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The US Department of Defense should prioritize the acquisition, development, and fielding of a military force with a logistical tail idealized for rapid movement and adaptability over other aspects of combat capability. As part of this philosophical change, the US military should more thoroughly embrace the theories of John Boyd, and a concept of Logistical Maneuverability that marries the tactics, techniques, and procedures of efficient and adaptable logistics with a new method of engaging an adversary. This paper proposes that the logistical 'tail' that supports operations can stop being a weakness for a military, and become an area where US forces gain initiative and advantage over an adversary.

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MASTER OF MILITARY STUDIES

LOGISTICAL MANEUVERABILITY: TACTICS WINS BATTLES, LOGISTICS WINS WARS

SUBMITTED IN PARTIAL FULFILLMENT
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Executive Summary

Title: Logistical Maneuverability: Tactics Wins Battles, Logistics Wins Wars

Author: Major Timothy J. Lundberg, United States Air Force Reserve

Thesis: The US Department of Defense should prioritize the acquisition, development, and fielding of a military force with a logistical tail idealized for rapid movement and adaptability over other aspects of combat capability.

Discussion: Since the beginning of the buildup for World War II, the United States has proven that it can move men and materiel in sufficient quantity to win a battle anywhere on Earth. However, this paper will argue that too much blood and treasure is spent to resupply the military and that a more capable system of supply regeneration is needed. This more capable system of supply regeneration system will decrease vulnerability for American troops while supporting greater maneuverability for operational units across the range of military operations. Fundamental to this transition is the need to determine the current cost of supply regeneration, in both blood and treasure. Right now, the US military does not even know the full nature of the problem it has, let alone what it will take to fix the problem. While there are mental and financial costs associated with transitioning to a supply regeneration system as part of Logistical Maneuver any mental costs serve to improve the US military's capabilities while decreasing its vulnerabilities. Furthermore, this paper will show the economic costs are short term while generating a long term positive returns on investment.

Conclusion: Logistical Maneuverability is about setting the conditions for victory, before and during a conflict. Fundamentally, it is designed to create both a peacetime and wartime advantage over an adversary. The case study of MacArthur in the Philippines showed that he failed to establish an advantage before the conflict began because of an ill-fated decision with how he positioned his supplies. This highlights that a commander must consider not just the combat power of a military unit, but how that unit will sustain itself in favorable or unfavorable conditions. The descriptions of system theory along with Boyd's E-M Theory are intended to present a point of reference for methods to quantify different types of supply regeneration. With such quantified data, the analysis of KPPs and balancing tradeoffs between areas like for protection and energy use will have greater importance for how future weapon systems are designed to work with the US military's legacy systems. Logistical Maneuverability can enhance how America equips, employs, and sustains its military at the tactical, operational, and strategic levels of warfare. It is designed to give a commander a suite of options wherein they can use both their intuition and hard data to view and determine the best way to build and employ a force capable of surviving and winning in today's A2-AD environment, or in a future environment.

Table of Contents

Page

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"Maneuver—A mental approach to conflict, born of opportunism, variety, and cunning, by which we create and exploit advantage as a means for success by creating a rapidly and continuously changing situation in which our enemy cannot effectively cope. We do this by focusing strength against critical enemy vulnerability, generating superior speed and distracting or disorienting our foe through ambiguity or deception." --Major John Schmitt, USMC[1]

INTRODUCTION

The word "logistics" is derived from the Greek adjective logistikos meaning "skilled in calculating." Its military application is equally ancient as the etymology. Throughout history, victory in battlehas often been determined not by strength of arms, military genius, or technological advantage, but by logistics. A military with a plan for efficiently obtaining supplies moves more quickly than a military with an enormous baggage train. Such a force defends in greater depth along multiple avenues of approach, attacks more ferociously, and finishes a fight while the poorly supplied side struggles to survive. Logistical Maneuverability embodies this crucial relationship between logistics as a form of calculating and maneuver warfare as a method of creating a cognitive and temporal advantage.

Any commander will understand the need for logistics to support operations once combat has begun, and this paper will detail how the United States can do much better at that task. But Logistical Maneuverability is also the notion that one can gain a temporal and mental lead over an adversary before combat begins, to the extent of deterring combat while achieving a political goal. Logistical Maneuverability supports a military force's ability to be present in a variety of sizes and configurations at a time and place of America's choosing. It supports the force's ability to sustain itself during a siege, or to appear and disappear from an adversary's awareness for as long as needed. Logistical Maneuverability supports operations for a special operations team, an amphibious assault group, or a mega-base like Bagram. Ultimately, Logistical Maneuverability provides the US military with initiative and options for the range of military operations, while presenting an opponent with problems and dilemmas with which they cannot cope.

Even in eras of relative stalemate between opposing armies, an advantage in supply may give one army an operational edge; see, for example, the Roman legions after the Marian reforms, or Napoleon's *Grande Armée* taking advantage of potato crops. The effects are sometimes decisive. However, few nations seem to focus on gaining this advantage and often concentrate on attrition in search of a decisive battle. Military planners instead often show a fixation with the newer sword, or the faster airplane; rather than with the question of how to get more food and fuel to the point where it is of greatest import. Indeed, famous American generals like Douglas MacArthur or Robert Lee saw tactical and operational victories rendered inconsequential when they lost the ability to move the materiel their forces needed to the decisive point of the battlefield. The US military cannot afford to continue forfeiting this advantage, particularly in a future operating environment of constrained resources and neer-peer adversaries.

The US Department of Defense should prioritize the acquisition, development, and fielding of a military force with a logistical tail idealized for rapid movement and adaptability over other aspects of combat capability. As part of this philosophical change, the US military should more thoroughly embrace the theories of John Boyd, and a concept of Logistical Maneuverability that marries the tactics, techniques, and procedures of efficient and adaptable logistics with a new method of engaging an adversary. With logistical maneuverability, the logistical 'tail' that supports operations can stop being a weakness for the military, and become an area where US forces gain initiative and advantage over an adversary, setting the conditions for ultimate victory.

FRAMING THE PROBLEM

Few nations seem to focus on gaining logistical maneuverability; many concentrate on a battle of attrition in search of a decisive battle. Rather than focusing intellectual energy on logistics, history instead shows a fixation with the newer sword, or the faster airplane; not how to get more food and fuel to the point where it is of greatest import. Indeed, famous American generals like Douglas MacArthur or Robert Lee saw tactical and operational victories rendered inconsequential when they lost the ability to move the materiel their forces needed to the decisive point of the battlefield.

Since the beginning of the buildup for World War II, the United States has proven that it can move men and materiel in sufficient quantity to win a battle anywhere on Earth. However, this paper will argue that too much blood and treasure is spent to resupply the military and that a more capable system of supply regeneration is needed. This more capable system of supply regeneration system will decrease vulnerability for American troops while supporting greater maneuverability for operational units across the range of military operations. Fundamental to this transition is the need to determine the current cost of supply regeneration, in both blood and treasure. Right now, the US military does not even know the full nature of the problem it has, let alone what it will take to fix the problem. While there are mental and financial costs associated with transitioning to a supply regeneration system as part of Logistical Maneuver, any mental costs serve to improve the US military's capabilities while decreasing its vulnerabilities. Furthermore, this paper will show that the economic costs are short term while generating a long-term positive return on investment.

With respect to financial costs since at least 2007, the Department of Defense (DoD) has required new acquisition programs to analyze key performance parameters (KPP) for weapon systems.[2] KPPs for weapon systems include areas like force protection, survivability, net-ready, sustainment, and energy efficiency. Unfortunately, the DoD currently focuses many of its energy efficiency programs on continental US (CONUS) infrastructure (installations) instead of weapon systems.[3] The author contends that in a future conflict, inefficient supply regeneration will make US military forces too slow and too visible for a broad range of anti-access area denial (A2-AD) systems likely to be fielded by numerous competitors. The US Army's Chief of Training and Doctrine Command, General William E. DePuy, recognized in the 1970s that on a modern battlefield "what can be seen, can be hit. What can be hit can be killed."[4] While the stand-off distances and hardening of contemporary overseas bases typically provided sufficient security, modern A2-AD systems, along with non-state actors like ISIS fielding weaponized drones, present a rapidly diminishing security for expeditionary forces and military bases. Furthermore, the ever-increasing maintenance cost of modern weapon systems first recognized by Franklin "Chuck" Spinney in *Defense Fact of Life* in 1980 seem to indicate that we cannot build our way of this problem as the United States was able to in World War II.[5] This will place continued pressure on the DOD to maximize the value and maintenance efficiency of any weapon system procurement. Logistical Maneuverability is an action that the United States can take now to create a future force that can live with the budget and operational realities likely to be seen within the next twenty years.

To fully explain Logistical Manueverability, this paper focuses on several areas. First, a case study of General Douglas MacArthur's Defense of the Philippines at the beginning of World War II highlights that once an army finds itself at a disadvantage with logistical resupply, it falls ever farther behind an adversary until it is destroyed. Next, a discussion of system theory, one of the cognitive keys to Logistical Maneuverability, which shows that efficiency alone does not necessarily lead to an advantage. Following that, this paper studies John Boyd's Energy-Maneuverability Theory and how it allowed military professionals to focus on aircraft performance trade-offs that created aircraft more able to fight and win, not just technology that was "bigger-higher-faster-farther."[6] Finally, this essay will describe the core of Logistical Maneuverability as a cognitive way to compare supply regeneration methodology to support military operations and discuss how future work will allow a quantitative analysis as well.

