime Fire Support Demonstrator, a mere demonstration of technology for a revitalized SC-21 program. Congress consequently cut funding for the arsenal ship program in October 1997. This did not mean the concept of an arsenal ship went away, however, as China unveiled several arsenal ship concepts of its own in 2017 (Mizokami, 2017).

In addition to the culture of the military workforce itself, wider cultural impediments remain to implement necessary reforms. With the rise of drones and AI, a new question has arisen, "How autonomous is too autonomous?" Russia and China have both experimented with a new and potentially fraught frontier in weapons design: weapons that can kill without human input. These "human out of the loop" weapons systems pose a serious challenge to those trying to plan for a future conflict. Will U.S. forces have the necessary systems to meet these challenges?

As the international community has met twice in 2018 alone under the Convention on Certain Conventional Weapons to discuss lethal autonomous weapons systems, clearly this is an area of international concern (Lawfare, n.d.). Yet the development of these systems continues, while efforts to ban them have stalled, with a resolution calling for further regulation blocked by Australia, Israel, Russia, and the U.S. Russia in particular has spent considerable resources on lethal autonomous weapons (LAWs), including autonomous assault vehicles and fighter aircraft. While China did not block the resolution, China's military is rushing to use artificial intelligence for military purposes as reported by MIT's Technology Review (Knight, 2019).

## Enablers

While the barriers described above should not be ignored, other advancements in the acquisition environment can enable the kind of modernization required for future conflict scenarios. These 'enablers' should not be seen as direct answers to the barriers described above, but are instead, new developments in the acquisitions process that can help advance the future of easily producible, adaptive, and smaller weapons systems. They include advancements in the design and manufacturing processes that will greatly reduce the time required to bring weapon systems from concept to combat.

The process of designing, manufacturing and sustaining weapons systems has changed substantially in the past hundred years, and the maturation of cutting edge technologies promises to transform this process yet again. The advent of AI, robotics and augmented reality (to name just a few promising technologies) provide industrial partners new tools to reduce labor and capital costs associated with the creation of new weapon systems. In addition, these new weapons systems have the potential to be easier and cheaper to sustain and operate. Such savings of time and money will prove essential to creating the lighter, more adaptive military envisioned above.

### *Design Processes*

The process for designing and testing new weapons systems can be extremely slow. It can take years, or even decades, from when a military need is identified to the testing of a working prototype; a major contribution to budgetary inertia. Acquisitions professionals have tried to shorten this process using special authorities and creative contracting types, with some success. Recent technological advancements in AI and 3D printing, however, promise efficiency gains that were previously unimaginable.

The weapons design process of today is faster than fifty years ago, thanks to ever more advanced and digital forms of CAD. However, these processes still rely on the human element. AI applications in the design process will likely reduce some of the more laborious components of design. AI design will give engineers the ability to create, prototype, and test a nearly infinite number of possible designs, without ever actually producing a physical version. Using digital environments that replicate real world conditions, prototypes can be tested and iteratively improved. This will reduce the more repetitive aspects of design and therefore allow top-tier engineers to focus on high-level conceptual innovations rather than endlessly iterating CAD designs.

While AI is often trumpeted as the future of everything, AI assisted design is happening now. A French company, Neural Concept, has developed a machine learning system capable of developing an intuition about the laws of physics (Baque, 2018). They were able to use this software, in conjunction with a team of researchers at IUT Annecy, to create an optimally aerodynamic bicycle with which they aim to set the world speed record (Dvorsky, 2018). While this software isn't ready to design fighter jets from scratch, it is not hard to envision a future version determining optimal wing, body, and engine configurations for drones and cruise missiles.

Of course improvements in AI assisted CAD doesn't mean prototyping and live testing will go away, nor should they. Testing equipment in field conditions will always be an essential part of weapons design and the maturation of additive manufacturing is already making this process easier and cheaper. AM is not a new technology and using it for full-scale production has significant barriers to implementation. Nonetheless, given the economy of scope provided by the technology (the ability to make various different objects without significant retooling), using AM to build prototypes allows designers to consider and test a wide variety of ideas with little actual investment. The unifying theme across both of these technologies is that they take some of the burden off of human acquisitions and weapons design professionals. Ultimately a completely closed system could take weapons requirements, design a variety of systems optimally capable of meeting those requirements, and producing prototypes for consideration and field-testing.