LITERATURE REVIEW

As the goal of this paper is to advocate for a US military able to operate with a greater maneuverability and logistical capability than it currently operates with a broad range of source material was consulted. The cognitive scope, processes, and data for this essay were derived from relevant literature in system theory, decision-making processes, the works and theories of John Boyd, the United States Marine Corps maneuver warfare philosophy, and contemporary 'green' technologies combined with the concept of the fully burdened cost of energy (FBCE). This literature review is not intended to operate as a thorough review of each of these areas, but to describe the origins of the model proposed by this paper to reconsider how the US military goes to war.

First, system theory provides an overarching framework within which logistical maneuver must lie. Robert Jervis' *System Effects: Complexity in Political and Social Life* provides an understanding of the fundamentals of human-based system and numerous historical examples of unintended consequences, or cascading effects of decisions. James Gleick's *Chaos* details how simple mathematical equations can produce incredibly complex outputs, outputs that can still contain discernable patterns if viewed from the correct vantage point, especially the 'strange attractors' of patterns that form in otherwise random systems. Information about decision-making was obtained from Lieutenant General Paul K. Van Riper, USMC, *An Introduction to System Theory and Decision Making* and Daniel Kahneman and Gary Klein's article *A Failure to Disagree.*

Centrally located in this literature review and central to the theory of logistical maneuver are the works of John Boyd. As Boyd published relatively little, it is necessary to approach his briefings and published works through his biographers. Robert Coram's *Boyd: The Fighter Pilot Who Changed the Art of War*, provides an excellent understanding of Boyd's thought processes and especially how Energy-Maneuverability Theory altered the paradigm of aircraft design and dogfighting. Next, Grant T. Hammond's *The Mind of War: John Boyd and American Security* provides much greater depth and breadth behind the intent and impetus of Boyd's work. Finally, Frans P.B. Osinga's *Science, Strategy and War: The Strategic Theory of John Boyd* serves as a guide through Boyd's seminal collection of briefings. Much of the model postulated by this essay draws heavily on Boyd's conclusions in *Patterns of Conflict* and *Conceptual Spiral.* However, those two briefings serve as the launching point for the concept of Logistical Maneuverability as Boyd detailed that logistics were essential to maneuver warfare, but neglected to detail how logistics enable victory. Furthermore, where Boyd describes historical examples of how maneuver and superior decision-making lead to battlefield victories, this essay shows an example of how improperly designed logistics can lead to defeat.

For this essay, background on how the USMC practices maneuver warfare as a philosophy and a cognitive process is drawn from *Fleet Marine Forces Manual 1 – Warfighting*. The fundamental nature of applying strength against an enemy's weakness and altering their ability to perceive the world accurately underpins the nature of Logistical Maneuver. Much as the Marines operate from the air, land, and sea, this essay advocates both adaptability and appropriateness.

Where the previous areas of this literature review describe methods of perceiving and interacting with the world and competing against an enemy, the final area provides the 'what' of Logistical Maneuver. Specifically, it covers literature about modern technological advancement in areas like photovoltaic cells, atmospheric water extraction, atmospheric carbon extraction, alternative methods of producing hydrocarbons, 3D or additive printing, microgrids, and regenerative electrical production among numerous other areas. Additionally, papers detailing methods and techniques of determining the FBCE for military operations were compared with DOD instructions and requirements for key performance parameters.

When delving into any of these areas, what quickly becomes apparent is the sheer volume of information, techniques, and technology that is available. Therefore, the author did not intend this literature review as a definitive description of what is available, but instead a snapshot indicating the sources that have been consulted to understand what is available now, and what is likely to be available in the future. The US defense of the Philippines in 1941 and 1942 presents an excellent case study to understand the importance of sufficient supplies on military operations, and the dangers of decision-making outpacing supply reality.

CASE STUDY: THE FALL OF THE PHILIPPINES IN 1942

As the Japanese Empire in the 1930s and 40s sought to secure guaranteed access to the raw resources and manpower to gain hegemony over the Western Pacific and Southeast Asia. US military forces on the Philippines represented a direct threat to Japan accomplishing this goal. So as part of a coordinated, multi-pronged attack on numerous locations throughout the

Pacific on December 7, 1941, Japan sought to remove the United States and other European colonial forces from its sphere of influence in a single campaign. The loss of Far East Air Force and US naval forces in the vicinity of the Philippines during the campaign caused a rapid degradation of US and Philippine combat power. However, the author does not agree with MacArthur that the loss of combat aircraft and naval ships was the primary reason for the eventual surrender of US and Philippine forces in June of 1942.[7] Instead, the author proposes that if MacArthur's forces had retreated to Bataan with sufficient food and ammunition, they could have held out against the Japanese for much longer than the six months they managed. It is even possible that the forces on Bataan could have held out until they were relieved by a rebuilt US Pacific Fleet in 1943 or 1944, if the supplies available to MacArthur before the conflict started had been correctly used.

There were three primary contributing factors to the American defeat in the Philippines. First, the Japanese destroyed the US fleet at Pearl Harbor before it could battle its way to, and then relieve, the Allied forces in the Philippines. Second, the Japanese quickly and simultaneously seized significant territory in Southeast Asia, eliminating all possible lines of communication or resupply for the Philippines. Finally, MacArthur's attempt to fight at the shore of Luzon, instead of using the pre-existing plan to fight a mobile battle and then retreat to Bataan, ensured that sufficient and necessary supplies were not available for the besieged forces at Bataan and Corregidor.

The US plan for the defense of the Philippines was War Plan Orange-3 (WPO-3), from the joint Army-Navy Orange plan of 1938.[8] While the plan may have been strategically outdated due to the realities of Japan's territorial conquests in Southeast Asia in 1941, the plan remained a tactically and operationally sound document for the defense of the Philippines.[9] The plan called for a defense of central Luzon, the largest and one of the northernmost of the islands in the Philippine archipelago, with a retreat to and a defense of the Bataan Peninsula. From there, American and Philippine forces would hold out for the six months WPO-3 expected it would take the US fleet to battle its way from Hawaii across the Pacific to relieve MacArthur's force.

The importance of Bataan lies in its geography and terrain. The Bataan Peninsula is approximately ten miles across and juts south thirty miles from the northern shore of Manila Bay. Two mountains, Mount Natib and Mount Mariveles, dominate the Bataan Peninsula and shield Manila Bay to create one of the best natural ports in South East Asia. The terrain of the peninsula is steep and rugged, with jungle canopy cover on volcanic soil. It is ideal for a defensive force and an imposing terrain for any attacking force. The opening of Manila Bay at the southern tip of the peninsula is approximately twelve miles across, therefore whoever controls Bataan controls access to Manila Bay completely. Bataan was correctly chosen as a bastion for American and Philippino forces, as it presented a natural fortress that could have provided a much more resilient defense if properly used by MacArthur. While the original plan called for a somewhat passive defense of Luzon and a strategic retreat to Bataan to hold until relieved by naval forces, MacArthur felt that if he was properly equipped and supplied he could repulse Japanese landings with an active defense.[10]

MacArthur assumed the position of Military Advisor to the Commonwealth Government in 1935 after his tenure as the Chief of Staff of the Army, and at the personal request of the President of the Philippines, Manuel Quezon.[11] MacArthur's initial plan was to create a nation capable of its own national security by 1946 when the islands were scheduled for independence from the United States.[12] From 1935 until 1940, MacArthur oversaw the creation of the entire Philippine force, such as managing the construction of training camps, establishing training regimes, and everything else that was required to create a military force from scratch. Unfortunately, by July 1941, world events had outpaced MacArthur's initial plans and the United States had to decide whether to defend the Philippines or leave them to their own devices after the Japanese invasion of China.

President Franklin D. Roosevelt's administration decided to defend the Philippines following a request from MacArthur and the US government's desire to keep its Chinese and remaining European allies invested in the defense of South East Asia. As part of this program on July 17, 1941, MacArthur was returned to active duty in the US military and reassigned as the commander of Army Forces in the Far East.[13] From mid-July to December 8, 1941, the United States would commit all of the personnel, materiels, and perhaps most importantly, shipping it could to build the Philippines into a redoubt against the Japanese so that the United States could gain the time it needed to complete a nation-wide rearmament. As forces and equipment flowed to the Philippines, MacArthur altered the plan for the Philippines from a defense and retreat to Bataan to an active defense at potential Japanese landing sites that would rely heavily on the P-40 and B-17 aircraft arriving on schedule. Combined with a full mobilization of the Philippine forces that MacArthur had trained over the last five years, he and the US military leadership felt that the Philippines could defeat a Japanese attack by April of 1942.[14] As a comparison for how the United States prioritized the defense of the Philippines, by December 1, 1941, there were 277 aircraft assigned to the Philippines, almost twenty percent more than the 231 stationed on Hawaii.[15] Additionally, a garrison of 31,000 American personnel were stationed in the Philippines. Combined with native Philippine forces, MacArthur had more than 110,000 men available for duty by the beginning of December.[16]

Against MacArthur's forces, the Japanese initially assigned a mix of 500 bombers and pursuit aircraft along with around 130,000 men for the assault and capture of the Philippines. The Philippines was part of the Japanese' larger, synchronized attack on the US, British, and Dutch forces throughout Southeast Asia. On December 8 (December 7 in the United States on the other side of the International Date Line), Japanese troops attacked Malaya, Singora, Singapore, Guam, Hong Kong, Wake Island, the Philippines, and Hawaii.[17] Most of the Japanese attacks were overwhelmingly successful with significant damage done to US Army Air Forces in Hawaii and the Philippines, along with significant damage to the US battleship fleet at Pearl Harbor. Much as on Hawaii, US aircraft were caught on the ground in the Philippines and eliminated as an effective fighting force during the initial Japanese attack. These synchronized attacks served to destroy most American and Allied combat power along with cutting off almost all lines of communication and supply for the Philippines.

MacArthur's ill-considered repositioning of his forces to prevent Japanese beach landings, combined with the overwhelmingly successful initial Japanese air attacks, gave the Japanese an operational and temporal advantage in the Philippines that the United States could never overcome. Furthermore, with the US battleship fleet in flames at Pearl Harbor, the United States had no forces capable of fighting their way through the Japanese Navy to resupply or relieve US troops in the Philippines. Over the next month, the Japanese used their air supremacy to degrade US defenses and force the defenders into the Bataan peninsula. Because MacArthur changed the plan for the defense of the Philippines, large stockpiles of food and ammunition were dispersed throughout Luzon instead of pre-positioned on the Bataan peninsula. It proved impossible for American and Philippino forces to fight a contested withdrawal while bringing along the various supplies they would need to the Bataan peninsula.

This last point illustrates the operational failure of MacArthur's plan for an active defense of the Philippines. By March or April of 1942, MacArthur may have been able to strike and defeat the inbound Japanese forces, and then repel any that made it ashore. However, by dispersing his troops in November and December, before he had built up sufficient combat power to enact the active defense plan, he presented a too-weak defense against the Japanese. While MacArthur could not have anticipated losing his entire Air Force in a single day, the Japanese had sufficient airpower in the area, almost a two to one advantage, to rapidly destroy his air forces even without catching the bulk of US Air Forces on the ground.

Having retreated to Bataan with its weak defenses and shortage of supplies, the US and Philippine forces were unable to gain the initiative over the Japanese assaulting forces. Upon their retreat to Bataan, the United States and Philippine forces had to go on short rations to stretch their meager supplies as long as possible. With too few calories available, MacArthur's forces were unable to build up their defenses to withstand Japanese air attacks and then counter-attack the initial Japanese land-based assaults that were repulsed. Even with this handicap, the United States and Allied forces were able to maul the first Japanese assault attempt, even with Japanese air superiority, but they lacked the caloric reserves and materiel to counterattack the Japanese troops. Therefore, the Japanese could retreat, maintain a siege perimeter, and build up combat power to assault MacArthur's forces at a time of their choosing. After the Japanese had been compelled to retreat, MacArthur's short-rationed forces could not take full advantage of the lull in Japanese attacks to build in-depth defensive positions as they lacked the caloric energy. This negative feedback loop continued for the Allied forces as they suffered greater casualties from Japanese air power than they might otherwise have if they had better entrenchments, decreasing their defense combat capability when the Japanese ground assaults resumed.

However, even under these conditions, American troops on the Bataan Peninsula and Corregidor (a fortified island just south of the peninsula) held out for 100 days and six months, respectively. They fought valiantly and defeated numerous Japanese attacks, which forced the Japanese to move additional and unplanned personnel and materiel to the Philippines. Despite the loss of US Army Air Forces and Naval assets in the Pacific, US forces on the Philippines, underfed and undersupplied, held the Japanese off for months.

The American and Philippine forces found themselves in a negative supply feedback loop from which they could not escape. If MacArthur had maintained the 1938 WPO-3 to retreat to Bataan, and had he perhaps built some initial fortifications and necessary supply depots on Bataan to support WP0-3 adequately, the defensive force there could have held out against the Japanese for years instead of weeks. Based on the amount of combat power that was ultimately required for the Japanese to defeat US troops, it seems likely that unless Japan committed truly overwhelming forces to its assault on Bataan, a well-supplied US military taking advantage of the imposing terrain of Bataan would have been much harder to defeat. Much as the Japanese island defenses were able to exact heavy tolls on US forces fighting their way westward across the Pacific, it appears probable that US and Philippine forces could have exacted similar or greater losses against the Japanese during the defense of the Philippines.

If Japan had sent more troops or set up a counter-siege of Bataan, it would have had to alter its deployment of personnel throughout South East Asia to contain the forces on Bataan. Even if the Japanese had chosen to cease their assaults on Bataan and establish a siege line, the loss of access to Manila Bay and the presence of a foreign force they could not defeat in the heart of their "Greater East Asian Co-Prosperity Sphere" would have been a powerful inspiration for resistance throughout South East Asia. Only overwhelming Japanese force, of a ration of four or five to one, would have been sufficient to dislodge well-supplied US and Allied forces on Bataan. Furthermore, with Bataan blocking Manila Bay and therefore much of Luzon from providing any support to Japan, a different war, one much more advantageous to the United States, may have unfolded in the Pacific between 1941 and 1945.

This case study highlights the paramount importance of properly supplying a military force to accomplish its mission as well as providing supplies that are capable of supporting a rapidly changing situation. By not stockpiling supplies in Bataan, MacArthur's combined US and Philippine forces were unable to hold off the Japanese. This led to the deaths of tens of thousands of US and Philippine personnel, and likely extended the war in the Pacific. This case study also highlights that great generals like MacArthur can make ill-fated decisions regarding logistics that they cannot overcome, no matter how skilled they are in the art of war.

The counter-factual 'what if' regarding MacArthur's choice not to pre-position supplies on Bataan depends on the proposed scenario playing out in a predictable manner. Obviously, it is impossible to know what might have happened if MacArthur had chosen differently. However, imagine for a moment another hypothetical situation, where in reaction to MacArthur's decision to create a more active defense, the Japanese felt they had to attack sooner than they otherwise would have, because given enough time for American forces to complete a more active defense, the Japanese knew any assault on Luzon would fail. So, while MacArthur may have made the right choice based on how he perceived the situation, the unpredictability of an adversarial human actor responds to his choice and takes advantage of the fact that Japan had a much shorter line of communication with the Philippines than MacArthur did from the United States. That cognitive interplay between move and countermove shows that warfare must always be viewed not as a linear system with predictable outcomes, but a non-linear system where the choices one makes generate unpredictable outcomes. However, a commander can still anticipate how to create a favorable outcome if they have an understanding of system theory.

SYSTEM THEORY AND THE SECOND LAW OF THERMODYNAMICS

Any time a military actor or asset consumes or regenerates energy more efficiently, only a brief window of opportunity exists to exploit the savings before the productivity dissipates.[18] Though seemingly pessimistic, that observation does not mean one should not try to become more efficient. On the contrary, if one uses system thinking to model the process, the competitive value of gaining efficiency becomes strikingly apparent. For example, when a military base achieves an efficiency, it may allow a commander to realize the benefits in a manner that improves the odds of survival for the base while it enhances the capacity of other areas in the base. Therefore, supply and logistics are an avenue to gain an operational advantage with system thinking

Just what is system thinking? It seems appropriate to start with an analogy. It is hard to explain what war is like to someone who has never been in a war. One can describe the danger, the weather, the sequence of events, and the sights and smells, but there is always something missing from the story. In any area of human endeavor, but in war especially, a truth exists that is different from the sum of the parts. That is what a system is, something one often understands only by participating in the system. Understanding a system is not just a matter of knowing or experiencing its parts; it is also appreciating that when one part of the system changes, the change propagates and ripples throughout the system in a manner defying mathematical predictability. As one thing changes in a system, the rest of the system does not remain constant.[19] One cannot describe in a war story the reality of all those parts interacting with each other. Therefore, system thinking means understanding that one cannot just learn about the parts of something and expect to know the whole of something. One must comprehend the parts, their relationship to one another, and finally the fact that "the whole is *different from,* not *greater than,* the sum of the parts."[20]

A military base's consumption and regeneration of energy is a problem rich with potential for an operational approach to such system thinking. First, a military base does in fact constitute an interactively complex and nonlinear system. People, equipment, an electrical grid, a perimeter fence, a flight line, and a tactical operations center are all parts of a base, but they are not what the base is. How the elements of the base interact with each other is what make the base militarily effective, because that interaction allows the base to accomplish a mission; that effectiveness is the whole that is different from the sum of the parts. Next, what happens as those parts interact? Every interaction on the base, between all those parts, consumes energy. Imagine for a moment that a discrete amount of potential energy exists at the base each morning. As the base accomplishes its mission during the day, some amount of that potential energy (PE) transfers to kinetic energy (KE). The base consumes, or transfers, PE to accomplish its mission with KE. A military act (MilAct) occurs with each small, individual mission accomplishment. Patrolling on foot, flying an aircraft, using a computer while sitting at a desk, manning a checkpoint, eating food, sleeping, firing an artillery piece: these are all MilActs and involve the transfer of one form of PE into a form of KE, or vice versa.

Given this consumption of energy to accomplish a MilAct, how does a base regenerate energy? Quite simply the base itself does not regenerate energy; it cannot. To increase or regenerate energy, a base must receive PE from outside the closed system. This requirement follows the Second Law of Thermodynamics, which states that in any closed system (such as a military base), entropy or chaos increases without the application of external energy.[21] If a person becomes a closed system and does not take in additional food, water, or oxygen, their entropy increases until they die. This is not a positive outcome for either the metaphorical person or the military base; thus, it is imperative to understand how best to get outside energy to the base.

External energy arrives in five different forms: foraging, resupply, on-site production, reduction, and recycling. Now some of those methods—on-site production, reduction, and recycling—do not sound like external means. However, a base can use these methods to capture PE that is otherwise not obtained; thus, increasing the PE of the military base. For example, a base can set up equipment to harvest sunlight and atmospheric water vapor and produce electricity or potable water. Furthermore, an analysis of energy use reduction indicates that reducing the amount of PE converted into KE—while still accomplishing the same MilAct—creates 'bonus' PE.