### *Manufacturing Processes*

The production process for weapons systems should move in a similar direction, with less (and smarter) human input and more adaptable production processes. The use of advanced robotic manufacturing processes gives defense partners the ability to build systems with a level of precision human workers are incapable of, and at scale. Furthermore, new technology can make teaching new production techniques and weapons systems to industrial workers effortless.

Robotic manufacturing has been around for decades; in fact, the default image of an American car factory could arguably be banks of robotic arms lining a conveyor belt. But technological advances have opened the door for the use of robots in a wide variety of manufacturing processes, with all the attendant savings in labor costs, retooling, and manufacturing precision. While a plant up until now has had to maintain a large human workforce for specific, important tasks, new factories are able to be nearly 100% automated. BMW's Spartanburg, SC factory is one recent example, with every step in the process, every weld, bolt and assembly process fully automated (J.C, 2012). Increased use of robotic manufacturing processes should bring those same savings in manpower and retooling costs to the defense industry.

Technological advancements should also enable significantly faster training times for the workers that remain. The Microsoft HoloLens 2, just unveiled at E3 in March 2019, demonstrates a future of augmented reality training. Workers in this future would be given a pair of glasses, and, with the assistance of holograms imposed over the real world, trained in any construction method without a human instructor. This technology has tremendous implications for sustainment as well, as technicians in the field could follow step-by-step instructions to maintain and use weapons systems, without an industry consultant. Creating the individual programs required for this style of training remains a challenge, but it is one industry partners can surmount: the HoloLens 2 is commercially available for $2,500 per headset (Bohn. 2019).

As noted above, additive manufacturing at scale faces some serious limitations. If implemented, the potential savings and economy of scope would allow for versatile factories located virtually anywhere, capable of producing a large variety of components, when supplied with the necessary technical data and the right mix of basic materials and AM machines. Issues with data security, intellectual property, and institutional opposition to the implementation of AM, however, remain major impediments to implementation.

### *Sustainment Improvements*

The emerging technologies discussed above will also have dramatic impacts on weapon system sustainment. Reducing and improving maintenance will act as a force multiplier. AI and AM are poised to revolutionize sustainment in the near term.

AI promises to improve planning, accelerate the implementation of prognostics health management, and reduce the man-hours spent on administrative tasks. Prognostics health management has two noteworthy benefits. When maintenance personnel can anticipate a component failure, they can preemptively replace it, improving the system's operational availability. Second, it will reduce, what may occasionally be, unnecessary preventive maintenance. AI can also be applied to improve supply chain management, to help with forecasting within inventory demand and supply, improving agility, and optimization of supply chains.

AM has the potential to dramatically shorten (and shrink) supply lines. With conventional production processes, parts are produced centrally, stockpiled, and distributed to depots around the world where they are stored until needed or disposed of. Aside from the administrative burden posed by the system, in an actual combat situation, the longer your supply lines, the more vulnerable your front line forces are of being starved of critical resources. Furthermore, AM also holds promise for peacetime operation and maintenance. Legacy systems, for example, are at times decommissioned before the end of their functional lives, due to depleted supplies of replacement parts and the excessive expense of restarting an assembly line. Recent accomplishments, particularly the first use of an AM part printed in the field, and the Navy approving its one thousandth AM part for use; show that this future is steadily advancing (Lai, 2018). In a similar manner, when developing new systems is considered, potential sustainment savings will come from simply reducing the number of parts in the first place. AM allows for the creation of seamless, highly complex and structurally resilient forms. With fewer parts, there are fewer potential failure points.

# Conclusion

There are many factors that are driving changes in the twenty-first century security environment. While at present the United States continues to maintain a significant military advantage in the world, we should not assume that this advantage would last forever. More importantly, our historic approach to industrial mobilization will be inadequate in the face of the emerging great power competition. Today's weapon systems are orders of magnitude more complex, the defense industrial base is globally dispersed, and the commercial sector continues to lead in the development of disruptive technologies. We believe the DoD must adapt to these changes and leverage the strengths of the nation's industrial base and commercially developed technologies to create weapon systems that can be produced quickly, are affordable, and can maximally leverage the existing, innovative commercial industrial base.  These changes will improve the nation's ability to mobilize by leveraging the entire industrial base.  This in turn will help to ensure victory, and consequently improve the deterrent effect of the our convetioninal military forces.

However, failure to take the necessary decisive actions may result in the loss of our national prestige, and, in the worst case, American lives and lost treasure. Prudent planning and vigilant leadership will be necessary to ensure the necessary steps are taken to provide for U.S. national security needs throughout the century—we have the means to do it, now we only need the necessary political will.  The nation deserves no less.

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