To start, the base consumes PE to accomplish a MilAct. Therefore, PE transfers into KE, or:[22]

$$Total\ Base\ (PE)_{current} - MilAct(PE) = Total\ Base\ (PE)_{new}$$

When 'reduce' decreases the amount of PE subtracted by the MilAct, then:

$$Total\ Base\ (PE)_{current} - \big(MilAct(PE) - Reduce(PE)\big) = Total\ Base\ (PE)_{new}$$

Hence, by diminishing the energy being consumed 'reduce' increases the amount of total base PE still available after the MilAct.

However, so far this formulation only represents linear thinking, not system thinking. The equations show that 'reduce' removes slack, or inefficiency; thus, in engineering terms, it "optimizes" the system. Optimization assumes a predictable outcome in a system, but applying system thinking means anticipating how this change in energy transfer propagates throughout the military base system in unexpected ways. For example, imagine a base commander was having difficulty with potable water availability and thirsty troops and determined he could save water for drinking by decreasing the amount of water used in showers. In this example stored water represents PE, a soldier taking a shower using ten gallons represent a MilAct. If 'reduce' saves five gallons of water, then the base has an additional five gallons of water to use for something else. Fantastic for the base, but with a system view, one can anticipate either a fortuitous or pessimistic sequence of events cascading throughout the system.

If all factors other than water usage remained unchanged, the base could perhaps support an additional soldier with the extra water, or it could save some amount of money usually spent on water each month. The base's leadership could purchase a new recreation facility to improve morale or even precision-guided bombs with the collected funds. However, in a system, when one changes one thing, everything else does not stay the same. Congress could learn that the base does not need as much money to purchase water, and decide to decrease appropriations for DoD while spending their newly saved funds on a tax cut or an environmental cleanup program. Or, thinking that other soldiers are each saving five gallons of water, soldier B could take a longer than usual shower and use twelve gallons of water, when soldier B typically only used ten. Regardless of the outcome, over time the water (PE) saved with the reduction will become the new baseline. In other words, the new standard for a shower becomes five gallons instead of ten. The following equation shows a re-baselining to a new normal level of energy with the variable $N(PE)$. This variable decreases the perceived reduction of $Reduce(PE)$ for the MilAct until it fully cancels out the percieved reduction entirely:

$$Total\ Base\ (PE)_{current} - \Big(\big(MilAct(PE) - N(PE)\big) - \big(Reduce(PE) - N(PE)\big)\Big)$$
$$= Total\ Base\ (PE)_{new}$$

$$N = (1,2,3,\ldots,Reduce(PE))$$

So how is it useful to anticipate how human actors will perceive a new baseline over time? If one forecasts that ‘reduce’ will create a new baseline, there is still a sum of water available for use that otherwise would not have existed.

One takes advantage of system thinking by creating models of possible outcomes of actions and then adapting rapidly. To anticipate though one must create a model to attempt to get ahead of the real world mentally.[23] In the water use analogy, the model envisions the military base will generate some amount of additional water until a re-base-lining occurs. This is not the system creating energy, but additional energy available because of decreased water use.

A feedback mechanism to test the model's accuracy is the final part of system thinking. Even after one works to create an advantage, the only way to determine an actual gain from the system is to establish a way to check for the expected result. However, just because an expected result occurs, it does not necessarily mean it occurs because of the change made by the base commander.

For those who prefer a different analogy for the MilAct, imagine the US Air Force creates a technology allowing its planes to fly a little faster or a little higher. The Air Force can anticipate that it will gain an advantage for a window of time, but in this system, everything else will not stay the same. Over time the adversary will design a countermeasure, perhaps a better radar system or better tactics, to overcome the Air Force’s advantage. Therefore, the Air Force can anticipate that it will have an edge, that it will have a limited timeframe to exploit the gain, that it will need time to see if the benefit exists, and that it must craft a feedback mechanism to determine the impact. This example also highlights that system thinking is not limited to energy management, but also applies to the interaction of human beings as well.

In sum, the key to an operational approach for applying system thinking means both the military base and the US Air Force should take all those factors into account when changing something in a system. Furthermore, both the base and the Air Force must ensure they do not fall into the trap of thinking a change will have a predictable result. However, if they can observe reality well, orient themselves advantageously, decide efficiently, and act with alacrity, then they will increase their ability to survive and their capacity for independent action.[24]

JOHN BOYD'S ENERGY-MANEUVERABILITY THEORY

Colonel John Boyd was an American Air Force fighter pilot and defense expert who made several distinct yet interrelated contributions to aircraft dogfighting tactics, aircraft design, and the art of war.[25] Much of Boyd's work describes how two forces compete against each other, and his writings about warfare are perhaps as important as the contributions of Clausewitz and Sun Tzu. However, Boyd's work primarily focuses on battles, campaigns, and grand strategy while only giving minimal attention to logistics and its effect on warfare. This paper seeks to present a cognitive framework to complement Boyd's work to quantify logistics in the same manner as the Energy-Maneuverability (E-M) equation analyzed aircraft performance.

The United States should use a logistical maneuverability method to analyze, design, and employ military forces with a flexible and sustainable capacity for rapid maneuverability rather than slow-moving forces with ponderous and vulnerable logistical tails. To ensure the reader is familiar with Boyd's E-M Theory, this paper presents a brief description of the theory and its relevance. With an explanation of how E-M Theory reduces complex real-world physics to sets of numbers, the author then shows how a military unit serves as a substitute to the aircraft in Boyd's equation and begins an analysis of how logistical maneuverability (L-M) might work. Finally, the paper presents some brief thoughts on applying L-M to the employment and design of military forces and operations in the future.

Boyd's seminal E-M Theory analyzes how aircraft gain and lose energy, and the relationships between specific energy (P_S), potential energy (PE), and kinetic energy (KE) provides the basis for a potential L-M Theory. Of Boyd's many contributions to warfare, E-M Theory is perhaps the most practical, as it explains an aircraft's maneuverability by its ability to transfer energy back and forth between PE and KE. The theory uses the equation $P_S = \left[\frac{\mathrm{T-D}}{\mathrm{W}}\right]$V to determine the specific energy for an aircraft during regular flight or maneuvering.[26] This equation indicates that specific energy (P_S) equals thrust (T) minus drag (D) divided by weight (W) then multiplied by velocity V.[27] Thrust is the force pushing an aircraft forward (jet propulsion), drag is the force slowing the aircraft down (air resistance), weight is the mass of the aircraft at one gravity (G), and velocity is the distance traveled in a specified time.

Specific energy measures energy unit per mass and Boyd determines this to a large extent by looking at thrust minus drag. Specific energy can indicate either PE or KE. For an aircraft, PE is energy related to gravity, therefore the higher an aircraft's altitude, the more PE it has.[28] Kinetic energy is more a measure of the airplane's speed and motion; if a plane's thrust matches its drag, then the plane's (P_S) is zero, all is balanced, and the aircraft is in level flight.[29] As thrust or drag increases, the aircraft's specific energy alters quickly, as weight and velocity affect flight performance. Boyd graphed (P_S) against airspeed on one axis and turn rate on another axis, the steepness and shape of the curve indicates the energy maneuverability of the aircraft.

With information about how to analyze one aircraft's performance, and then compare two aircraft against each other, Boyd took E-M Theory a step further and developed aircraft from the drawing board to make the best use of E-M. Engineers designed both the F-16 and F/A-18 with extensive input from Boyd so that the aircraft could rapidly gain or lose airspeed and altitude (PE and KE) to dominate other aircraft in close-quarter aerial dogfighting. The information from an E-M diagram does not eliminate the consequences of various elements of human choice and Clausewitzian "friction" that will occur in any military conflict,[30] but the E-M diagrams do provide a comparative measure of aircraft performance at certain parameters of altitude, airspeed, weight, and configuration.[31] By using the favorable areas of the E-M envelope, the pilot's ability to observe, orient, decide, and act (Boyd's OODA Loop) shapes the outcome of the battle. An E-M chart does not eliminate the skill of one pilot over another to achieve a victory, but indicating where an E-M advantage exists has proven revolutionary for both aerial combat and aircraft design.[32]

With this basic description of how E-M Theory works, the question is: could one apply a similar technique to the logistics maneuverability of a military unit? This paper will use a Marine Air-Ground Task Force (MAGTF) in place of the aircraft used in Boyd's E-M Theory. A MAGTF operates with integrated ground, air, logistics, and command elements on land, from the sea, or in the air. The MAGTF then provides a useful proxy for an aircraft to consider how the maneuverability of logistics supports military operations.

The following idea for using Boyd's E-M Theory for an L-M theory is in the early stages of design. Boyd spent years perfecting the E-M equation, creating a method to interpret the raw data, and obtaining "the numbers" regarding aircraft thrust and drag.[33] The author of this paper intends only to explore the possibility of an L-M theory and determine a way ahead for future study. Much as Boyd's E-M equation solves for (P_S) by primarily looking at thrust minus drag, logistical maneuverability for a MAGTF would need to determine a (P_S) equivalent, based on how quickly the force can regenerate supplies (thrust) minus the inefficiency, or energy lost, during supply regeneration (drag). Furthermore, the size of the MAGTF would relate to aircraft weight with the rate of consumption generally equaling velocity. Altitude (PE) would be more akin to the total days of supply remaining for the MAGTF and speed (KE) would relate most to the tempo of operations.

Therefore, at a basic level, L-M equals the rate of supply regeneration (SR) minus supply inefficiency (SI) or $\mathrm{LM} = \mathrm{SR} - \mathrm{SI}$. Much as Boyd wasn't concerned about an ideal, or greatest possible (P_S), L-M is not about the amount of supplies on hand, or how many supplies arrive in a single resupply convoy.[34] The concept is based around how efficiently and quickly logistics can support operational maneuverability. For instance, supply regeneration occurs in five different categories: reduce, recycle, forage, produce, or resupply. The MAGTF commander should select the method of supply regeneration most appropriate to continue maneuver operations depending on the situation. Furthermore, the best method of supply regeneration will change as realities on the ground change. For instance, enemy action or increased distance of travel could make resupply disadvantageous when compared against producing on-site. And conversely the extra equipment needed for producing on-site may be too bulky for a small maneuver unit, so resupply would then become the most appropriate method.

A MAGTF's drag or friction does not equal the consumption of supplies, but the resistance (energy lost) as the supplies reach the MAGTF and become available for use. For example, if a coal power plant wants to deliver a kilowatt-hour of electricity to a house, it purchases a certain amount of coal to burn, which after a process occurs it then transmits as electric power. But, by looking farther upstream in the supply chain for the coal, there is an even greater amount of energy purchased and consumed to bring the coal from the mine to the power plant. The energy lost to friction and waste along the path from the coal mine to the residential home is the supply inefficiency (SI), or drag. With this basic understanding of how L-M might work—supply regeneration minus supply inefficiency—the rest of this paper will show how to design and employ forces with L-M theory in mind.

In *Patterns of Conflict,* Boyd discusses the history of warfare and the nature of maneuver and attrition in war. He also describes how better led and more maneuverable forces can overcome a stronger army. Boyd details how the massive armies of the Napoleonic era through World War I became slow, plodding forces with rigid supply lines that telegraphed attacks. While Boyd does not delve deeply into how militaries used logistics well, he does discuss the importance of "essential" logistics "to support high-speed movement and rapid shift among routes of advance."[35] That support with essential logistics represents the cognitive basis for L-M.

First and foremost, L-M must enhance a commander's ability to make timely decisions and to force the opponent to react in a time and manner not of their choosing. It cannot force a pause in operations while the logistical tail catches up to the front. Furthermore, operations cannot outpace logistics. Moving too fast is as bad as moving too slowly since forces are vulnerable to annihilation if separated from their supply lines or supply regeneration methods. Both operations and logistics must travel through, over, and around terrain seamlessly and in-step, the "essential logistics to maintain cohesion and overall effort and sustain appropriate pace of operations."[36] Fundamentally, this means that logistics cannot always depend upon any specific method of supply generation, especially resupply. Only with a broad mix of different techniques and technologies can a force ensure cohesion between the 'tooth' and 'tail' in a military operation. Descriptions of these techniques and technologies are in the next section of this paper.

To employ a cohesive force like this, the US military must adapt. The individual services must move away from a concept of only massive resupply and iron mountains of supplies and to a more balanced approach of reducing, recycle, produce, forage, and resupply. That does not mean a move to only small forces, as a large force with a robust stockpile of supplies is sometimes essential, but logistical maneuver and Boyd's work indicates that the ability to quickly move between small and large, slow and fast, is the most important aspect of warfare. With a more rendered L-M theory and the ability to analytically break down plans to show logistical supportability, the US military can maintain a decisive edge. Finally, as Boyd's E-M Theory led to the design and production of dominate fighter aircraft, L-M theory could someday help develop ships, aircraft, tanks, command and control centers, or rifles better able to work with a highly maneuverable and adaptable force. The optimal employment of such a force would be its ability to defeat an enemy's plan, by forcing them to react to a friendly situation that could rapidly change.

The longest journeys begin with a first step, and so far this paper has only described an initial concept regarding Logistical Maneuverability. The remainder of this paper delves deeper into Logistical Maneuverability and how a commander or military planner might incorporate the theory and comparative analysis to support a maneuver force, or to build that force. There is significant potential for the concept of logistical maneuverability to provide a similar paradigm shift to maneuver warfare as Boyd's work did to aircraft design.[37]

WHAT IS THE MATRIX

To produce real-world results, Boyd's E-M Theory needed three things. First was the equation to determine specific energy, $P_S = \left[\frac{T-D}{W}\right]V$. Next, he needed accurate data—the thrust, drag, weight—for each aircraft he analyzed. Finally, he had to determine a way to present this information to make it understandable for a wide range of audiences. This paper will focus on the first and third areas for Logistical Maneuverability. Acquiring the raw data about how weapons systems use energy is important, but data processing efforts is not relevant to the intent of this paper, which proposes and details what Logistical Maneuverability is. Specifically, this paper focuses on determining relevant consumption variables and a method for comparing different types of supply regeneration. This paper creates a product of use to a commander or logistics planner in determining the most flexible way to support a highly maneuverable force.

The US military has a problem: quite simply, it has too much stuff and too much money. For most militaries it is hard to imagine that anyone in that military would ever think that having too much stuff and too much money was a problem. However, generations of US servicemembers have served without ever truly experiencing the truth of Winston Churchill's famous quote, "Gentlemen, we have run out of money; now we have to think."[38] Americans have fought and served in horrific conditions, they have suffered scarcity and every tribulation a person can endure, but the system that supports the military has always produced copious amounts of supplies and the most modern and technically advanced equipment that one of history's wealthiest nations could provide. The US servicemember has taken advantage of this wealth and largess and won nearly every engagement or battle since the Korean War. Victory or defeat for the US, from the latter half of the Twentieth century to today, has been determined by the ability of politicians and generals to frame success and to get all sides of the conflict to agree to that decision, not by the application of overwhelming combat power.

However, the disparity in combat power enjoyed by the United States may not last. By looking at current trends in technology, such as small commercially available quadcopter drones and how quickly these drones could become a swarm of precision strike munitions, it is not difficult to imagine a very different operating environment from the one that currently exists. To operate and survive in a future battlefield, the US military must become more maneuverable and it must present a smaller target to an adversary, both in time and in space. A US military capable of operating with a flexible and maneuverable logistic support system could also fight from a large megabase if an adversary was willing to give America the time or space to build that combat power. But if the US military only maintains a force capable of fighting from a large megabase, American will continue to pay a high cost in blood and treasure.

To move from attrition, large mega-base warfare to maneuver warfare, a commander cannot only determine how much energy they need at the end of the supply chain, but must analyze the entire cost of the energy the force is using. Then commanders must determine what key performance parameters (KPP) they require for their mission and how they balance trade-offs between different KPPs. Finally, when designing future fighting forces, commanders must advocate for technological advancements that may have some significant upfront costs when compared to the sunk cost of legacy systems, but can produce enormous returns on investment for a maneuver force.

FULLY BURDENED COST OF ENERGY

Unfortunately, the DoD is not even sure how big of a problem it has. While KPPs have been a requirement for new acquisition programs since 2009, legacy systems do not have an energy-use measurement in place. In 2008, Christopher DiPetto, the Director of Developmental Testing at the Office of the Secretary of Defense, testified before Congress that "our force planning process almost always plug fuel logistics in at the back end, after the capability we want." DiPetto continued by saying that this had negative consequences for our combat forces as we couldn't accurately predict what type of 'tail' we were creating for the 'tooth' we wanted. Not understanding how a military force uses energy relates back to the authors' comment about too much money. No person, no business, would or could operate this way, and it is not enough to say that the cost should not matter. Wasteful thinking like that helped turn relatively affordable gasoline purchased by the Defense Logistics Agency at $2.82 per gallon gasoline in 2008 into gasoline that cost $400, $600,[39] or even possibly $1000[40] per gallon by the time it consumed by an end-user.

Perhaps no concept better encapsulates the waste of taxpayer dollars that can occur in a war than the fully burdened cost of energy (FBCE). FBCE incorporates the tracking of not just the wholesale cost of energy (say diesel fuel) but the cost of the entire supply chain to deliver the fuel to the end user. Therefore, FBCE requires commanders to consider the cost of fuel burned to deliver energy, the cost of wear and tear on vehicles delivering the fuel, and the cost of buying new equipment to recapitalize the now worn out equipment that delivered fuel. Commanders not tracking the FBCE led to $400 per gallon fuel during Operation ENDURING FREEDOM in Afghanistan.[41] The author does not intend to indicate that a horde of accountants should deploy with expeditionary military forces to argue over every penny spent, but President John F. Kennedy was not describing costs like this when he said the United States would "pay any price, bear any burden, meet any hardship." Especially since the $400 per gallon fuel was most likely air-dropped to a remote forward operating base (FOB) or combat outpost (COP) in Afghanistan and used in a generator for, at most, a few hours of electricity.

This paper argues that an analysis of how such a remote outpost could regenerate supplies should have occurred. Assuming that the FOB or COP met a necessary military function, other methods should have been employed to provide the outpost with the energy it needed. Specifically, remote outposts should use solar panels with integrated battery systems for electricity production. While the solar panel system may have a higher upfront cost, or required a larger physical footprint to house the panels, they have a high return on investment (ROI) as the systems produce electricity at a lower cost.

The cost of energy, combined with uninformed or poor decisions by commanders does not just cost the United States exorbitant sums of money; it also costs lives. Improvised explosive devices (IED) were responsible for more than eighty percent of US military casualties in Afghanistan as of 2010.[42] Supply convoys were a frequent target for these IEDs, which in turn drove the push towards larger, more secure convoys, route clearance packages (RCP),[43] or aerial resupply.[44] Furthermore, from 2003 to 2007, 3,000 lives were lost just in fuel delivery operations.[45] The techniques used to attempt to counter IEDs increased the cost, sometimes logarithmically, of military operations and supply regeneration.

To help decrease the number of casualties that IEDs were causing in both Afghanistan and Iraq, the US army increased the armor on highly mobile multipurpose wheeled vehicles (HMMWV or Humvee) and employed mine-resistant ambush protected (MRAP) vehicles.[46] Both programs were effective to a point, but the enemy responded by increasing the explosive weight of their IEDs and by using explosively formed penetrators (EFPs) to counter the up-armored Humvees and MRAPs.[47] Along with larger convoys with more vehicle and airborne security, increased armor, RCPs, and a changing insurgency ultimately lowered the rate of casualties per convoy.[48] However, the heavier MRAPs and increased armor had much lower fuel efficiency than the legacy Humvees. This meant that more fuel resupply convoys were needed to bring energy needed to the FOBs. So even if the rate of casualties per convoy decreased, an increase in the total number of convoys could have brought the aggregate number of casualties back to where it was before the increased armor was employed. Furthermore, heavier security for the resupply convoys meant that the FBCE per gallon that reached the FOB increased dramatically, the $400-$1000 per gallon fuel previously mentioned.

Larger supply convoys and heavier security requirements also cause logistics and security to telegraph operations. The requirement for heavily armored vehicles and more personnel for security on convoys means that actual operations require such a large 'tail' that the 'tooth' becomes overburdened. Large MRAPs and numerically large convoys cannot move about terrain freely. They become channelized onto routes that can support the weight of the vehicles, and they must avoid narrow roads.[49] So, in the quest for more security and fewer casualties, the ability to conduct operations is significantly decreased, while telegraphed movement give the enemy time to retreat or prepare an attack as they see fit.

<u>KPPS AND TRADE-OFFS</u>

Too much 'tail' is why commanders must put more thought and analysis into the tradeoffs between different KPPs. There are six mandatory KPPs for all new weapon systems: services must analyze force protection, system survivability, sustainment, net-ready, training, and energy KPPs for every new military platform.[50] For the energy KPP, the Duncan Hunter National Defense Authorization Act for Fiscal Year 2009 required services to analyze if a new platform can "successfully perform its mission as intended and is it sustainable using planned force structure, (concept of operations, and (tactics, techniques, and procedures.)"[51] The act requires the services to analyze a full unit of maneuver, like a brigade combat team, for the entire fully burdened supply chain to determine how much energy the unit of maneuver requires to conduct its actual combat mission. Services must analyze how an adversary force might attack a logistics tail, along with requirements for defense of the supply tail. Once the services have determined the energy needs of the new platform, they must compare it against the legacy system it is replacing, and ascertain how any increased fuel demands would affect existing war plans.

A commander cannot ignore the energy requirements of conflict through or focus on a perceived need for effectiveness. One source used for this paper quotes a finger-wagging commander as stating, "to hell with efficiency, effectiveness is all I care about."[52] That commander was clearly accustomed to having too much stuff and too much money, and therefore did not think. That commander, or someone like them, created a US military so focused on 'effectiveness' that it has increased the fuel consumption of a US soldier by 175 percent per day since the Vietnam War,[53] created FOBs that require 300 gallons of diesel fuel every day,[54] and Army units where seventy percent of the tonnage moved to position the unit for combat is fuel.[55]

The balance between energy usage and force protection or offensive capability is not a linear process: a commander must approach it with an understanding of system theory. Each of the six KPPs must be balanced by considered tradeoffs to determine the most useful outcome. For instance, while there is a consensus that increasing the armor on Humvees and transitioning to MRAPs saved lives in Iraq and Afghanistan, there are also counterarguments that the increased armor had less impact on the decrease in casualties than other changes in the conflict.[56] And while the larger MRAPs could not travel on as many roads because of their height and weight, they also cost at least $600,000 per copy, compared to $50,000 for a standard Humvee and $120,000 for an up-armored Humvee.[57] Counterarguments to the anti-MRAP argument include that more secure vehicle transports caused the insurgents to move away from IEDs or to use their existing stockpiles more quickly by creating larger IEDS in an attempt to destroy the more secure vehicles.[58]

THE ROI OF ON-SITE ENERGY PRODUCTION

Something as simple as adding insulation to semi-permanent structures on FOBs can have many mission impacts. In 2007 the Army found that by spraying foam insulation on the exterior of otherwise inefficient structures, they could reduce the energy required to heat and cool the structures by eighty percent.[59] After ensuring the foam met required safety, fire and disposal requirements, a program that cost $95 million saved more than $1 billion (with a B) and took more than 11,000 fuel trucks off the road.[60] While the FOB buildings may not be as mobile after having insulation sprayed on them, the decrease in energy consumption creates a force that is more maneuverable. The benefits of energy efficiency translate back throughout the supply system in numerous beneficial ways. Fewer trucks on the roads mean fewer convoys, fewer convoys mean fewer casualties (on average there is one casualty every twenty-four supply convoys), fewer convoys also mean less personnel needed in theater, a smaller servicemember footprint requires fewer supplies overall, and so on.[61]

The return on investment (ROI) for the spray foam in the previous example was a little more than ten to one in a year ($\frac{\$1{,}000\ million}{\$95\ million}$), a ration of more than ten to one. As a comparison, one would consider a five to one ROI as a strong investment and a ten to one ratio as exceptional.[62] While not all energy efficiency projects at a deployed location will have as high an ROI, there are significant advantages to how an expeditionary unit or a FOB operates beyond just the dollar savings. Specifically, smaller forces with less logistical tail have enormous advantages with regard to cost and the patience of the American public. The author contends that a smaller, less costly force, especially one not taking a lot of casualties, will draw less negative attention from the American public. While the public needs to know of the operation and why the military is deployed on foreign soil, a smaller force can actually have greater potential for long-term mission accomplishment by staying out of a fickle 24-hour news cycle. Furthermore, money that the DoD spends on research, development or acquisitions of energy efficient technology can have positive second and third order effects within the larger US economy. One kind find numerous examples of DoD research, development, and purchasing power having beneficial effects on US society for decades.[63]

All of this has lead back to the paper's thesis: That the US Department of Defense should prioritize the acquisition, development, and fielding of a military force with a logistical tail idealized for rapid movement and adaptability over other aspects of combat capability. A traditional method of thinking about energy use within the DoD has created an inefficient system where commanders can make lazy, ill-informed, and expensive decisions that are counterproductive to their operational goals. By chasing capability and 'effectiveness,' America has a military that is too vulnerable and too slow to meet either modern counter-insurgency requirements or to project combat power against an adversary's A2-AD envelope.

While there are many areas that the DoD could focus on for a more rapidly moveable and adaptable logistic system, the author advocates that focusing on electrical and hydrocarbon production at the FOB presents a high ROI, radically alters the current FBCE paradigm, and creates a future military force with more logistical maneuverability. There are two ways to change the current energy paradigm for expeditionary or deployed forces. One is through altering how a large base like Camp Leatherneck or a FOB in Afghanistan produce electricity;

another is looking at how a future, expeditionary, more maneuverable force might pre-position its power generation requirements.

In a current base like Camp Leatherneck (or any FOB in Afghanistan), the base is wholly dependent on diesel generators for their daily electrical production. Diesel fuel for those generators is provided via ground or air resupply and has an FBCE of anywhere from $7 to $400 (or $1000 as previously stated).[64] At $7 per gallon fuel per kilowatt hour (kWh) costs $0.90 for the nine megawatts (MW) that were produced daily at Camp Leatherneck.[65] Conversely, Tesla[66] recently signed a twenty-year contract with the Hawaiian Island of Kauai to provide solar power-based electricity at $0.139 per kWh using a fifty-two MWh battery system combined with a thirteen MW solar panel array.[67] Even tripling the price based on the increased cost of shipping to a war zone, repairing battle damage, and additional military hardening, a system is commercially available today and could provide electricity at less than half the cost (forty-six percent) of a diesel generator. That doesn’t even include the savings in decreased vehicle wear and tear, fewer deployed personnel, and casualties from fewer resupply convoys. Furthermore, for those building military budgets, the solar panel system have little cost variability, unlike oil. This from a solar panel system with basically zero moving parts to maintain, an operating temperature range from negative twenty-two to 122 degrees Fahrenheit, and no audible emissions.

For operations involving a future expeditionary force, perhaps in the Pacific or Africa, it is easy to imagine that a mix of solar panels, batteries, and inverters could be installed in an ISO container. The solar panels could potentially deploy from an articulating system within the ISO container, similar to how satellite solar panels expand post-launch. Such an ISO container could then be placed in the existing pre-positioned military system for rapid employment along with other maneuver forces. The ISO containers could be offloaded from naval shipping or flown in using cargo aircraft or helicopter sling-loading. The system as described can already employ in a modular fashion, so the correct number of ISO containers could be brought to a site based on the needs of the mission and hooked together to provide the necessary electrical microgrid.[68]

Pre-positioning power generation capabilities in this manner meets the 2012 Joint Operational Access Concept (JOAC) requirements for preparing an operational area in advance for facilitated access, and maximizes surprise through deception, stealth, and ambiguity to complicate enemy targeting.[69] Furthermore, the JOAC advocates that large bases disaggregate into a greater number of smaller bases to complicate enemy targeting efforts.[70] A modular, ISO solar power system would decrease logistical burdens as sites without vehicle fuel requirements would not need hydrocarbon resupply missions.

Current on-site energy production has even more interesting ways of reducing resupply requirements. By combining current technologies there exists an opportunity for a military unit to produce hydrocarbons like diesel fuel or JP-8 on site, with only the sun and air as ingredients. There is an upfront cost of moving additional equipment to a deployed site, but the cost savings from not having to use resupply convoys would be large within a very short amount of time.

The key ingredient for a military unit in using this technology is the ready availability of electricity. It would not make sense to burn a hydrocarbon in a generator to power a system to produce a hydrocarbon from the atmosphere. Furthermore, basic thermodynamics instructs that the processes to obtain water and carbon dioxide from the air requires more energy than what is available in the finished product.

The basics of producing a hydrocarbon from air involves a combination of two types of technology: one to acquire the necessary hydrogen, one to acquire the necessary carbon. As hydrogen is easily obtained from liquid water, a dehumidifier like one finds in many houses but built larger and to military specifications, pulls water vapor from the atmosphere and converts it into liquid water. The carbon comes from atmospheric carbon dioxide, and equipment to separate out the carbon dioxide from the air is currently available and has been successfully field tested. From there, the harvested carbon dioxide is combined with hydrogen from water using a Fisher-Tropsch[71] process to create a hydrocarbon.[72] Interestingly, the hydrocarbon produced via this method is useful in a couple of areas. The first method is to use the fuel in military vehicles, either ground vehicles or aircraft. The second method involves considering the hydrocarbon as a battery. If inclement weather prevents adequate levels of photovoltaic power, and the base's batteries have used up their charge, a hydrocarbon can be burned in a generator to produce the electricity required until sufficient sunlight is available.

This is only one way that current and future technology allows for the potential elimination of some or all resupply missions for expeditionary forces. On-site production accomplishes the supply regeneration needed for an expeditionary force to continue functioning. This paper does not argue though that such on-site production methods will always be ideal for mission accomplishment. Instead, a commander must balance different methods of supply regeneration to best support their mission. To aid a commander with that mental balancing, the following matrix is intended to provide an aide to compare and contrast the most appropriate methods for efficient supply regeneration.

THE SUPPLY REGENERATION MATRIX

Expeditionary commanders, logisticians, or acquisition specialist can use the proposed supply regeneration matrix (SRM) for both current planning operations for a variety of terrains and climates and as a model for determining the most critical areas for future acquisitions. Furthermore, the author believes that there are ways to mathematically determine the most efficient way for a military force to regenerate its consumable supplies.

There has been a consistent and growing trend within the DoD to anticipate a future expeditionary force unable to fight from large megabases. Ever since the first Gulf War, the United States and coalition forces have been able to bring troops and supplies into a theater and build up the combat and logistical power needed to fight a decisive engagement at a time of the United States' choosing. This build-up has occurred at installations proximate to the battlefield and capable of receiving and supporting scores of troops and supplies. However, because a future force may not have a partner nation willing to grant access to its facilities, and because of the proliferation of anti-access area-denial weapons, a future mega-base may not exist. Therefore, the DoD is seeking the ability to operate with a more expeditionary construct from more dispersed locations. Within the DoD, each military service seeks to decrease the vulnerability of its supply chain, or line of communication in military parlance, through the employment of of new tactics and technologies that allow forces more flexibility.

Military planners must determine how to support a maneuverable and flexible future military force now. This paper proposes the SRM to aid an expeditionary force in obtaining supplies, along with a general listing of the consumable supplies any military force needs to operate. Military planners can use the SRM as a quick template to determine potential shortfalls or as a long-term, in-depth, analytical method of determining future requirements for a military force based on terrain, weather, or technological developments. Furthermore, as a framework for existing DoD acquisition principles like KPP, the SRM can assist in designing a future force.

To determine how the DoD can logistically support expeditionary forces without an “iron mountain” of supplies, the problem is broken down into something that is workable in the many different geographic locales and climates where forces could operate, along with the means and methods a force has to either better use its supplies or receive additional supplies. Additionally, the SRM allows for forecasting to 2035 to determine areas that require more research and development to support a maneuver force. Finally, a commander can focus on specific areas or take a holistic look at what a military unit needs to operate.

	Reduce	**Recycle**	**Forage**	**Produce**	**Resupply**
Fuel					
Water					
Food					
Medical Supplies					
Parts					
Ammo					

The SRM presents six types of consumable materiel that an expeditionary force would require along a Y axis, with five ways a force could acquire said materiel along an X axis. This matrix can be referenced for any geographic region, and a particular field like ‘Recycle – Parts’ can be projected along a Z axis to predict current shortfall risks or future requirements.

This matrix is useful for both military planners and those in the acquisitions, research, and development. A military planner could look at orders to a specified geographic region and fill in each field of the matrix with either a technique or a necessary piece of equipment the unit needs to requisition. For instance, an expeditionary force, operating from a small base in a coastal region of Africa to prevent the area from being used as a base for piracy could create a matrix like the following:

Sub-Saharan Coastal Africa 2020					
	Reduce	Recycle	Forage	Produce	Resupply
Fuel and Power	Minimize electrical device usage to military necessity	Collect C02 emitted from generators	Contract for local sources of energy (power grid and/or available fuel stocks)	Use solar panels with battery backup and microgrid to collect sunlight for use. Use recycled water and atmospherically collected CO2 to produce hydrocarbon fuel	Receive resupply of water and CO2 via airdrop and convert to hydrocarbon fuel locally
Water	Operate when possible during cooler parts of the day	Retain and Reuse gray and black water	Water harvesting, desalinization, contract for a well if feasible.	Bring equipment to harvest water (relative humidity) from the atmosphere or desalinate non-potable water	Transport water from a logistics storage facility/asset (point).
Food	Focus on food with high-calorie content	Use food scraps for methane digester	Determine if local flora or fauna is edible without disturbing local economy	Use vertical farm in an (ISO) to produce limited fresh produce	Transport food from a logistics storage facility
Medical Supplies	Emphasize proper hygiene and safe individual practices such as sexual contact, air and waterborne disease	Biodegradable medical supplies could be placed in a methane digester, plastics and metals would need to be sterilized and shredded before re-use	Acquire and store blood from US service members as able depending on military operations.	Re-use metal and plastics (sterilized) as feeder stock for 3D printers for medical and surgical tools. Use artificial blood substitutes[73]	Transport from a logistics storage facility
Spare Parts	Conduct proper preventative maintenance checks and services.	Shred metal parts for use by 3d printer to make new parts	Determine if there are junkyards or scrap materiels in local area for shredder	Use 3d printer to produce spare parts on site	Receive stock supply for 3d metal or plastic printer, and any mission essential parts such as microprocessors not producible with 3d printer
Ammunition	Emphasize fire discipline Maximize use of weapons systems with standard ammo	Save expended brass casing for re-use as feedstock for 3d printers	Obtain metal feeder stock for 3d printers	3D print ammunition	Transport ammunition from storage point

Where this matrix currently lists capabilities, specific systems could be requested, like a solar panel array system based on the locally available sunlight and weather patterns. If the area did not have enough expected sunshine to supply the base with the necessary power from photovoltaics, then an electrical generator along with an expected amount of fuel to be resupplied could be planned. The SRM is intended to aid in determining how to best trade off efficiency, capability, and requirements to ensure US forces can operate at the highest level. The SGM enables the commander or logistician to visualize the range of options available to choose an optimal means of supply generation for a given scenario. Logistical Maneuverability is then intended to calculate and quantify the tradeoffs involved in the different options available. A commander should consider the relevant terrain, climate, and local supply availability when considering how to best generate supplies for their force. As the situation on the ground changes and the relative cost benefits change then commanders should alter the methods they use to best support their forces mission and operating tempo.

CONCLUSION

This essay represents the first two parts of what Logistical Maneuverability will eventually become. It has framed the current problem with how the DoD views logistics and it presents a model for how a military can model a better solution for regenerating supplies. To fully realized the advantages of this theory the Department of Defense must determine the current fully burdened cost of energy for all existing legacy systems and units of maneuver within the department of defense. Once the DoD has completed that analysis it can begin to design future weapon systems and better organize maneuver units to gain a temporal and cognitive advantage over an adversary.

This paper has endeavored to show that Logistical Maneuverability is about setting the conditions for victory, before and during a conflict. Fundamentally, it is designed to create both a peacetime and wartime advantage over an adversary. The case study of MacArthur in the Philippines showed that he failed to establish an advantage before conflict began because of an ill-fated decision with how he positioned his supplies. This highlights that a commander must consider not just the combat power of a military unit, but how that unit will sustain itself in favorable or unfavorable conditions. The descriptions of systems theory along with Boyd's E-M Theory are intended to present a point of reference for methods to quantify different types of supply regeneration. With such quantified data, the analysis of KPPs and balancing tradeoffs between areas like for protection and energy use will have greater importance for how future weapon systems are designed to work with the US military's legacy systems. Logistical Maneuverability can enhance how America equips, employs, and sustains its military at the tactical, operational, and strategic levels of warfare. It is designed to give a commander a suite of options wherein they can use both their intuition and hard data to view and determine the best way to build and employ a force capable of surviving and winning in today's A2-AD environment, or in a future environment.

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[1] John F. Schmitt, "Understanding Manuever as the Basis for a Doctrine," *Marine Corps Gazette* 74 no. 8, (November 1990): 99.
[2] Chairman of the Joint Chiefs of Staff Manual: Operation of the Joint Capabilities Integration and Development system, JCSM 3170.01C, 1 May 2007, http://www.acq.osd.mil/log/mr/.mr_library.html/CJCSM_3170_01C-01May07.pdf
[3] This assertion is based upon numerous hours of research and open source searches by the author where relatively few studies were found. Studies may exist the author was not able to access because of classification.
[4] Richard M. Swain, *Camp Colt to Desert Storm: The History of the U.S. Armed Forces*, The University Press of Kentucky, Lexington, edited by Donn A. Starry and George F. Hoffman, 367. 1999. https://books.google.com/books?id=Hfw2AgAAQBAJ&pg=PA367&lpg=PA367&dq=depuy+to+be+seen+is+to+be+killed&source=bl&ots=VfqpYrq_p4&sig=f-1DqNhaoS6nC53CCtMQCnO1LXM&hl=en&sa=X&ved=0ahUKEwiSmM39oLjTAhUBYiYKHUODDlAQ6AEILTAC#v=onepage&q=depuy%20to%20be%20seen%20is%20to%20be%20killed&f=false
[5] Franklin C. Spinney, *Defense Facts of Life*, Department of Defense, Washington D.C., 1980, http://pogoarchives.org/labyrinth/defense-facts-of-life-1980.pdf
[6] Robert Coram, *Boyd: The Fighter Pilot Who Changed the Art of War*, (New York: Back Bay Books/Little, Brown and Company, 2002), 191.
[7] Louis Morton, *The Fall of the Philippines*, (Washington, D.C.: The Center of Military History United States Army, 1993), 88, http://www.history.army.mil/html/books/005/5-2-1/CMH_Pub_5-2-1.pdf.
[8] *Ibid*.
[9] *Ibid*.
[10] *Ibid*, 64.
[11] *Ibid*, 9.
[12] *Ibid*.
[13] *Ibid*, 17.
[14] *Ibid*, 50.
[15] *Ibid*, 42.

[16] *Ibid*, 401.
[17] *Ibid*, 77.
[18] The following section on system theory as well as the following section on John Boyd's Energy Maneuverability Theory and its application to supply regeneration are from papers submitted for academic requirements for the elective portion of Marine Command and Staff College Academic Year 2017. The reuse of these papers was done with the knowledge and pre-approval of the instructors for both of the elective courses and the advisors for the Advanced Studies Program. Both sections have been edited for content and flow within this larger paper. Another endnote will indicate where the second paper ends.
[19] Robert Jervis, *System Effects: Complexity in Political and Social Life* (Princeton, New Jersey: Princeton University Press, 1997), 7, 9.
[20] *Ibid*, 12-13.
[21] R. Nave, "Second Law: Entropy," *Georgia State University*, 2005, http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/carnot.html#c1.
[22] These equations are not intended to replicate arithmetic or indicate a particular linear process within a system. The equations are used to establish a cognitive framework or another way of communicating the intent for those who may find it easier to interpret an equation than a sentence.
[23] Alan Beyerchen, "February 16, 2017, Introduction to System Theory class" (paraphrased from comments made during Introduction to System Theory class at Marine Command and Staff College, Quantico, Virginia, February 16, 2017).
[24] Observe, orient, decide, and act (the OODA loop) and "increase its ability to survive and its capacity for independent action," reference the work of Colonel John Boyd, United States Air Force (ret.). Boyd was a master of system thinking. "The Essence of Winning and Losing," describes Boyd's OODA loop on Slide 3 and his theories about survival are in "The Strategic Game of ? and ?," on Slide 14. Both of these briefs are accessible online at "John Boyd Compendium," *Project on Government Oversight: Defense and the National Interest*, last modified December 6, 2007, http://dnipogo.org/john-r-boyd/.
[25] Coram, *Boyd: The Fighter Pilot Who Changed the Art of War*, 144.
[26] *Ibid*, 146.
[27] *Ibid*, 147-148.
[28] Only by descending can the aircraft turn potential energy into kinetic energy.
[29] *Ibid*, 147.
[30] Carl Von Clausewitz, *On War*, edited and translated by Michael Howard and Peter Paret (Princeton: NJ: Princeton University Press, 1976), 119.
[31] Coram, *Boyd*, 147.
[32] *Ibid*, 163.
[33] *Ibid*, 149.
[34] *Ibid*, 148.
[35] John Boyd, *Patterns of Conflict*, December, 1986, (Defense and the National Interest,) ed. Chet Richards and Chuck Spinney, January, 2007, 88. http://www.dnipogo.org/boyd/patterns_ppt.pdf.
[36] *Ibid*, 128.
[37] This is the end of the reused sections.
[38] Winston Churchill may or may not have said this. The quote, or a variation of it, is also attributed to New Zealand chemist and physicist Ernest Rutherford. https://en.wikiquote.org/wiki/Winston_Churchill.
[39] Sandra I. Erwin, "How Much Does the Pentagon Pay for a Gallon of Gas," National Defense Magazine, April, 2010, http://www.nationaldefensemagazine.org/archive/2010/April/Pages/HowMuchforaGallonofGas.aspx.
[40] Roxana Tiron, "$400 per gallon gas to drive debate over cost of war in Afghanistan," The Hill, October, 16, 2009, http://thehill.com/homenews/administration/63407-400gallon-gas-another-cost-of-war-in-afghanistan-.
[41] Erwin, "How Much Does the Pentagon Pay for a Gallon of Gas."
[42] Tiron, "$400 per gallon gas to drive debate over cost of war in Afghanistan."
[43] Route clearance packages are military convoys comprised solely of specialized anti-IED and security vehicles that traveled along lines of communication to attempt to keep IEDs from striking resupply convoys or other convoy missions. See http://www.wood.army.mil/engrmag/PDFs%20for%20May-Aug%2010/Law.pdf for more information.
[44] Tiron, "$400 per gallon gas to drive debate over cost of war in Afghanistan."
[45] Sean R. Dubbs, "Estimating the fully burdened cost of fuel using an input-ouput model - a micro-level analysis" Naval Postgraduate School, http://calhoun.nps.edu/handle/10945/5605.

[46] MRAPs have increased armor, higher chassis, and v-shaped hulls to help avoid or deflect the energy from IED blasts.
[47] EFPs are IEDs designed to act like a rocket propelled grenade or bazooka. They use an explosive shaped charge to superheat and plastically deform copper into a molten stream to burn through armor and penetrate the crew compartment of a vehicle.
[48] Chris Rohfls and Ryan Sullivan, "The MRAP Boondoggle," Foreign Affairs, July 26, 2012, https://www.foreignaffairs.com/articles/2012-07-26/mrap-boondoggle?page=show
[49] The author of this paper has first-hand experience on a provincial reconstruction team in Afghanistan that had to turn back part way through a mission because the MRAPs could not traverse a village road.
[50] Mandatory Key Performance Parameters (KPPs), Glossary of Defense Acquisition Acronyms and Terms, Defense Acquisitions University, https://dap.dau.mil/glossary/pages/3043.aspx.
[51] Alan Bohnwagner, "An Overview of the Energy Key Performance Parameter (KPP)," Aqcuisitions.osd.mil, December, 9, 2013, http://www.acq.osd.mil/eie/Downloads/OE/Energy%20KPP_12-09-13.pdf
[52] Steven M. Anderson, "Save Energy, Save Our Troops," New York Times, January 21, 2011, http://www.nytimes.com/2011/01/13/opinion/13anderson.html.
[53] Charles F. Wald and Tom Captain, "Energy Security: America's Best Defense," Deloitte Development LLC., 2009, abstract, http://www.offiziere.ch/wp-content/uploads/us_ad_EnergySecurity052010.pdf.
[54] *Ibid.*
[55] *Ibid.*
[56] *Ibid.*
[57] Chris Rohfls and Ryan Sullivan, "The MRAP Boondoggle," Foreign Affairs, July 26, 2012, https://www.foreignaffairs.com/articles/2012-07-26/mrap-boondoggle?page=show
[58] David Axe, "The Great MRAP Debate: Are Blast-Resistant Vehicles Worth It?," Breaking Defense, October 01, 2012, http://breakingdefense.com/2012/10/the-great-mrap-debate-are-blast-resistant-vehicles-worth-it/.
[59] Anderson, "Save Energy, Save Our Troops."
[60] *Ibid.*
[61] *Ibid.*
[62] Chris Leone, "What Is A Good Marketing ROI," Web Strategies, September 9, 2016, https://www.webstrategiesinc.com/blog/what-is-a-good-marketing-roi.
[63] The internet, microprocessors, and GPS are only a few technological developments were US society has benefitted greatly from DoD R&D and purchasing power.
[64] Chris Garvin and Jim Codling, "Making Grid Connection Happen," The Military Engineer, http://themilitaryengineer.com/index.php/item/111-making-grid-connection-happen.
[65] *Ibid.*
[66] Tesla is used as an example only; this paper does not endorse or recommend any non-DoD company.
[67] Jordan Golson, "Tesla built a huge solar energy plant on the island of Kauai," The Verge, March 8, 2017, http://www.theverge.com/2017/3/8/14854858/tesla-solar-hawaii-kauai-kiuc-powerpack-battery-generator
[68] Powerpack Utility and Business Energy Storage, Tesla, https://www.tesla.com/powerpack.
[69] Joint Operational Access Concept (JOAC), ii-iii, https://www.defense.gov/Portals/1/Documents/pubs/JOAC_Jan%202012_Signed.pdf.
[70] *Ibid*, 20.
[71] The Fischer-Tropsch process is a chemical reaction that can turn combinations of elements like coal, carbon monoxide, carbon dioxide, hydrogen, methane, or other elements into a liquid hydrocarbon such as diesel fuel or jet fuel. It was originally developed in Germany in 1925. https://en.wikipedia.org/wiki/Fischer%E2%80%93Tropsch_process.
[72] Fiona MacDonald, "Audi Has Successfully Made Diesel Fuel From Carbon Dioxide and Water," *Science Alert*, April 27, 2015, http://www.sciencealert.com/audi-have-successfully-made-diesel-fuel-from-air-and-water.
[73] Lecia Bushak, "Scientists Create Artificial Blood That Can Be Produced On An Industrial Scale: A Limitless Supply Of Blood?," Medical Daily, April 15, 2014, http://www.medicaldaily.com/scientists-create-artificial-blood-can-be-produced-industrial-scale-limitless-supply-blood-276830.

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